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EDGE Wireless Test Benches

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EDGE RF Power Amplifier Power Added Efficiency Test

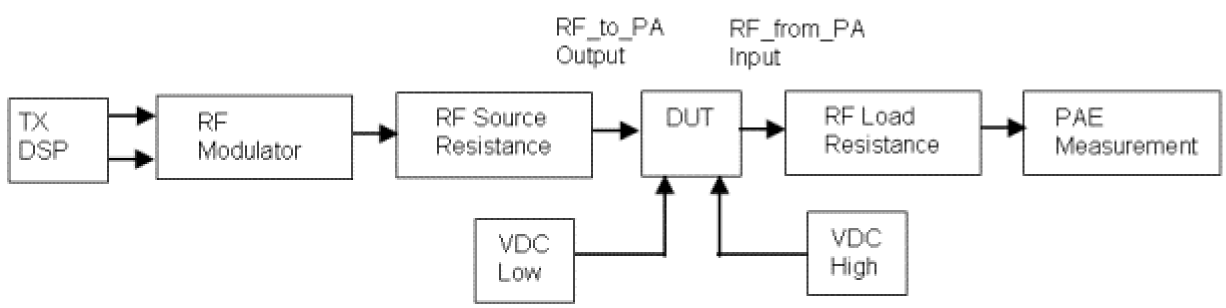
EDGE_RF_PAE_test is the test bench for testing RF Power Amplifiers (PA) with an EDGE signal to measure the PA Power Added Efficiency (PAE). The test bench provides a way for users to connect to an RF circuit device under test (DUT) and determine its PAE performance over EDGE signal frame intervals that the user specifies.

EDGE PAE measurements are not specified by the EDGE Technical Specification.

This EDGE signal model is compatible with Agilent E443xB ESG Vector Signal Generator (E443xB, Firmware Revision B.03.50
Option 202 - "Real-time EDGE" Personality for the E4438C ESG Vector Signal Generator). Details regarding Agilent E443xB ESG are included at the website http://www.agilent.com/find/esg .

This test bench includes a DSP section, an RF modulator, RF output source resistance, RF DUT connection, and DSP measurement blocks, as illustrated in the following figure. The generated test signal is sent to the DUT.

RF PAE Wireless Test Bench Block Diagram



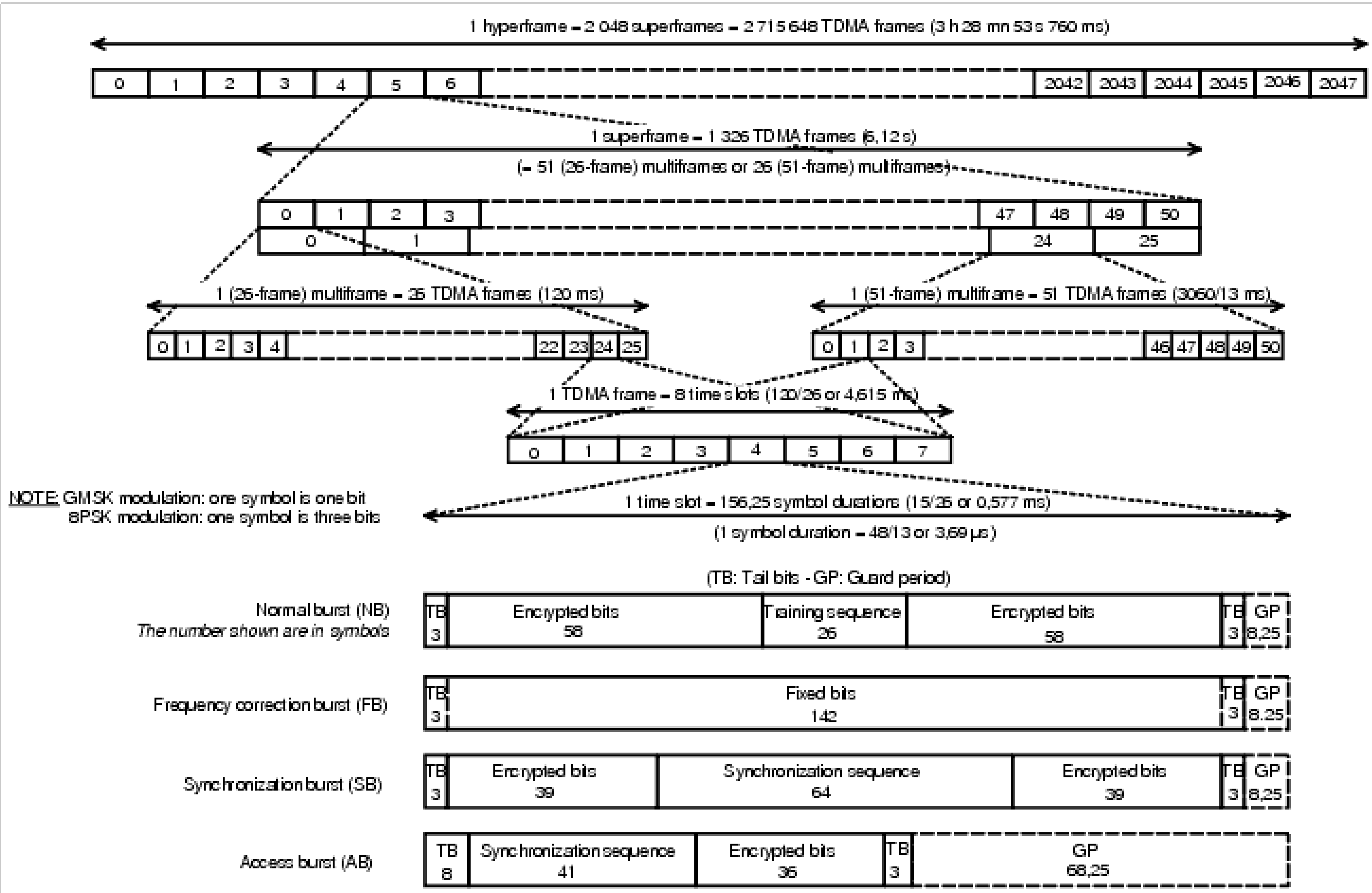
In the EDGE signal frame structure, one frame has a duration of 4.615 msec and consists of 7 slots; each slot contains 156.25 symbols; each symbol is an RF signal symbol.

