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RF System Budget Analysis

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About RF System Budget Analysis 7
  Comparison with the Generic Budget Analysis Functions 9
Using the Budget Controller 11
  License Requirements 11
  When to Use RF Budget Analysis 11
  How to Use the Budget Controller 11
  Example Designs 12
Performing Budget Simulations 14
  A Simple Budget Design 14
  Using Mixers and Multiple Paths 15
  Using Two-Port, Two-Pin S-Parameter Files 17
  Using AGC Control Loops 17
  Using Budget with Sweep 18
  Using Budget with Optimization and Yield 19
Working with RF System Budget Analysis Results 22
  Viewing Results Using the ADS Data Display 22
  Exporting and Post-Processing Results 27
Reference Measurements and Models for RF System Budget Analysis 31
  RF Budget Cascade Measurements 31
  RF Budget Summary Measurements 37
  RF Budget Analysis Component Models 38
Limitations of RF System Budget Analysis 50
  S-Parameter Based Measurements 51
  Measurements for Budget Controller without "Enable nonlinear analysis" 51
  Measurements for Budget Controller with "Enable nonlinear analysis" 52
  System Signal Source 52
  System Termination 52
  System Components 52
  Subnetworks 53
  Nonlinear Components 53
  Optimization 54
Parameters for RF System Budget Analysis 55
  Setting up a Budget Analysis 55
  Selecting Measurements 56
Theory of Operation for RF System Budget Analysis 58
  S-Parameters for the Cascade of Two, Two-Port, Two-Pin Components 58
  S-Parameters for a Nonlinear Channel 59
  Noise Parameters for the Interconnection of Two Components 60
  2nd and 3rd-Order Intercept Definition 62
  2nd and 3rd-Order Intercept for a Cascade Network 65
  Raw Data Generated for an RF Budget Analysis 66
Troubleshooting RF System Budget Analysis 72
  Using Components with Three or More Pins 72
  Using Unsupported Networks 72
  Using Unsupported Components 72
  Enabling Other Simulation Controllers in a Design 72
  Instance Name Conflict in Subnetworks 73
  Setting the CmpMaxPin Parameter 73
  Using 1 dB Power Compression Measurements 73
  Error Messages During Large Signal Analysis 74
  Internal Errors 74
References for RF System Budget Analysis 75

About RF System Budget Analysis

The Budget controller enables you to perform an RF system budget analysis to determine the linear and nonlinear characteristics of an RF system comprising a cascade of two-port, two-pin linear or nonlinear components. The RF system may also include automatic gain control (AGC) loops to control gain and set power levels at specific points in the RF system.

RF system budget analysis is achieved by using the Budget controller in an ADS analog/RF schematic. You can use the Budget controller to determine the linear and nonlinear characteristics of an RF system comprising a cascade of two-port, two-pin linear or nonlinear components. The characteristics are derived at the system input, system output (system summary measurements), and at the nodes between the components (system cascade measurements). The system may include such measurements as Power, Third-Order Intercept, Signal-to-Noise Ratio, and others.

RF budget analysis is based on using frequency domain characteristics for each top-level two-port, two-pin component in the RF system design. The components may include mixers and nonlinear amplifiers. The analysis is performed at the single RF tone with specified power from the system input signal source. Each component is characterized for its S-parameter (small-signal and large-signal) and noise parameters. The collection of these parameters for each component in the cascade of two-port, two-pin components composing the RF system design are then used by the Budget controller to calculate the system performance at each node of the system design for the RF budget measurements that you select.

Characteristics of the RF system design on which budget analysis is performed, are:

- The RF system must be a cascade of two-port, two-pin components.
- The components may be any analog/RF two-port, two-pin component that has an S-parameter representation.
- The RF system may include multiple paths of cascaded two-port, two-pin components and use path switching components defined for use with RF budget analysis. The path switch settings must result in only a single cascade two-port path in the RF system design.
- The RF system may also include automatic gain control (AGC) loops to control gain and set power levels at specific points in the RF system. The AGC loops must be achieved using power detectors and voltage-controlled amplifiers defined for use with RF budget analysis.
- No other analog/RF analyses (DC, AC, Harmonic Balance, etc.) can be active in the schematic when the RF budget analysis is performed. When the Budget controller is removed or deactivated, then other analog/RF analyses can be set up with the same RF system design for more detailed circuit analysis.
  See the following topics for details on RF system budget analysis:
- *Using the Budget Controller* (rfsysbudget) describes when you might use the Budget controller, its benefits, how to begin using it, and the location of an example workspace.
- *Performing Budget Simulations* (rfsysbudget) describes application-focused examples including
  - *A Simple Budget Design* (rfsysbudget)

  - *Using Mixers and Multiple Paths* (rfsysbudget)
  - *Using Two-Port, Two-Pin S-Parameter Files* (rfsysbudget)
  - *Using AGC Control Loops* (rfsysbudget)
  - *Using Budget with Sweep* (rfsysbudget)
  - *Using Budget with Optimization and Yield* (rfsysbudget)
- *Working with RF System Budget Analysis Results* (rfsysbudget) describes how to use the Data Display to view results, and how to export results for post-processing.
- *Reference Measurements and Models for RF System Budget Analysis* (rfsysbudget) describes measurements used for component inputs and outputs, noise figure, and system performance, in addition to various component models.
- *Limitations of RF System Budget Analysis* (rfsysbudget) describes the limitations of this frequency domain approach.
- *Parameters for RF System Budget Analysis* (rfsysbudget) describes details of the dialog box fields and parameters for the Budget controller.
- *Theory of Operation for RF System Budget Analysis* (rfsysbudget) describes the budget analysis process.
- *Troubleshooting RF System Budget Analysis* (rfsysbudget) explains how to recover from analysis problems.
- *References for RF System Budget Analysis* (rfsysbudget) lists information sources that discuss this approach to budget analysis.

Comparison with the Generic Budget Analysis Functions

In addition to using the Budget controller in ADS analog/RF schematics, ADS also offers built-in RF budget MeasEqn function capability. Here are points that compare these two budget analysis approaches:

- Using the Budget controller is in addition to and does not replace the built-in RF budget MeasEqn function capability.
- The Budget controller is separate from and does not rely on the built-in budget MeasEqn function items.

The key advantages of the Budget controller over budget analysis functions are:

- Much easier to use.
- Provides many more built-in budget measurements that you can select.
- Provides improved budget noise measurements.
- Supports tuning, sweeps, optimization, yield, etc.
- Supports AGC loops.
- Supports selection between alternate budget paths.
- Supports export of results in ASCII files for use in third-party tools, including Excel.

The advantages of built-in RF budget MeasEqn function capability are:

- Supports flexible circuit topologies.
- Supports more flexible path selection.
- Supports user-defined subnetworks with frequency conversion.
- Supports more general mixer models.
- Supports concurrent simulation with other analog/RF analyses.

The key Budget controller restrictions are:

- For use primarily with cascaded two-port, two-pin RF systems, though it will also support these multi-pin components:
    - *S2P*
    - *AGC_Amp*
    - *AGC_PwrControl* (for setting up AGC control loops)
    - *PathSelect2* (for setting up selectable RF paths)
- Input source must be either _P_1Tone_ or _P_nTone_ and requires Z=50 ohms.
- Output load must be either *Term* or *R* and requires Z(R)=50 ohms; with no noise.
- Allows use of only one mixer model: *MixerWithLO* .
- User-defined circuit subnetworks must be two-port, two-pin networks and no frequency conversion is presumed.
- Does not allow concurrent simulation with other analog/RF analyses.
- Cannot be used with Gradient-like optimization types.

Using the Budget Controller

This section will help you decide when to use the Budget controller, and introduces the basic requirements of an RF system design.

License Requirements

The Budget controller will use the Harmonic Balance simulation license (sim_harmonic) or the RF System simulation license (sim_syslinear). You must have one of these licenses to run simulations using the Budget controller. You can work with the examples described in *Performing Budget Simulations* (rfsysbudget) without the license, but you will not be able to simulate them.

When to Use RF Budget Analysis

Use the Budget controller to perform budget analysis on an RF system. This RF system budget analysis provides a simple and easy-to-use capability to determine the linear and nonlinear characteristics of an RF system comprising a cascade of two-port, two-pin linear or nonlinear components. Each component in the RF system chain must have an S-parameter representation.

Using the Budget controller provides you with the following benefits:

- Easily accessible user interface to set up your budget analysis.
- Provides a large number of built-in budget measurements that you can select.
- Provides improved budget noise measurements.
- Enables you to modify your simulation by using tuning, parameter sweeps, optimization, yield analysis, etc.
- Enables you to include AGC loops in your design to control gain and set power levels at specific points in the RF system.
- Enables you to select between alternate budget paths.
- Export results in ASCII files for use in third-party tools, including Microsoft Excel.