Five types of bursts are used for EDGE transmission: normal, frequency correction, synchronization, access, and dummy. There are two models for each burst, one for construction, one for disassembly.

Bursts have a total length of 156.25 symbols and only differ in structure. The normal burst is used to carry data and most signaling; it is made up of two 57-symbol information bits, a 26-symbol training sequence used for equalization, one stealing symbol for each information block (used for FACCH), three tail symbols at each end, and an 8.25-symbol guard sequence. The 156.25 symbols are transmitted in 0.577 msec, giving a gross bit rate of 270.833 kilosymbols per second.

The following figure illustrates the relationship of time frames, time slots and bursts. The number of symbols is the same for 8PSK and GMSK modulation; each 8PSK modulated symbol corresponds to 3 bits while each GMSK modulated symbol corresponds to 1 bit. In 8PSK modulation, each pre-defined bit (training sequence, fixed, synchronization sequence, and tail) is transferred into 3 bits by mapping 0 to 001 and 1 to 111.

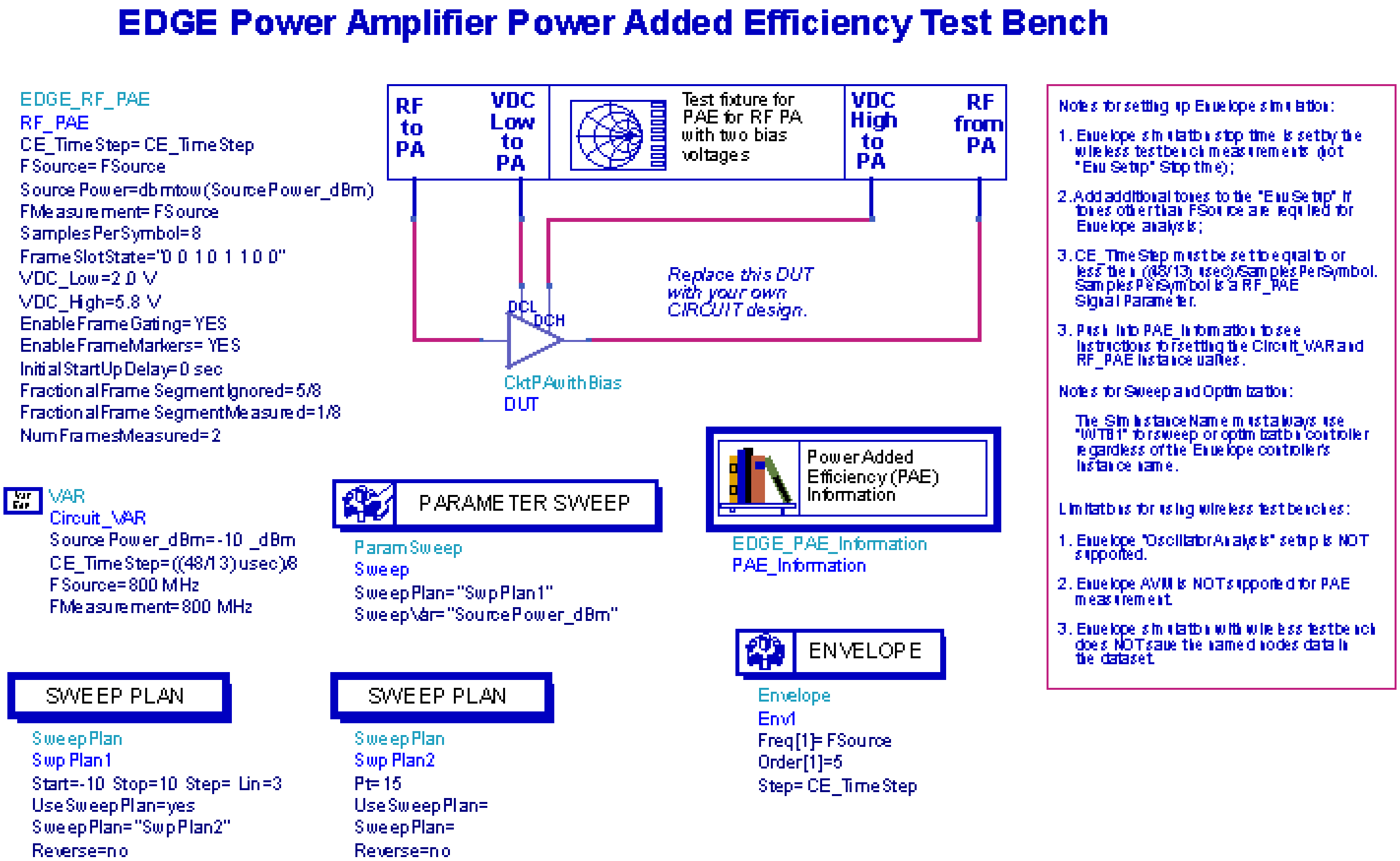
Time Frames, Time Slots and Bursts



Test Bench Basics

A template is provided for this test bench.

EDGE RF Power Amplifier Power Added Efficiency Test Bench



To access the template:

1. In an Analog/RF schematic window select *Insert > Template.*
2. In the *Insert > Template* dialog box, choose *EDGE_RF_PAE_test*, click *OK*; click left to place the template in the schematic window.

The basics for using the test bench are:

- Connect to an RF DUT that is suitable for this test bench.
- Configure SweepPlans to define a power sweep. You can add more SweepPlan controllers as needed.
- Set the Circuit_VAR values for: SourcePower_dBm, CE_TimeStep, FSource, and FMeasurement.
- Run the simulation and view Data Display page for your measurement.

ℹ	**Note** The default values work with the DUT provided. Set the values based on your DUT requirements.

Test Bench Details

The following sections provide details for setting up a test bench, setting measurement parameters for more control of the test bench, simulation measurement displays, and baseline performance.

Test bench setup is detailed here.

1. Replace the DUT (CktPAwithBias is provided with this template) with an RF DUT that is suitable for this test bench. For information regarding using certain types of DUTs, see *RF DUT Limitations for EDGE Wireless Test Benches* (edgewtb).
2. Set the Circuit_VAR values that define the power sweep
   - These parameters are used to define a power sweep for the RF signal input to the DUT so that the PAE measurement can be observed as a function of the DUT input power.
   - SourcePower_dBm defines the swept variable used by the ParameterSweep controller. Configure SweepPlans to define the power sweep. You can add more SweepPlans as needed.
3. Set the *Required Parameters*

   > **Note**
   > Refer to *EDGE_RF_PAE* (edgewtb) for a complete list of parameters for this test bench.

   Generally, default values can be accepted; otherwise, values can be changed by the user as needed.

   - Set CE_TimeStep.
     Cosimulation occurs between the test bench (using Agilent ADS Ptolemy Data Flow simulation technology) and the DUT (using Circuit Envelope simulation technology). Each technology requires its own simulation time step with time-step coordination occurring in the interface between the technologies.
     CE_TimeStep defines the Circuit Envelope simulation time step to be used with this DUT. The CE_TimeStep must be set to a value equal to or a submultiple of (less than) WTB_TimeStep; otherwise, simulation will stop and an error message will be displayed.
     Note that WTB_TimeStep is not user-settable. Its value is derived from other test bench parameter values; with default settings WTB_TimeStep=approx. 461.5 nsec. The value is displayed in the Data Display pages as TimeStep.

     WTB_TimeStep = ((48/13) usec/SamplesPerSymbol

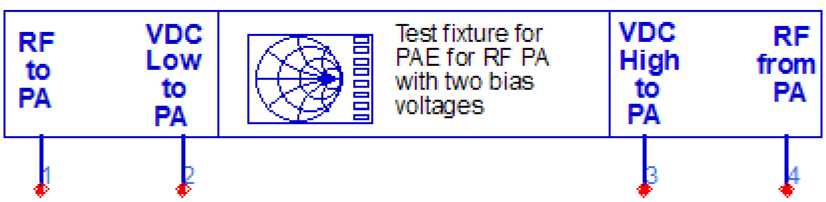
     where SamplesPerSymbol is the number of waveform sampling points used to create each symbol (RF signal symbol).
   - Set FSource, SourcePower and FMeasurement.
     - FSource defines the RF frequency for the signal input to the RF DUT.
     - SourcePower is defined as the average power during the non-idle time of the signal. It should be set to the dbmtow(SourcePower_dBm).
   - FMeasurement defines the RF frequency output from the DUT to be measured. It is typically set to the FSource value unless the output frequency of the DUT is other than FSource.
4. More control of the test bench can be achieved by setting *Basic Parameters*, *Signal Parameters*, and parameters for the measurement. The additional measurement control enables the user to specific the measurement of the PAE performance over EDGE signal frame intervals specified by the user. For details refer to *Parameter Settings* (edgewtb).
5. The RF modulator (shown in the block diagram in RF PAE Wireless Test Bench Block Diagram) uses FSource, SourcePower (*Required Parameters*).
   The RF output resistance uses SourceR. The RF output signal source has a 50-ohm (default) output resistance defined by SourceR.