How to Use the Budget Controller

To use the Budget controller, start by creating an RF system design containing cascaded two-port, two-pin components. For a successful analysis, be sure your design follows these requirements:

- Apply pins to the input and output of the two-pin cascaded network. Use either *P_1Tone* or *P_nTone* power sources to drive the input. Terminate the end of the cascaded network using port-impedance terminations (*Term* or *R*). Verify impedance is set to 50 ohms.
- Do not use any components with three or more pins in your design except for *S2P*, *AGC_Amp*, *AGC_PwrControl*, and *PathSelect2*.

- Use only the *MixerWithLO* component to define mixers in the RF system. Using any other mixer component, such as *Mixer2*, with the Budget controller will result in the frequency conversion of the mixer being ignored during simulation.
- Add the Budget component to the design from the Simulation-Budget palette or library. Double-click the controller to open its setup dialog box. Click *Help* from the dialog box for descriptions about each field.
    - On the *Setup* tab, you may choose to enable *Auto format display with overwrite*. This causes the controller to send a request to the Data Display to automatically display the simulation results in tables and plots at the end of the simulation.
    - On the *Measurements* tab, select the system cascade measurements required to be evaluated. Cascade measurements produce a measurement value at each system node. For example, a system with five components will produce five values for each cascade measurement.
      You may choose to not select any cascade measurements, in which case only the system summary measurements will be evaluated. Summary measurements define overall system performance from input to output.

The following table lists the components located on the Simulation-Budget palette and library that are commonly used for budget simulations and sweeps.

Components Available in the Simulation-Budget Palette and Library

Component	**Description**	**Comments**
Budget	Budget simulation controller	Budget controller must be used to perform budget analysis
SweepPlan	Sweep plan controller	
ParamSweep	Parameter sweep controller	
P_1Tone	Power source: single frequency	
Term	Port impedance termination	
AGC_Amp†	Voltage-controller amplifier	Amplifier for use in AGC loops
AGC_PwrControl†	AGC loop power control	
MixerWithLO†	RF Mixer with internal oscillator	Required for defining mixers used in the RF system
PathSelect2†	RF path selection from two paths	
DisplayTemplate	Automatic display template	
MeasEqn	Simulation measurement equation	

†Components AGC_Amp, AGC_PwrControl, MixerWithLO, and PathSelect2 are conveniently listed in this library to build RF systems for budget analysis. They may also be used in other Analog/RF simulations. Details about these components are available in the *System Models* (ccsys) documentation.

Example Designs

For examples of designs prepared for RF system budget analysis, see the simulation workspace provided at:
$HPEESOF_DIR/examples/Tutorial/RF_Budget_Examples_wrk

For demonstrations of various simulation setups, see *Performing Budget Simulations* (rfsysbudget).

Performing Budget Simulations

This section describes the following example designs included with ADS and how to use the Budget controller with them to perform budget simulations:

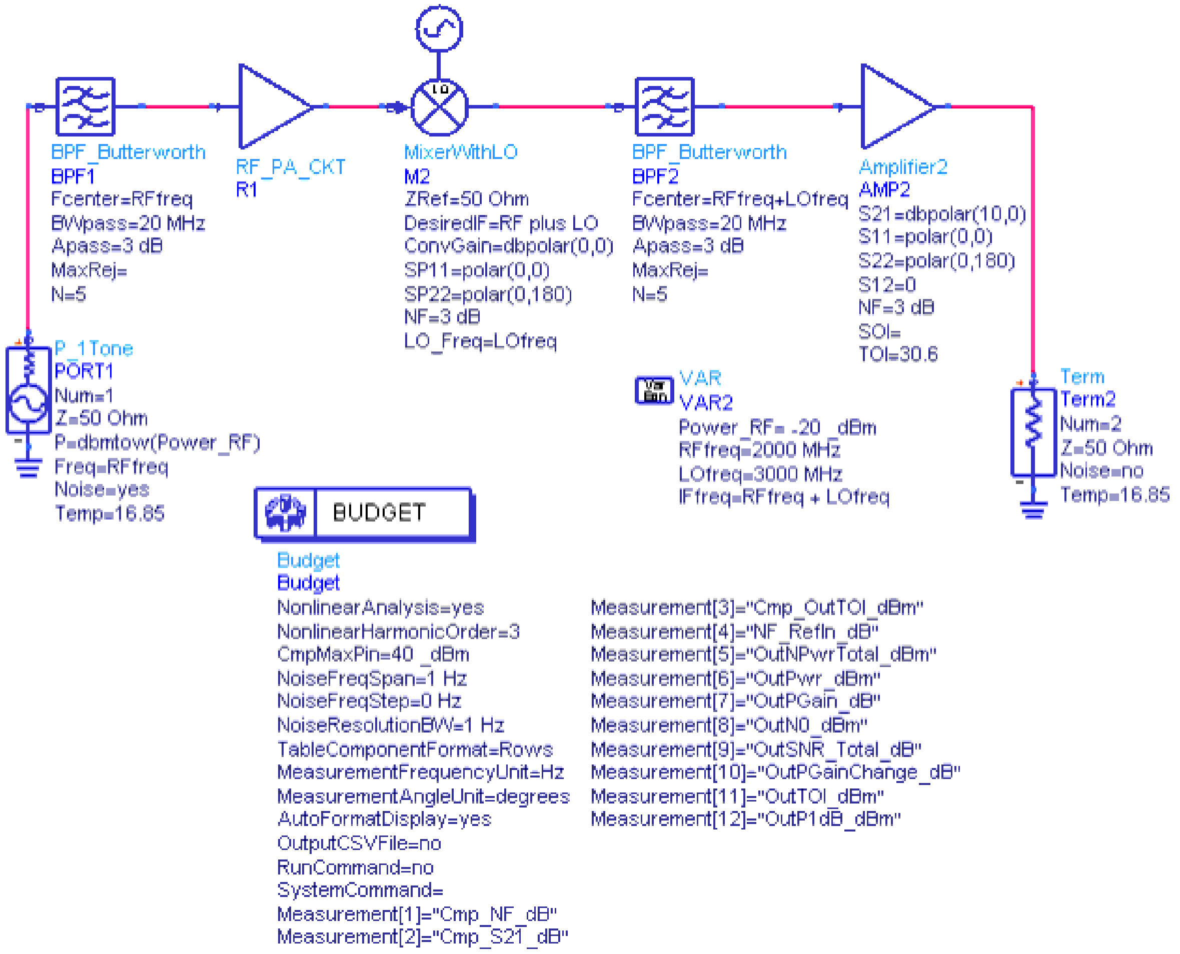
- A Simple Budget Design performs a basic budget simulation of a two-port, two-pin cascaded network.
- Using Mixers and Multiple Paths performs a budget simulation of a two-port, two-pin cascaded network containing a mixer component.
- Using Two-Port, Two-Pin S-Parameter Files describes the special conditions about using the *S2P* component in a cascaded two-port, two-pin design.
- Using AGC Control Loops performs a basic budget simulation of a two-port, two-pin cascaded network containing an AGC loop.
- Using Budget with Sweep performs a budget simulation of a two-port, two-pin cascaded network containing a *Parameter Sweep* controller.
- Using Budget with Optimization and Yield performs a budget simulation of a two-port, two-pin cascaded network containing an *Optimization* controller.

For detailed descriptions of the Budget controller parameters, see *Parameters for RF System Budget Analysis* (rfsysbudget). For information on the use of the Data Display in the context of budget simulations, see *Working with RF System Budget Analysis Results* (rfsysbudget).

A Simple Budget Design

The following figure illustrates an example setup for performing a basic budget simulation of a two-port, two-pin cascaded network.

Note
This design, *Budget_Baseline*, is in the *examples* directory under *Tutorial/RF_Budget_Examples_wrk*. The results are in *Budget_Baseline.dds*.



BPF_Butterworth
BPF1
Fcenter=RFfreq
BWpass=20 MHz
Apass=3 dB
MaxRej=
N=5

RF_PA_CKT
R1

MixerWithLO
M2
ZRef=50 Ohm
DesiredIF=RF plus LO
ConvGain=dbpolar(0,0)
SP11=polar(0,0)
SP22=polar(0,180)
NF=3 dB
LO_Freq=LOfreq

BPF_Butterworth
BPF2
Fcenter=RFfreq+LOfreq
BWpass=20 MHz
Apass=3 dB
MaxRej=
N=5

Amplifier2
AMP2
S21=dbpolar(10,0)
S11=polar(0,0)
S22=polar(0,180)
S12=0
NF=3 dB
SOI=
TOI=30.6

P_1Tone
PORT1
Num=1
Z=50 Ohm
P=dbmtow(Power_RF)
Freq=RFfreq
Noise=yes
Temp=16.85

VAR
VAR2
Power_RF= -20 _dBm
RFfreq=2000 MHz
LOfreq=3000 MHz
IFfreq=RFfreq + LOfreq

Term
Term2
Num=2
Z=50 Ohm
Noise=no
Temp=16.85

BUDGET
Budget
Budget
NonlinearAnalysis=yes
NonlinearHarmonicOrder=3
CmpMaxPin=40 _dBm
NoiseFreqSpan=1 Hz
NoiseFreqStep=0 Hz
NoiseResolutionBW=1 Hz
TableComponentFormat=Rows
MeasurementFrequencyUnit=Hz
MeasurementAngleUnit=degrees
AutoFormatDisplay=yes
OutputCSVFile=no
RunCommand=no
SystemCommand=
Measurement[1]="Cmp_NF_dB"
Measurement[2]="Cmp_S21_dB"
Measurement[3]="Cmp_OutTOI_dBm"
Measurement[4]="NF_RefIn_dB"
Measurement[5]="OutNPwrTotal_dBm"
Measurement[6]="OutPwr_dBm"
Measurement[7]="OutPGain_dB"
Measurement[8]="OutN0_dBm"
Measurement[9]="OutSNR_Total_dB"
Measurement[10]="OutPGainChange_dB"
Measurement[11]="OutTOI_dBm"
Measurement[12]="OutP1dB_dBm"

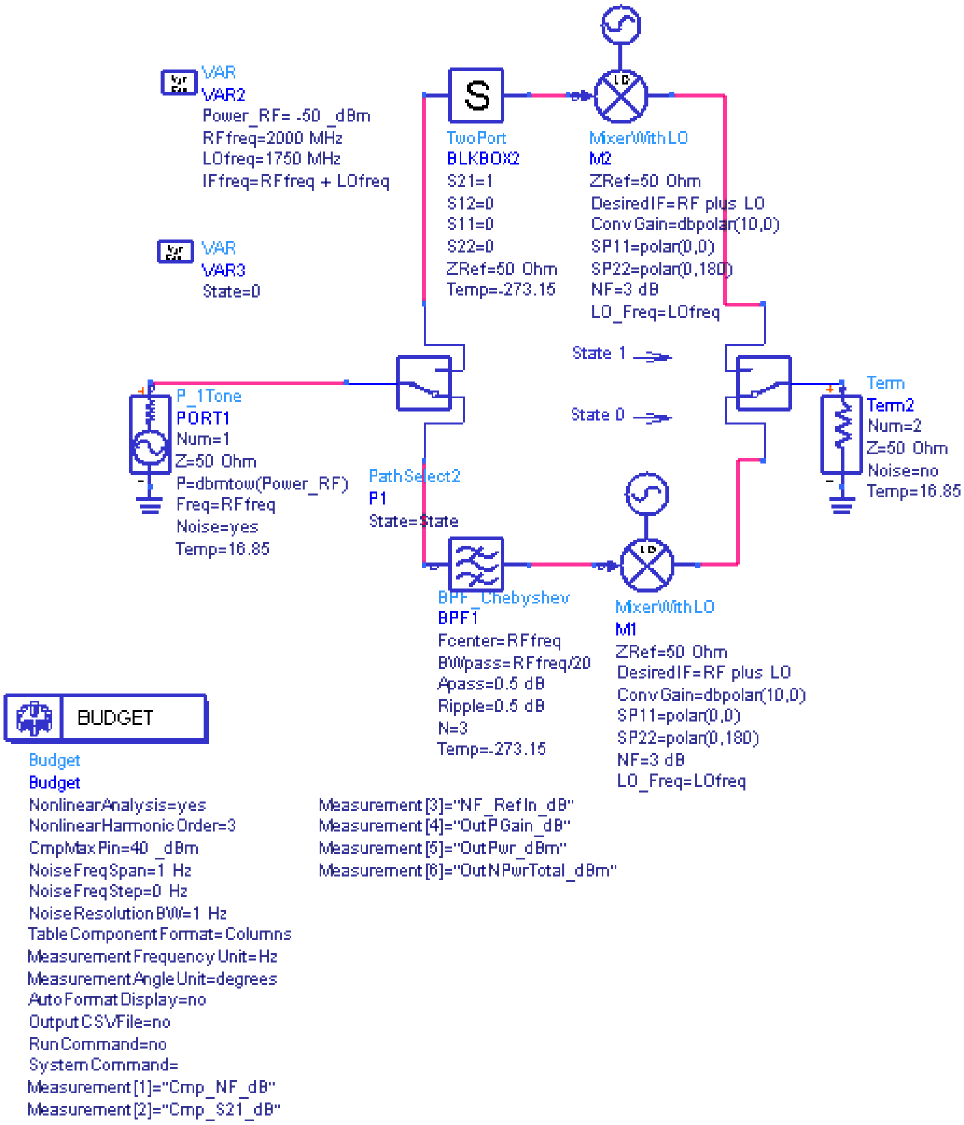
Basic Budget simulation of a two-port, two-pin cascaded network

This design shows a typical RF system design used with budget analysis. It uses a P_1Tone as the source, *Term* to terminate the cascaded network, and contains a filter, a nonlinear amplifier, a mixer, a second filter, and a second nonlinear amplifier connected in a chain. The measurements selected in this design are typical ones including measurements for component performance, noise, power, and intercept points.

Using Mixers and Multiple Paths

The following figure illustrates an example setup for performing a budget simulation of a two-port, two-pin network with multiple paths to mixer components.

Note
This design, *Budget_Mixer*, is in the *examples* directory under *Tutorial/RF_Budget_Examples_wrk*. The results are in *Budget_Mixer.dds*.



VAR
VAR2
Power_RF= -50 _dBm
RFfreq=2000 MHz
LOfreq=1750 MHz
IFfreq=RFfreq + LOfreq

VAR
VAR3
State=0

P_1Tone
PORT1
Num=1
Z=50 Ohm
P=dbmtow(Power_RF)
Freq=RFfreq
Noise=yes
Temp=16.85

TwoPort
BLKBOX2
S21=1
S12=0
S11=0
S22=0
ZRef=50 Ohm
Temp=-273.15

MixerWithLO
M2
ZRef=50 Ohm
DesiredIF=RF plus LO
ConvGain=dbpolar(10,0)
SP11=polar(0,0)
SP22=polar(0,180)
NF=3 dB
LO_Freq=LOfreq

PathSelect2
P1
State=State

BPF_Chebyshev
BPF1
Fcenter=RFfreq
BWpass=RFfreq/20
Apass=0.5 dB
Ripple=0.5 dB
N=3
Temp=-273.15

MixerWithLO
M1
ZRef=50 Ohm
DesiredIF=RF plus LO
ConvGain=dbpolar(10,0)
SP11=polar(0,0)
SP22=polar(0,180)
NF=3 dB
LO_Freq=LOfreq

Term
Term2
Num=2
Z=50 Ohm
Noise=no
Temp=16.85

BUDGET
Budget
Budget
NonlinearAnalysis=yes
NonlinearHarmonicOrder=3
CmpMaxPin=40 _dBm
NoiseFreqSpan=1 Hz
NoiseFreqStep=0 Hz
NoiseResolutionBW=1 Hz
TableComponentFormat=Columns
MeasurementFrequencyUnit=Hz
MeasurementAngleUnit=degrees
AutoFormatDisplay=no
OutputCSVFile=no
RunCommand=no
SystemCommand=
Measurement[1]="Cmp_NF_dB"
Measurement[2]="Cmp_S21_dB"
Measurement[3]="NF_RefIn_dB"
Measurement[4]="OutPGain_dB"
Measurement[5]="OutPwr_dBm"
Measurement[6]="OutNPwrTotal_dBm"

Budget simulation of a network with two paths to mixers

This design shows the performance of a mixer (*MixerWithLO*) with and without an input image rejection filter. It also demonstrates use of the *PathSelect2* switch which is useful in budget analysis to set up alternate paths for budget analysis. By using two paths, noise figure analysis can be performed both with and without rejection filters for each mixer. For details about *MixerWithLO* and *PathSelect2*, see the *System Models* (ccsys) documentation.

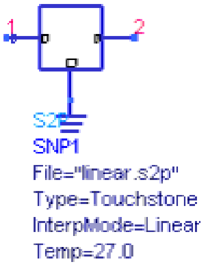
- The *MixerWithLO* is the only mixer component supported in an RF budget simulation. *MixerWithLO* is available from the Simulation-Budget and System-Amps & Mixers palettes, and the Component Library. It is based on the *Mixer2* component and has a built-in LO.
- *PathSelect2* is available from the Simulation-Budget and System-Switch & Algorithmic palettes, and the Component Library. It is based on two SPDT switches, and enables you to select from multiple paths in a simulation.

To measure the output of the mixer *M1* with the image filter *BPF1* at its input, set *PathSelect2* parameter *State=0*. The system noise figure is 4.77 dB and includes noise from the mixer at the image frequency reflected by the input filter back to the mixer.

To measure the output of the mixer *M2* without the image filter at its input, set *PathSelect2* parameter *State=1*. The system noise figure is 6 dB and includes noise from the source at the image frequency. The *TwoPort* component is used in this path so the same number of components exist in each path. The number of component must be equal so the results have an equal number of rows and columns regardless of the PathSelect2 settings.