RF output (and input to the RF DUT) is at the frequency specified (FSource), with the specified source resistance (SourceR) and with power (SourcePower) delivered into a matched load of resistance SourceR.
Note that the RF_from_PA point of the test bench provides a resistive load to the RF DUT set by the MeasR value (50-ohm default) (*Basic Parameters*).
The RF_from_PA signal contains linear and nonlinear signal distortions and time delays associated with the RF DUT input to output characteristics.
The RF PAE DSP block (shown in the block diagram in RF PAE Wireless Test Bench Block Diagram) uses other *Signal Parameters*.

6. More control of Circuit Envelope analysis can be achieved by setting Envelope controller parameters. Setting these simulation options is described in *Setting Circuit Envelope Analysis Parameters* (adswtbsim). However, Circuit Envelope settings for Fast Cosim are not intended for use with PAE measurements.
7. After running a simulation, results will appear in a Data Display window for the measurement. *Simulation Measurement Displays* (edgewtb) describes results for each measurement. For general WTB Data Display details refer to *Viewing WTB Analysis Results* (adswtbsim).

EDGE_RF_PAE

This section provides parameter information for *Required Parameters, Basic Parameters, Signal Parameters,* and parameters for the measurement.



Description EDGE RF Power Amplifier Power Added Efficiency test

Parameters

Name	Description	Default	Sym	Unit	Type	Range
RequiredParameters						
CE_TimeStep	Circuit envelope simulation time step	((48/13) usec)/8		sec	real	(0, ∞)
WTB_TimeStep	Set CE_TimeStep < = ((48/13) usec)/SamplesPerSymbol. SamplesPerSymbol is in Signal Parameters tab.					
FSource	Source carrier frequency	890.2 MHz		Hz	real	(0, ∞)
SourcePower	Source power	dbmtow(-20.0)		W	real	[0, ∞)
FMeasurement	Measurement carrier frequency	890.2 MHz		Hz	real	(0, ∞)
Basic Parameters						
SourceR	Source resistance	50 Ohm		Ohm	real	(0, ∞)
MeasR	Measurement resistance	50 Ohm		Ohm	real	[10, 1.0e6]
Signal Parameters						
SamplesPerSymbol	Samples per symbol	8	S		int	[2, 32]
FrameSlotState	State of each of the eight time slots in a frame; 0 for idle, 1 for active	1 1 1 1 1 1 1 1			intarray	[0, 1]
Measurement Parameters						
VDC_Low	Low DC bias voltage	2.0		volts	real	(-∞, ∞)
VDC_High	High DC bias voltage	5.8		volts	real	(-∞, ∞)
EnableFrameGating	Enable frame measurement gating: NO, YES	YES			int	[0, 1)
EnableFrameMarkers	Enable frame markers (used when EnableFrameGating=YES): NO, YES	YES			int	[0, 1)
InitialStartUpDelay	Source signal delay before first frame starts	0		sec	real	[0, ∞)
FractionalFrameSegmentIgnored	Fractional frame segment ignored for each frame (used when EnableFrameGating=YES)	0			real	[0, 1]
FractionalFrameSegmentMeasured	Fractional frame segment measured per frame (used when EnableFrameGating=YES)	1			real	[0, 1]
NumFramesMeasured	Number of frames measured	2			real	[1, ∞]

Pin Inputs

Pin	Name	Description	Signal Type
4	RF_from_PA	Test bench measurement RF input from RF circuit	timed

Pin Outputs

Pin	Name	Description	Signal Type
1	RF_to_PA	Test bench RF output to RF circuit	timed
2	VDC_Low_to_PA	Test bench Low VDC voltage to RF circuit	timed
3	VDC_High_to_PA	Test bench High VDC voltage to RF circuit	timed

Parameter Settings

More control of the test bench can be achieved by setting parameters on the *Basic Parameters*, *Signal Parameters*, and *measurements* categories for the activated measurements. Parameters for each category are described in the following sections.

> **Note**
> For *required* parameter information, see *Set the Required Parameters* (edgewtb).

Basic Parameters

1. SourceR is the RF output source resistance.
2. MeasR defines the load resistance for the RF DUT output RF_from_PA signal into the test bench. This resistance loads the RF DUT output; it is also the reference resistance for the RF_from_PA signal measurements.

Signal Parameters

1. SamplesPerSymbol is used to set the number of samples in a symbol.
2. FrameSlotState is used to set each of eight slots a frame to on (value 1) or off (value 0).

Measurement Parameters

1. VDC_Low specifies the low DC voltage bias voltage provided to the RF power amplifier DUT.
2. VDC_High specifies the high DC voltage bias voltage provided to the RF power amplifier DUT.
3. EnableFrameGating and EnableFrameMarkers are the frame gating parameters EnableFrameMarkers is used only when EnableFrameGating=YES.
   When EnableFrameGating = NO, there is no frame gating.
   When EnableFrameGating = YES and EnableFrameMarkers = NO, the measurement is made for all gated frame intervals combined.
   When EnableFrameGating = YES and EnableFrameMarkers = YES, the measurement is made for the gated frame interval in each frame and reset at the beginning of each

frame.