Using Two-Port, Two-Pin S-Parameter Files

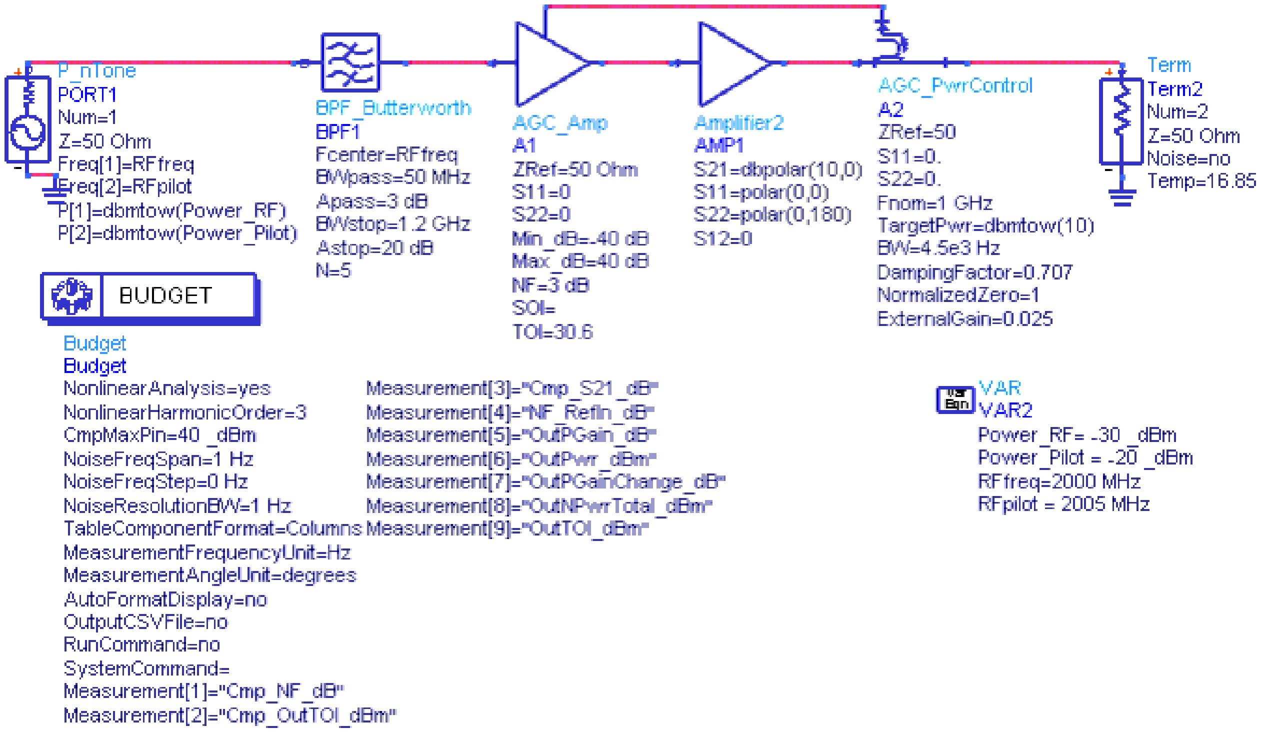
If you use a two-port, two-pin S-parameter file as a component in a budget simulation, the *S2P* component may be used in the cascaded two-port, two-pin design, but its pin 3 must be connected to ground as shown here.



Using AGC Control Loops

The following figure illustrates an example setup for performing a basic budget simulation of a two-port, two-pin cascaded network that contains an AGC loop.

Note
This design, *Budget_AGC_Pilot*, is in the *examples* directory under *Tutorial/RF_Budget_Examples_wrk*. The results are in *Budget_AGC_Pilot.dds*.



P_nTone
PORT1
Num=1
Z=50 Ohm
Freq[1]=RFfreq
Freq[2]=RFpilot
P[1]=dbmtow(Power_RF)
P[2]=dbmtow(Power_Pilot)

BPF_Butterworth
BPF1
Fcenter=RFfreq
BWpass=50 MHz
Apass=3 dB
BWstop=1.2 GHz
Astop=20 dB
N=5

AGC_Amp
A1
ZRef=50 Ohm
S11=0
S22=0
Min_dB=-40 dB
Max_dB=40 dB
NF=3 dB
SOI=
TOI=30.6

Amplifier2
AMP1
S21=dbpolar(10,0)
S11=polar(0,0)
S22=polar(0,180)
S12=0

AGC_PwrControl
A2
ZRef=50
S11=0.
S22=0.
Fnom=1 GHz
TargetPwr=dbmtow(10)
BW=4.5e3 Hz
DampingFactor=0.707
NormalizedZero=1
ExternalGain=0.025

Term
Term2
Num=2
Z=50 Ohm
Noise=no
Temp=16.85

Budget
Budget
NonlinearAnalysis=yes
NonlinearHarmonicOrder=3
CmpMaxPin=40 _dBm
NoiseFreqSpan=1 Hz
NoiseFreqStep=0 Hz
NoiseResolutionBW=1 Hz
TableComponentFormat=Columns
MeasurementFrequencyUnit=Hz
MeasurementAngleUnit=degrees
AutoFormatDisplay=no
OutputCSVFile=no
RunCommand=no
SystemCommand=
Measurement[1]="Cmp_NF_dB"
Measurement[2]="Cmp_OutTOI_dBm"
Measurement[3]="Cmp_S21_dB"
Measurement[4]="NF_RefIn_dB"
Measurement[5]="OutPGain_dB"
Measurement[6]="OutPwr_dBm"
Measurement[7]="OutPGainChange_dB"
Measurement[8]="OutNPwrTotal_dBm"
Measurement[9]="OutTOI_dBm"

VAR
VAR2
Power_RF= -30 _dBm
Power_Pilot = -20 _dBm
RFfreq=2000 MHz
RFpilot = 2005 MHz

Typical RF system design containing an AGC loop

This design shows a typical RF system design containing an AGC loop used with budget analysis. The AGC loop is controlled by the *AGC_Amp* and *AGC_PwrControl* components. For details about these two components, see the *System Models* (ccsys) documentation.

- *AGC_Amp* and *AGC_PwrControl* are the only components supported in an RF budget simulation for defining AGC loops. They are available from the Simulation-Budget and System-Amps & Mixers palettes, and the Component Library.

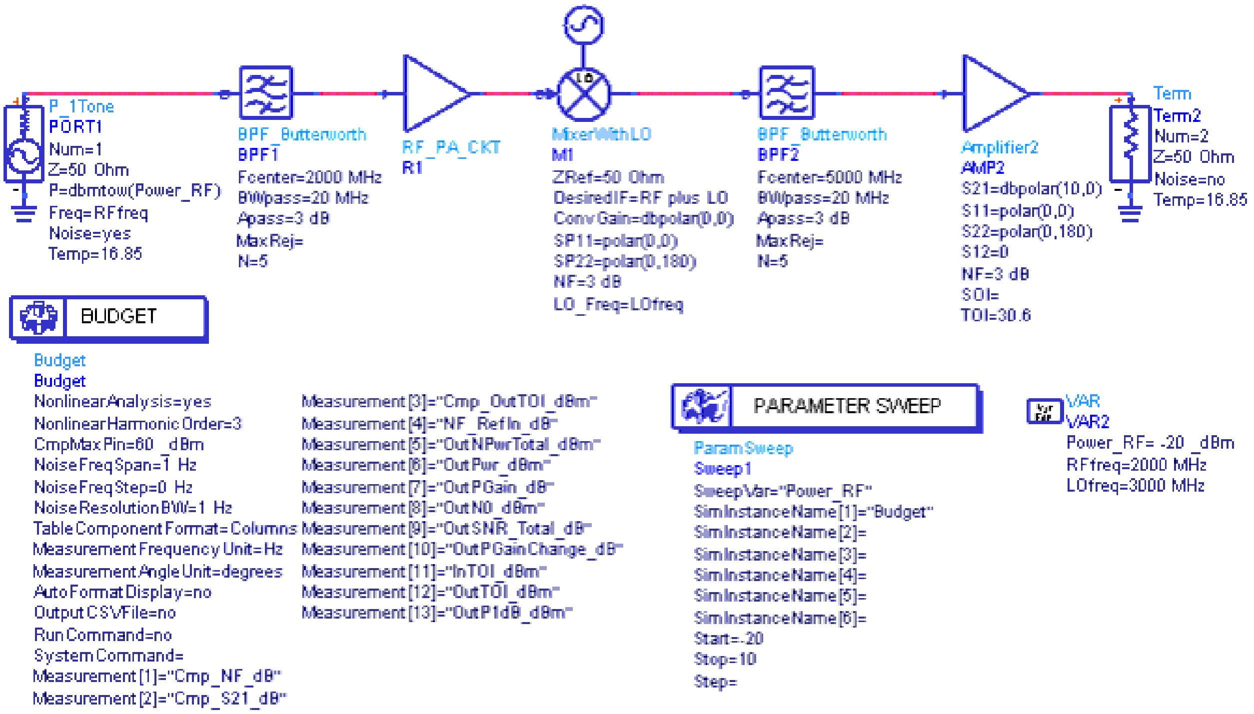
This example uses a Signal tone and an AGC Pilot tone. The AGC Pilot tone controls the AGC loop. The Signal tone is defined in the P_nTone source by *Freq[1]=RFfreq* and *P[1]=dbmtow(Power_RF)*. The Pilot tone is defined in the P_nTone source as *Freq[2]=RFpilot* and *P[2]=dbmtow(Power_Pilot)*. Using *Freq[2]* to set the Pilot tone identifies which signal the feedback loop should use; this is a defined operation of the P_nTone source. The *AGC_PwrControl* component's *TargetPwr* parameter is set to 10 dBm. Feedback to the *AGC_Amp* drives the *AGC_Amp* within its limits of *Min_dB* and *Max_dB* to achieve the *TargetPwr* level. In this example, the *AGC_Amp* stabilizes to the required Pilot tone gain of 10 dB to achieve the *TargetPwr* level of 10 dBm for the Pilot tone. This also results in an output power for the Signal tone at 0 dBm.