4. InitialStartUpDelay specifies the time that the measurement begins at the DUT output and marks the start of the first frame to be measured.
5. NumFramesMeasured specifies the number of frames measured.
6. FractionalFrameSegmentIgnored and FractionalFrameSegmentMeasured define the interval in each frame that is measured. The frame measurement interval starts after the start of a frame defined by the fraction of the frame interval defined by FractionalFrameSegmentIgnored. After this instant in the frame, the following fraction of the frame interval is measured as defined by FractionalFrameSegmentMeasured. The frame interval time is defined within the EDGE_RF_PAE model.

For information about TimeStep and FrameTime, see Test Bench Variables for Data Displays.

Simulation Measurement Displays

After running the simulation, results are displayed in the Data Display pages for each measurement activated.

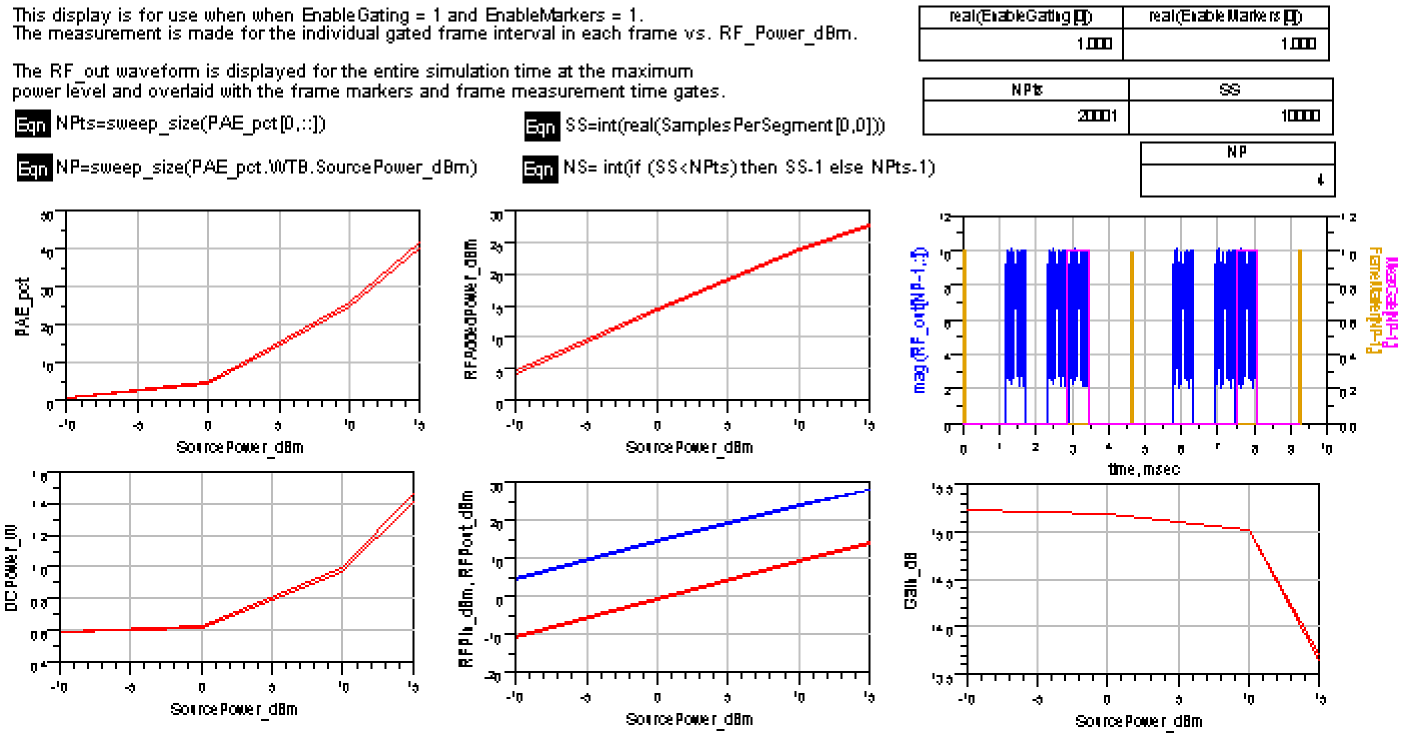
> **Note**
> Measurement results from a wireless test bench have associated names that can be used in Data Display Expressions. For more information, refer to *Measurement Results for Expressions for EDGE Wireless Test Benches* (edgewtb).

Power Added Efficiency Measurement

The Power Added Efficiency measurement (not defined in EDGE specifications) measures the RF power amplifier (DUT) power added efficiency (in percent). This is the ratio of the RF output power minus the RF input power, divided by the DC power consumed. This measurement is made only over the gated frame time interval specified for each frame measured.