Using Budget with Sweep

The following figure illustrates an example setup for performing a budget simulation of a two-port, two-pin cascaded network that includes a *Parameter Sweep* controller.

Note
This design, *Budget_PSweep*, is in the *examples* directory under *Tutorial* / *RF_Budget_Examples_wrk*. The results are in *Budget_PSweep.dds*.

This example demonstrates an RF system budget analysis where the *Parameter Sweep* controller sweeps the source power (*Power_RF*). Other component parameters can be swept as allowed by ADS. Typical budget measurements are used for component performance, noise, power, and intercept points.



P_1Tone
PORT1
Num=1
Z=50 Ohm
P=dbmtow(Power_RF)
Freq=RFfreq
Noise=yes
Temp=16.85

BPF_Butterworth
BPF1
Fcenter=2000 MHz
BWpass=20 MHz
Apass=3 dB
MaxRej=
N=5

RF_PA_CKT
R1

MixerWithLO
M1
ZRef=50 Ohm
DesiredIF=RF plus LO
ConvGain=dbpolar(0,0)
SP11=polar(0,0)
SP22=polar(0,180)
NF=3 dB
LO_Freq=LOfreq

BPF_Butterworth
BPF2
Fcenter=5000 MHz
BWpass=20 MHz
Apass=3 dB
MaxRej=
N=5

Amplifier2
AMP2
S21=dbpolar(10,0)
S11=polar(0,0)
S22=polar(0,180)
S12=0
NF=3 dB
SOI=
TOI=30.6

Term
Term2
Num=2
Z=50 Ohm
Noise=no
Temp=16.85

BUDGET
Budget
Budget
NonlinearAnalysis=yes
NonlinearHarmonicOrder=3
CmpMaxPin=60 _dBm
NoiseFreqSpan=1 Hz
NoiseFreqStep=0 Hz
NoiseResolutionBW=1 Hz
TableComponentFormat=Columns
MeasurementFrequencyUnit=Hz
MeasurementAngleUnit=degrees
AutoFormatDisplay=no
OutputCSVFile=no
RunCommand=no
SystemCommand=
Measurement[1]="Cmp_NF_dB"
Measurement[2]="Cmp_S21_dB"
Measurement[3]="Cmp_OutTOI_dBm"
Measurement[4]="NF_RefIn_dB"
Measurement[5]="OutNPwrTotal_dBm"
Measurement[6]="OutPwr_dBm"
Measurement[7]="OutPGain_dB"
Measurement[8]="OutN0_dBm"
Measurement[9]="OutSNR_Total_dB"
Measurement[10]="OutPGainChange_dB"
Measurement[11]="InTOI_dBm"
Measurement[12]="OutTOI_dBm"
Measurement[13]="OutP1dB_dBm"

PARAMETER SWEEP
ParamSweep
Sweep1
SweepVar="Power_RF"
SimInstanceName[1]="Budget"
SimInstanceName[2]=
SimInstanceName[3]=
SimInstanceName[4]=
SimInstanceName[5]=
SimInstanceName[6]=
Start=-20
Stop=10
Step=

VAR
VAR2
Power_RF= -20 _dBm
RFfreq=2000 MHz
LOfreq=3000 MHz

Performing a Budget simulation of a two-port, two-pin cascaded network including a Parameter Sweep controller

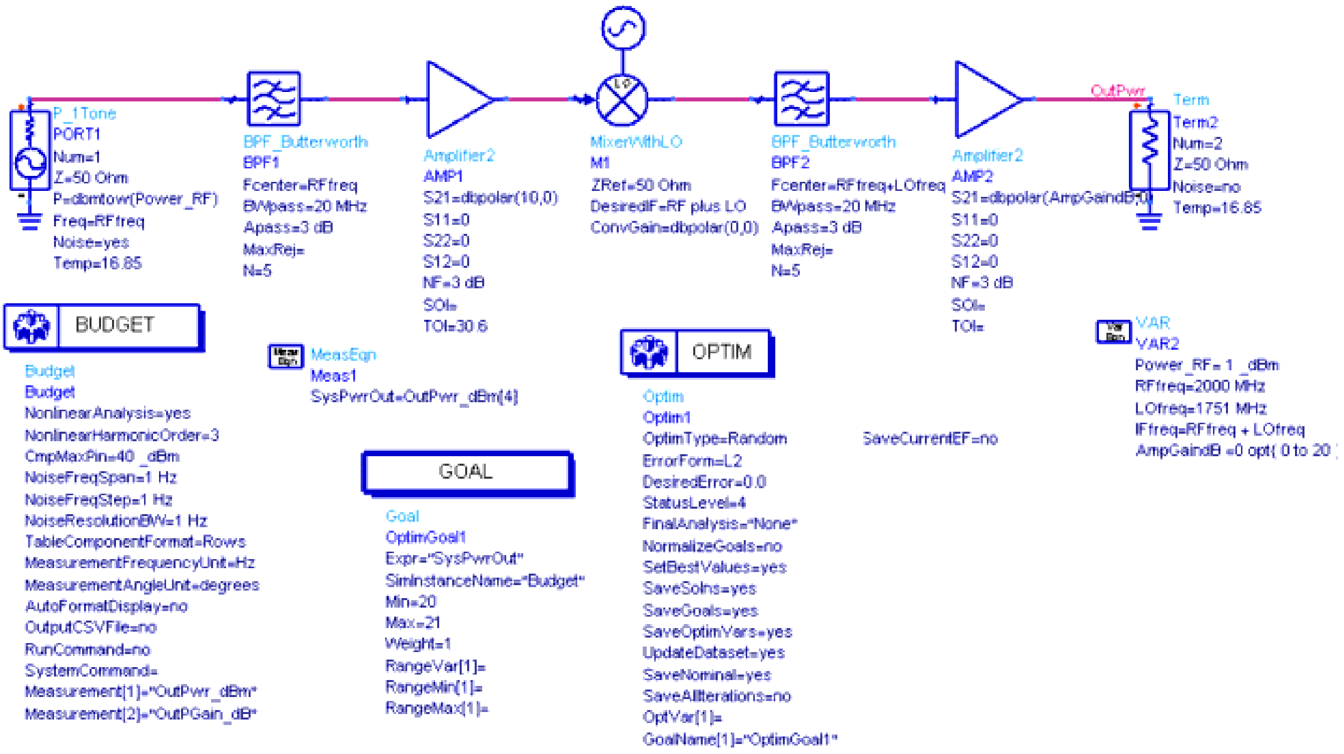
Using Budget with Optimization and Yield

The following figure illustrates an example setup for performing a budget simulation of a two-port, two-pin cascaded network that includes an *Optim* controller.

Note
This design, *Budget_Power_Optimization*, is in the *examples* directory under *Tutorial/RF_Budget_Examples_wrk*. The results are in *Budget_Power_Optimization.dds*.

This design demonstrates an RF system budget analysis with power optimization. Typical budget measurements are used for component performance, noise, power, and intercept points.