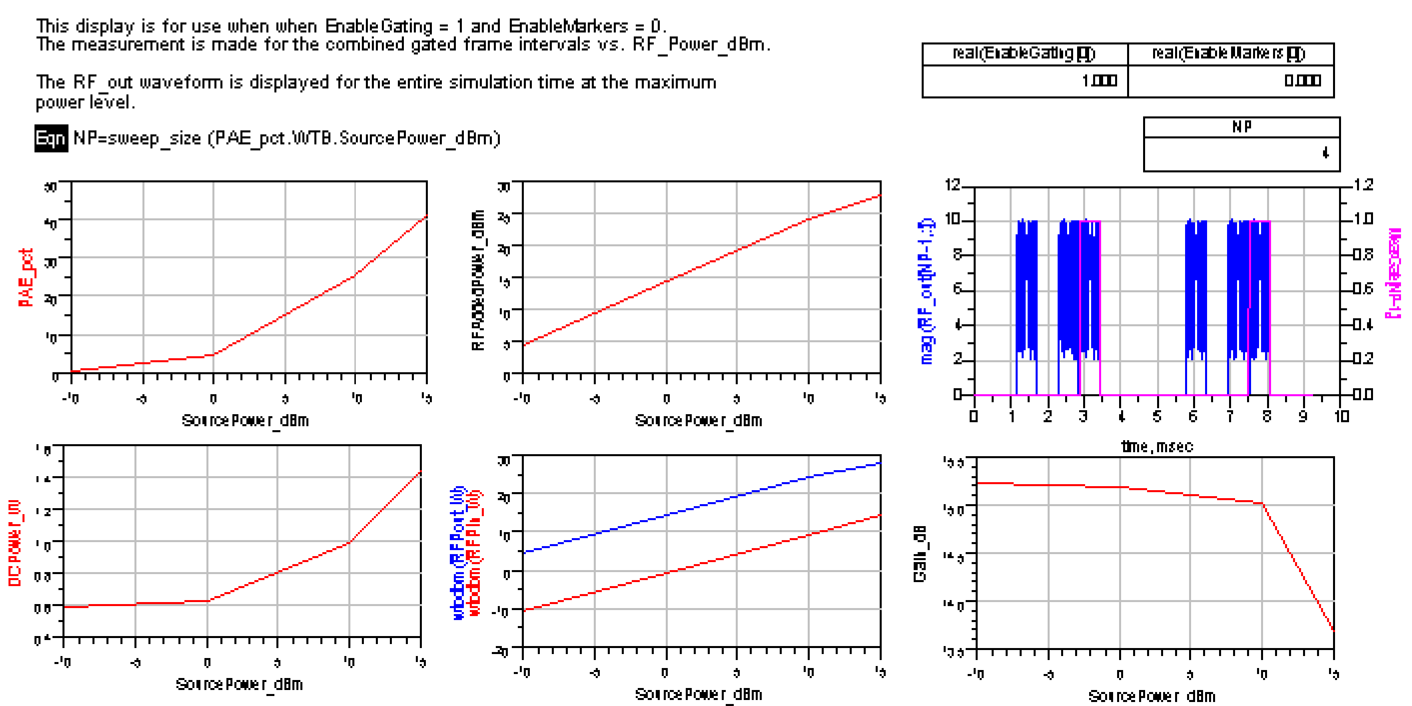
The following figure shows results with EnableFrameGating=YES and EnableFrameMarkers=YES for FrameSlotState = "0 0 1 0 1 1 0 0".

Power Added Efficiency Measurement Results with EnableFrameGating=YES and EnableFrameMarkers=YES



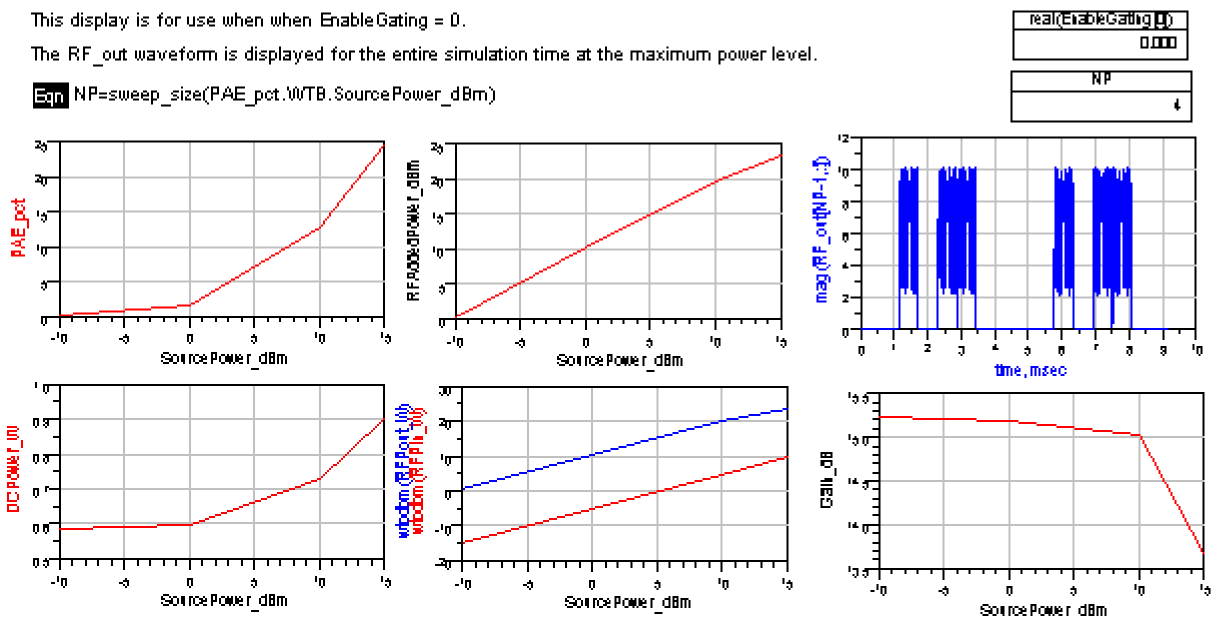
The following figure shows results with EnableFrameGating=YES and EnableFrameMarkers=NO for FrameSlotState = "0 0 1 0 1 1 0 0".