The optimization type is set to Random because budget analysis cannot be used with Gradient-like optimization types such as Gradient, Gradient Minmax, Quasi Newton, Least Path, Minmax, Hybrid, and Sensitivity.



```
P_1Tone
PORT1
Num=1
Z=50 Ohm
P=dbmtow(Power_RF)
Freq=RFfreq
Noise=yes
Temp=16.85

BPF_Butterworth
BPF1
Fcenter=RFfreq
BWpass=20 MHz
Apass=3 dB
MaxRej=
N=5

Amplifier2
AMP1
S21=dbpolar(10,0)
S11=0
S22=0
S12=0
NF=3 dB
SOI=
TOI=30.6

MixerWithLO
M1
ZRef=50 Ohm
DesiredIF=RF plus LO
ConvGain=dbpolar(0,0)

BPF_Butterworth
BPF2
Fcenter=RFfreq+LOfreq
BWpass=20 MHz
Apass=3 dB
MaxRej=
N=5

Amplifier2
AMP2
S21=dbpolar(AmpGaindB,0)
S11=0
S22=0
S12=0
NF=3 dB
SOI=
TOI=

Term
Term2
Num=2
Z=50 Ohm
Noise=no
Temp=16.85

Budget
Budget
NonlinearAnalysis=yes
NonlinearHarmonicOrder=3
CmpMaxPin=40 _dBm
NoiseFreqSpan=1 Hz
NoiseFreqStep=1 Hz
NoiseResolutionBW=1 Hz
TableComponentFormat=Rows
MeasurementFrequencyUnit=Hz
MeasurementAngleUnit=degrees
AutoFormatDisplay=no
OutputCSVFile=no
RunCommand=no
SystemCommand=
Measurement[1]="OutPwr_dBm"
Measurement[2]="OutPGain_dB"

MeasEqn
Meas1
SysPwrOut=OutPwr_dBm[4]

Goal
OptimGoal1
Expr="SysPwrOut"
SimInstanceName="Budget"
Min=20
Max=21
Weight=1
RangeVar[1]=
RangeMin[1]=
RangeMax[1]=

Optim
Optim1
OptimType=Random
ErrorForm=L2
DesiredError=0.0
StatusLevel=4
FinalAnalysis="None"
NormalizeGoals=no
SetBestValues=yes
SaveSolns=yes
SaveGoals=yes
SaveOptimVars=yes
UpdateDataset=yes
SaveNominal=yes
SaveAllIterations=no
OptVar[1]=
GoalName[1]="OptimGoal1"
SaveCurrentEF=no

VAR
VAR2
Power_RF= 1 _dBm
RFfreq=2000 MHz
LOfreq=1751 MHz
IFfreq=RFfreq + LOfreq
AmpGaindB =0 opt{ 0 to 20
```

Performing a Budget simulation of a two-port, two-pin cascaded network including an Optimization controller

You must use *MeasEqn* to identify the goal for specific budget results.

- You can define their measurements in the Schematic using *MeasEqn*.
- Budget data is used in *MeasEqn* using indexed numbering, where indexing starts at zero for the first component after the source. For example, *OutPwr_dBm[4]* refers to the output power for the fifth component after the source.
- *SysPwrOut* can be used for optimization, yield, etc. as shown in the example in the previous figure.

For a complete listing of names for all available *Budget* measurements, see the tables in *RF Budget Cascade Measurements* (rfsysbudget) and *RF Budget Summary Measurements* (rfsysbudget). These tables show the short names for the *Budget* measurements. The long name for a *Budget* measurement is defined as:

<*schematic_design_name*>.Budget.<*measurement_name*>

When setting up system summary measurements to use for optimization:

- The independent variable is *Index*.
- The name to be used in the *MeasEqn* is *System_Value[x]*, where *x* is the *Index* for the Summary Measurement desired.
- For example, the *SystemNF_dB* system summary measurement has *Index=5*, so the *MeasEqn* should use *System_Value[5]*.

When setting up system cascade measurements to use for optimization:

- On the Setup tab, when *Components In* is set to *Columns*:
  - The independent variable is *Cmp_Index*.

  - The name to be used in the *MeasEqn* is the actual cascade measurement name associated with the specific component.
  - For example, the *OutPwr_dBm* system cascade measurement for the fourth component should use *OutPwr_dBm[3]*.
- On the Setup tab, when *Components In* is set to *Rows*:
  - The independent variable is *Meas_Index*.
  - The name to be used in the *MeasEqn* is the system reference designator associated with the specific cascade measurement.
  - For example, the fourth measurement for the component with reference designator *A1* should use *A1[3]*. If you had defined the fourth measurement to be *OutPwr_dBm*, then *A1[3]* means the *OutPwr_dBm* is associated with the component whose reference designator is *A1*.

Working with RF System Budget Analysis Results

This section describes how to work with results from budget simulations:

- Viewing Results Using the ADS Data Display describes how to format and display results in the Data Display.
- Exporting and Post-Processing Results describes how to export simulation results to a text file using the Comma Separated Values (CSV) format.

Viewing Results Using the ADS Data Display

There are different ways to format and display budget simulation results in the Data Display:

- Enable the automatic formatting feature in the Budget controller.
- Use an existing Data Display page or template that is custom formatted the way you prefer.

Automatic Formatting

The results from a budget simulation can be formatted and displayed automatically in tables and plots preconfigured for the Budget controller. Enabling this feature causes the Budget controller to send a command to the Data Display window at the end of the budget simulation to format and display the results.

⚠ **Caution**
Enabling the automatic formatting feature can overwrite an existing formatted Data Display page. Make sure valuable data is not overwritten and lost.

To enable automatic formatting:

- In the Budget controller's setup dialog box, select the option **Auto format display with overwrite** on the Setup tab in the Results section.
  or
- On the schematic, set the parameter **AutoFormatDisplay=Yes**.

In addition to enabling the automatic formatting feature, you must be sure to set up the simulation so a default Data Display window opens at the end of the simulation. In the Schematic window, choose *Simulate > Simulation Setup*, then select the option *Open Data Display when simulation completes*. For more information about setting up simulations, see *Simulation Basics* (cktsim).

If you are not familiar with setting up formatting in the Data Display, enable the automatic formatting option the first time you run a budget simulation to help you learn how to display results. However, use this feature carefully to avoid accidently overwriting existing results. When you are comfortable with the Data Display and its formatting features, disable the automatic formatting.

> **Note**
> If automatic formatting is disabled, the simulation results are still written to the dataset, but they are not automatically formatted and displayed in the Data Display. This can be useful when you have a custom formatted Data Display page or template that you prefer for displaying simulation results.

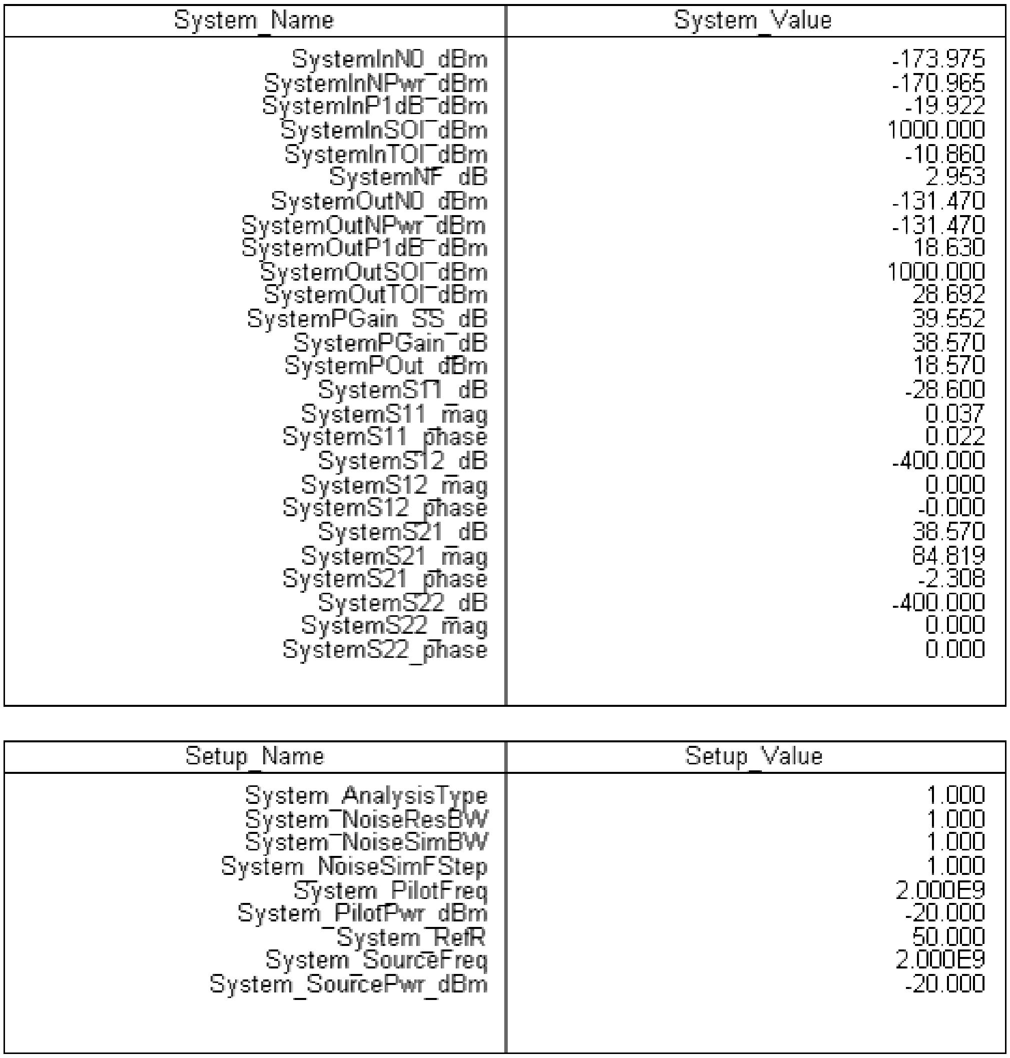
With the correct setup to display cascade and summary measurements, and after a successful simulation, a Data Display window will open at the end of the simulation containing three pages, which are discussed in the following sections:

- *Summary tables* which displays results for the default system summary measurements. See Summary Measurements Tables.
- *Measurement tables* which displays results for the selected system cascade measurements. See Cascade Measurements Tables.
- Measurement plots which displays plots for the selected system cascade measurements. See Cascade Measurements Plots.