Power Added Efficiency Measurement Results with EnableFrameGating=YES and EnableFrameMarkers=NO



The following figure shows results with EnableFrameGating=NO.

Power Added Efficiency Measurement Results with EnableFrameGating=NO



Test Bench Variables

Reference variables used to set up this test bench are listed in the following tables.

Test Bench Constants for Signal Setup

Constant	Value
SamplesPerSymbol	8
SlotsPerFrame	8
SymbolsPerSlot	156.25

Test Bench Equations Derived from Test Bench Parameters

Data Display Parameter	Equation with Test Bench Parameters
TimeStep	((48/13) usec)/SamplesPerSymbol This is the test bench simulation time step
FrameTime	SlotsPerFrame*SymbolsPerSlot*SamplesPerSymbol*TimeStep This is the time duration of each frame

References

Setting up a Wireless Test Bench Model (adswtbsim) explains how to use test bench windows and dialogs to perform analysis tasks.

Setting Circuit Envelope Analysis Parameters (adswtbsim) explains how to set up circuit envelope analysis parameters such as convergence criteria, solver selection, and initial guess.

Measurement Results for Expressions for EDGE Wireless Test Benches

Measurement results from a wireless test bench have associated names that can be used in Expressions. Those expressions can further be used in specifying goals for Optimization and Monte Carlo/Yield analysis. For details on using expressions, see the *Measurement Expressions* (expmeas) documentation. For details on setting analysis goals using Optimization and Monte Carlo/Yield analysis, see the *Tuning, Optimization, and Statistical Design* (optstat) documentation.

You can use an expression to determine the measurement result independent variable name and its minimum and maximum values. The following example expressions show how to obtain these measurement details where MeasResults is the name of the measurement result of interest:

- The *Independent Variable Name* for this measurement result is obtained by using the expression
  `indep(MeasResults)`
- The *Minimum Independent Variable Value* for this measurement result is obtained by using the expression
  `min(indep(MeasResults))`
- The *Maximum Independent Variable Value* for this measurement result is obtained by using the expression
  `max(indep(MeasResults))`

The following tables list the measurement result names and independent variable name for each test bench measurement. Expressions defined in a MeasEqn block must use the full *Measurement Results Name* listed. Expressions used in the Data Display may omit the leading test bench name. You can also locate details on the measurement result minimum and maximum independent variable values by

- Referring to the measurement parameter descriptions when they are available (not all measurement parameter descriptions identify these minimum and maximum values).
- Observing the minimum and maximum independent variable values in the Data Display for the measurement.

EDGE_RF_PAE Measurement Results

Measurement Results Name	Independent Variable Name
RF_PAE.DCPower_W	time
RF_PAE.FrameMarker	time
RF_PAE.MeasGate	time
RF_PAE.PAE_pct	time
RF_PAE.RFAddedPower_W	time
RF_PAE.RFPin_W	time
RF_PAE.RFPout_W	time
RF_PAE.RF_in	time
RF_PAE.RF_out	time

RF DUT Limitations for EDGE Wireless Test Benches

This section describes test bench use with typical RF DUTs, improving test bench performance when certain RF DUT types are used, and improving simulation fidelity.

The RF DUT, in general, may be a circuit design with any combination and quantity of analog and RF components, transistors, resistors, capacitors, etc. suitable for simulation with the Agilent Circuit Envelope simulator. More complex RF circuits will take more time to simulate and will consume more memory.

Test bench simulation time and memory requirements can be considered to be the combination of the requirements for the baseline test bench measurement with the simplest RF circuit plus the requirements for a Circuit Envelope simulation for the RF DUT of interest.

An RF DUT connected to a wireless test bench can generally be used with the test bench to perform default measurements by setting the test bench *Required Parameters*. Default measurement parameter settings can be used (exceptions described below), for a typical RF DUT that:

- Requires an input (RF) signal with constant RF carrier frequency.
  The test bench RF signal source output does not produce an RF signal whose RF carrier frequency varies with time. However, the test bench will support an output (RF) signal that contains RF carrier phase and frequency modulation as can be represented with suitable I and Q envelope variations on a constant RF carrier frequency.
- Produces an output (Meas) signal with constant RF carrier frequency.
  The test bench input (Meas) signal must not contain a carrier frequency whose frequency varies with time. However, the test bench will support an input (Meas) signal that contains RF carrier phase noise or contains time varying Doppler shifts of the RF carrier. These signal perturbations are expected to be represented with suitable I and Q envelope variations on a constant RF carrier frequency.
- Requires an input (RF) signal from a signal generator with a 50-ohm source resistance. Otherwise, set the SourceR parameter value in the *Basic Parameters* tab.
- Requires an input (RF) signal with no additive thermal noise (TX test benches) or source resistor temperature set to 16.85^{o} C (RX test benches). Otherwise, set the SourceTemp (TX and RX test benches) and EnableSourceNoise (TX test benches) parameters in the *Basic Parameters* tab.
- Requires an input (RF) signal with no spectrum mirroring. Otherwise, set the MirrorSourceSpectrum parameter value in the *Basic Parameters* tab.
- Produces an output (Meas) signal that requires a 50-ohm external load resistance. Otherwise, set the MeasR parameter value in the *Basic Parameters* tab.
- Produces an output (Meas) signal with no spectrum mirroring.
- Relies on the test bench for any measurement-related bandpass signal filtering of the RF DUT output (Meas) signal.
  - When the RF DUT contains a bandpass filter with bandwidth that is on the order of the test bench receiver system (~1 times the test bench receiver bandwidth)

and the user wants a complete characterization of the RF DUT filter, the default time CE_TimeStep must be set smaller.
  - When the RF DUT bandpass filter is much wider than the test bench receiver system (>2 times the test bench receiver bandwidth), the user may not want to use the smaller CE_TimeStep time step to fully characterize it because the user knows the RF DUT bandpass filter has little or no effect in the modulation bandwidth in this case.

Improving Test Bench Performance

This section provides information regarding improving test bench performance when certain RF DUT types are used.

- Analog/RF models (TimeDelay and all transmission line models) used with Circuit Envelope simulation that perform linear interpolation on time domain waveforms for modeling time delay characteristics that are not an integer number of CE_TimeStep units. Degradation is likely in some measurements, especially EVM.
  This limitation is due to the linear interpolation between two successive simulation time points, which degrades waveform quality and adversely affects EVM measurements.
  To avoid this kind of simulator-induced waveform quality degradation: avoid use of Analog/RF models that rely on linear interpolation on time domain characteristics; or, reduce the test bench CE_TimeStep time step by a factor of 4 below the default CE_TimeStep (simulation time will be 4 times longer).
- Analog/RF lumped components (R, L, C) used to provide bandpass filtering with a bandwidth as small as the wireless signal RF information bandwidth are likely to cause degradation in some measurements, especially Spectrum. These circuit filters require much smaller CE_TimeStep values than would otherwise be required for RF DUT circuits with broader bandwidths.
  This limitation is due to the smaller Circuit Envelope simulation time steps required to resolve the differential equations for the L, C components when narrow RF bandwidths are involved. Larger time steps degrade the resolution of the simulated bandpass filtering effects and do not result in accurate frequency domain measurements, especially Spectrum and EVM measurements (when the wireless technology is sensitive to frequency domain distortions).
  To determine that your lumped component bandwidth filter requires smaller CE_TimeStep, first characterize your filter with Harmonic Balance simulations over the modulation bandwidth of interest centered at the carrier frequency of interest. Though it is difficult to identify an exact guideline on the Circuit Envelope time step required for good filter resolution, a reasonable rule is to set the CE_TimeStep to 1/(double-sided 3dB bandwidth)/32.
  To avoid this kind of simulator-induced waveform quality degradation, avoid the use of R, L, C lumped filters with bandwidths as narrow as the RF signal information bandwidth, or reduce the CE_TimeStep.
- Analog/RF data-based models (such as S-parameters and noise parameters in S2P data files) used to provide RF bandpass filtering with a bandwidth as small as 1.5 times the wireless signal RF information bandwidth are likely to cause degradation in

some measurements, especially EVM.
This limitation is due to causal S-parameter data about the signal carrier frequency requiring a sufficient number of frequency points within the modulation bandwidth; otherwise, the simulated data may cause degraded signal waveform quality. In general, there should be more than 20 frequency points in the modulation bandwidth; more is required if the filter that the S-parameter data represents has fine-grain variations at small frequency steps.
To avoid this kind of simulator-induced waveform quality degradation, avoid the use of data-based models with bandwidths as narrow as the RF signal information bandwidth, or increase the number of frequency points in the data file within the modulation bandwidth and possibly also reduce the CE_TimeStep simulation time step.

- An additional limitation exists when noise data is included in the data file. Circuit Envelope simulation technology does not provide frequency-dependent noise within the modulation bandwidth for this specific case when noise is from a frequency domain data file. This may result in output noise power that is larger than expected; if the noise power is large enough, it may cause degraded signal waveform quality. To avoid this kind of simulator-induced waveform quality degradation avoid the use of noise data in the data-based models or use an alternate noise model.

Improving Simulation Fidelity

Some RF circuits will provide better Circuit Envelope simulation fidelity if the CE_TimeStep is reduced.

- In general, the default setting of the test bench SamplesPerChip provides adequate wireless signal definition and provides the WTB_TimeStep default value.
- Set CE_TimeStep = ((48/13) usec)/(SamplesPerSymbol×N)

    where N is an integer ≥ 1
- When CE_TimeStep is less than the WTB_TimeStep (i.e., N>1), the RF signal to the RF DUT is automatically upsampled from the WTB_TimeStep and the RF DUT output signal is automatically downsampled back to the WTB_TimeStep. This sampling introduces a time delay to the RF DUT of 10×WTB_TimeStep and a time delay of the measured RF DUT output signal of 20×WTB_TimeStep relative to the measured RF signal sent to the RF DUT prior to its upsampling.