> **Note**
> If no measurements are selected for a budget simulation, the *Measurement tables* and *Measurement plots* pages are not created since no cascade measurement results are evaluated. The *Summary tables* page is displayed by default.

Summary Measurements Tables

The *Summary tables* page displays a table with the system summary measurements for the design being simulated. Summary measurements define overall system performance from input to output. The results are formatted as shown in the example in the following figure. All of the summary measurements are evaluated and written to the dataset for every budget simulation, so they are not available for individual selection on the Budget controller's Measurements tab. For information on the individual measurements, see *RF Budget Summary Measurements* (rfsysbudget).



System_Name	System_Value
SystemInN0_dBm	-173.975
SystemInNPwr_dBm	-170.965
SystemInP1dB_dBm	-19.922
SystemInSOI_dBm	1000.000
SystemInTOI_dBm	-10.860
SystemNF_dB	2.953
SystemOutN0_dBm	-131.470
SystemOutNPwr_dBm	-131.470
SystemOutP1dB_dBm	18.630
SystemOutSOI_dBm	1000.000
SystemOutTOI_dBm	28.692
SystemPGain_SS_dB	39.552
SystemPGain_dB	38.570
SystemPOut_dBm	18.570
SystemS11_dB	-28.600
SystemS11_mag	0.037
SystemS11_phase	0.022
SystemS12_dB	-400.000
SystemS12_mag	0.000
SystemS12_phase	-0.000
SystemS21_dB	38.570
SystemS21_mag	84.819
SystemS21_phase	-2.308
SystemS22_dB	-400.000
SystemS22_mag	0.000
SystemS22_phase	0.000

Setup_Name	Setup_Value
System_AnalysisType	1.000
System_NoiseResBW	1.000
System_NoiseSimBW	1.000
System_NoiseSimFStep	1.000
System_PilotFreq	2.000E9
System_PilotPwr_dBm	-20.000
System_RefR	50.000
System_SourceFreq	2.000E9
System_SourcePwr_dBm	-20.000

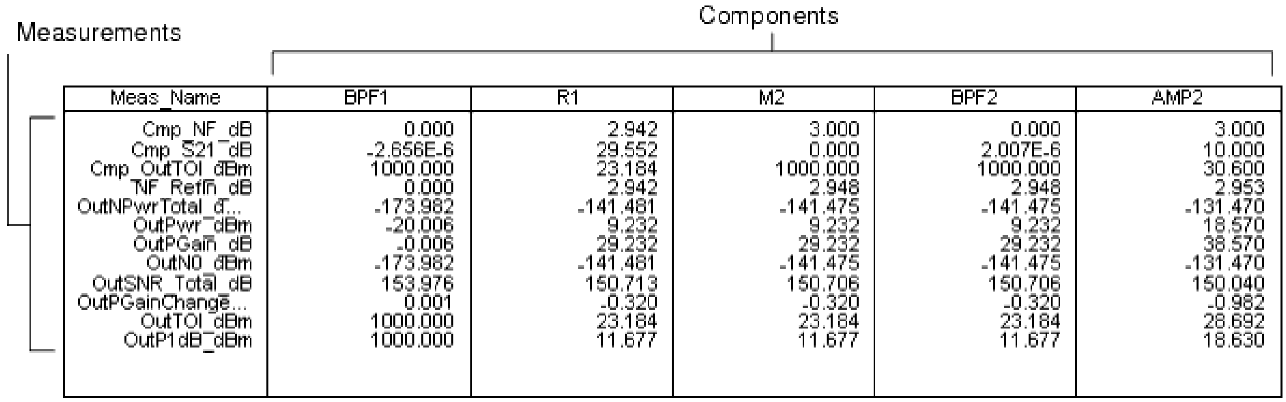
Summary measurements tables for a Budget simulation

Cascade Measurements Tables

The *Measurement tables* page displays a table with the system cascade measurements that are selected on the Budget controller's Measurements tab. These measurements are evaluated for each component on the schematic except the source and the termination. For information on the individual measurements, see *RF Budget Cascade Measurements* (rfsysbudget).

There are two ways that these measurements can be displayed to be useful.

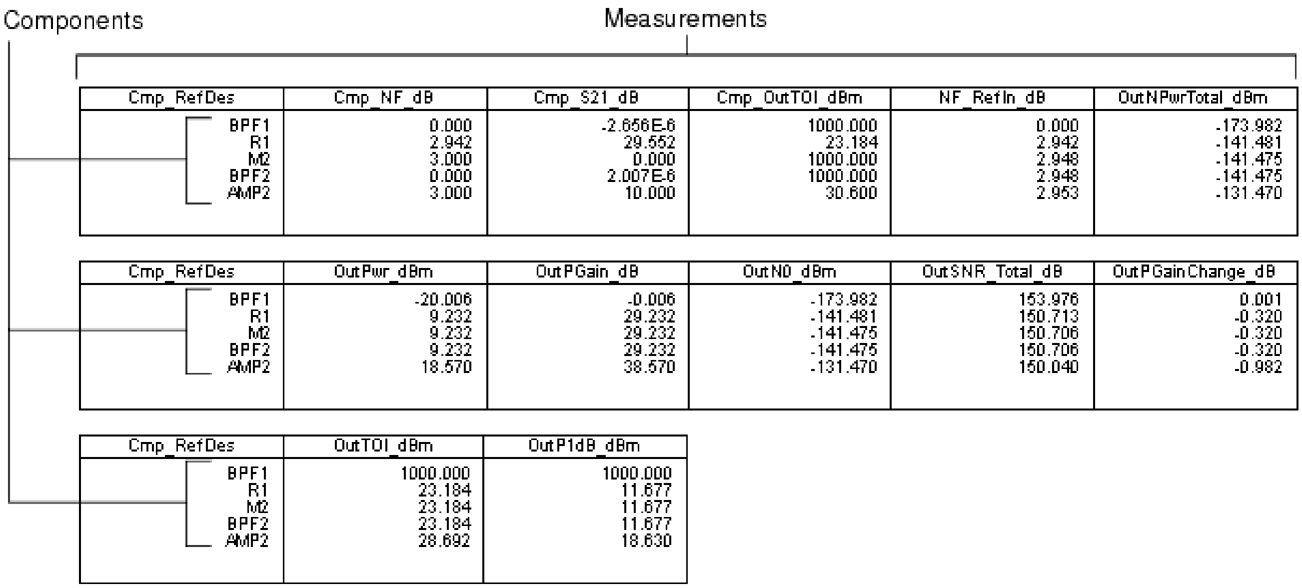
- Display the results for each component in columns as shown in the following figure. To select this format:
    - In the Budget controller's setup dialog box, select **Components in - Columns** on the Setup tab in the Results section.
      or
    - On the schematic, set the parameter **TableComponentFormat=Columns**.



Meas_Name	BPF1	R1	M2	BPF2	AMP2
Cmp_NF_dB	0.000	2.942	3.000	0.000	3.000
Cmp_S21_dB	-2.656E-6	29.552	0.000	2.007E-6	10.000
Cmp_OutTOI_dBm	1000.000	23.184	1000.000	1000.000	30.600
NF_RefIn_dB	0.000	2.942	2.948	2.948	2.953
OutNPwrTotal_d...	-173.982	-141.481	-141.475	-141.475	-131.470
OutPwr_dBm	-20.006	9.232	9.232	9.232	18.570
OutPGain_dB	-0.006	29.232	29.232	29.232	38.570
OutN0_dBm	-173.982	-141.481	-141.475	-141.475	-131.470
OutSNR_Total_dB	153.976	150.713	150.706	150.706	150.040
OutPGainChange...	0.001	-0.320	-0.320	-0.320	-0.982
OutTOI_dBm	1000.000	23.184	23.184	23.184	28.692
OutP1dB_dBm	1000.000	11.677	11.677	11.677	18.630

Cascade measurements tables with results for each component formatted in columns

- Display the results for each component in rows as shown in the following figure. To select this format:
    - In the Budget controller's setup dialog box, select **Components in - Rows** on the Setup tab in the Results section.
      or
    - On the schematic, set the parameter **TableComponentFormat=Rows**.



Cmp_RefDes	Cmp_NF_dB	Cmp_S21_dB	Cmp_OutTOI_dBm	NF_RefIn_dB	OutNPwrTotal_dBm
BPF1	0.000	-2.656E-6	1000.000	0.000	-173.982
R1	2.942	29.552	23.184	2.942	-141.481
M2	3.000	0.000	1000.000	2.948	-141.475
BPF2	0.000	2.007E-6	1000.000	2.948	-141.475
AMP2	3.000	10.000	30.600	2.953	-131.470

Cmp_RefDes	OutPwr_dBm	OutPGain_dB	OutN0_dBm	OutSNR_Total_dB	OutPGainChange_dB
BPF1	-20.006	-0.006	-173.982	153.976	0.001
R1	9.232	29.232	-141.481	150.713	-0.320
M2	9.232	29.232	-141.475	150.706	-0.320
BPF2	9.232	29.232	-141.475	150.706	-0.320
AMP2	18.570	38.570	-131.470	150.040	-0.982

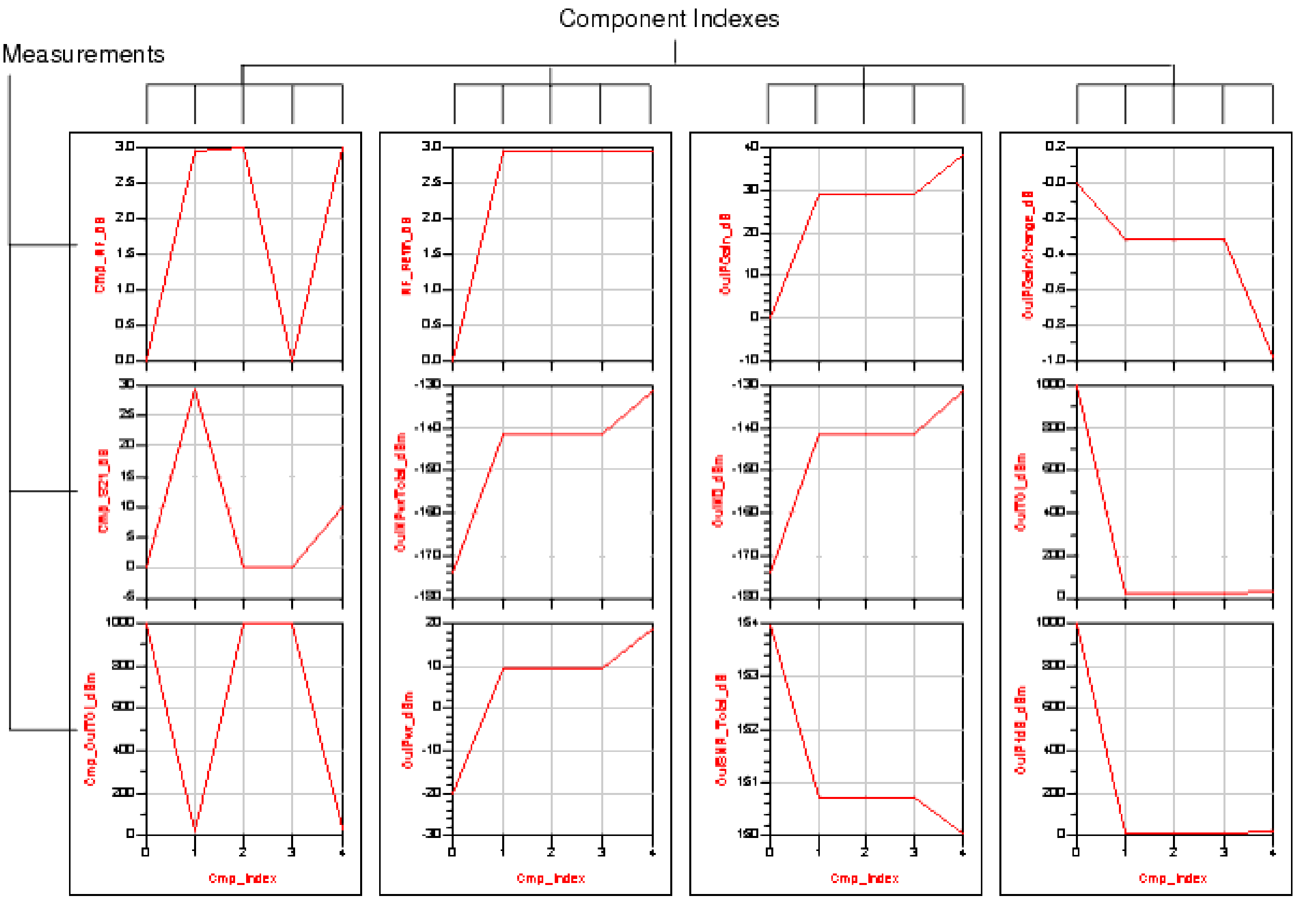
Cmp_RefDes	OutTOI_dBm	OutP1dB_dBm
BPF1	1000.000	1000.000
R1	23.184	11.677
M2	23.184	11.677
BPF2	23.184	11.677
AMP2	28.692	18.630

Cascade measurements tables with results for each component formatted in rows

Cascade Measurements Plots

The *Measurement plots* page displays plots of the system cascade measurements that are selected on the Budget controller's Measurements tab. The plots display the same data as the *Measurement tables* page, but formatted in stacked plots instead of tables as shown in the following figure. These measurements are evaluated for each component on the schematic except the source and the termination. For information on the individual measurements, see *RF Budget Cascade Measurements* (rfsysbudget).

The plots are stacked in groups of three plots per column, and the X-axis in each plot is the component index. Component indexing starts at *0* starting with the first component after the source (the source is not included). For example, in a design where the fifth component after the source is *AMP1*, the index for this component is *4* in each plot.



Cascade measurements tables with results for each component formatted in rows

Custom Formatting

If you have an existing Data Display page or template that is formatted the way you prefer, then disable the automatic format display feature. When the simulation finishes, a default Data Display page or template is opened if selected.

To disable automatic formatting:

- In the Budget controller's setup dialog box, deselect (uncheck) the option **Auto format display with overwrite** on the Setup tab in the Results section.
  or
- On the schematic, set the parameter **AutoFormatDisplay=No**.
  If needed, make sure that the Simulation Setup is configured such that a default Data Display window is opened at the end of the simulation (in the Schematic window, choose *Simulate* > *Simulation Setup*).

Exporting and Post-Processing Results

The results from a budget simulation can be exported to a text file, in the Comma Separated Values (CSV) format. This can be useful if you are familiar with using spreadsheet applications for budget analysis such as Microsoft Excel.

To enable exporting results to a CSV file:

- In the Budget controller's setup dialog box, enable the option **Output results as comma separated values (CSV) to file** on the Setup tab in the Results section.
  or
- On the schematic, set the parameter **OutputCSVFile=Yes**.

When this feature is enabled, the simulation results are written to the *data* directory of the current ADS workspace. The results are written into a text file named < *design_name* >.*csv*, where < *design_name* > is the name of the ADS schematic design being simulated. You cannot specify an alternate directory or file name. The results written to the CSV file include:

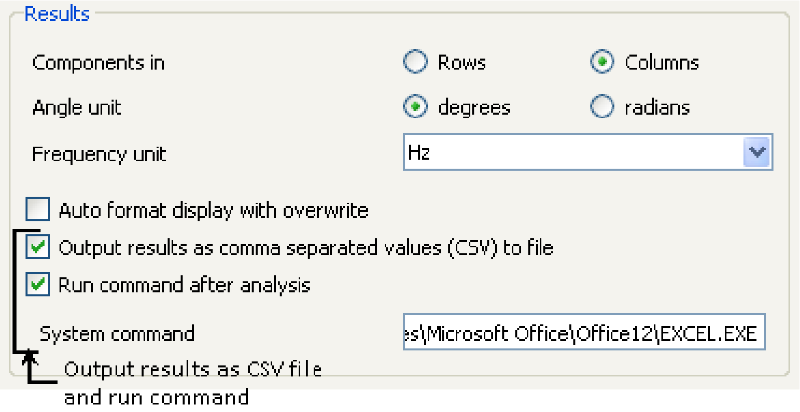
- Summary measurements data
- Cascade measurements data

The Budget controller also provides a facility for post-processing the CSV file at the end of the simulation. It enables you to run a command to reformat the CSV file into a format that's easier to use.

To enable the post-processing facility:

- In the Budget controller's setup dialog box, enable the option **Run command after analysis** on the Setup tab in the Results section. Then, enter the command that post-processes the CSV file in the entry field for **System command**. Here is an example of a command that you can enter:
  `C:\Program Files\Microsoft Office\Office12\Excel.exe`
  or
- On the schematic, set the parameter **RunCommand=Yes**, and enter the command that post-processes the CSV file for the **SystemCommand** parameter. Here is an example of a command you can enter (including quotation marks):
  `"C:\Program Files\Microsoft Office\Office12\Excel.exe"`

The following figure shows an example of how the setup dialog is prepared to output a CSV file and post-process the file.



Results

Components in ○ Rows ● Columns

Angle unit ● degrees ○ radians

Frequency unit Hz

☐ Auto format display with overwrite

☑ Output results as comma separated values (CSV) to file

☑ Run command after analysis

System command ·s\Microsoft Office\Office12\EXCEL.EXE

Setup tab set for post-processing CSV file

> **Note**
> The Budget controller parameters, *RunCommand* and *SystemCommand* are supported on Windows platforms only. On UNIX/Linux platforms, these parameters do not execute a command; instead, the simulator reports a warning stating that these parameters are not supported and proceeds with the simulation.

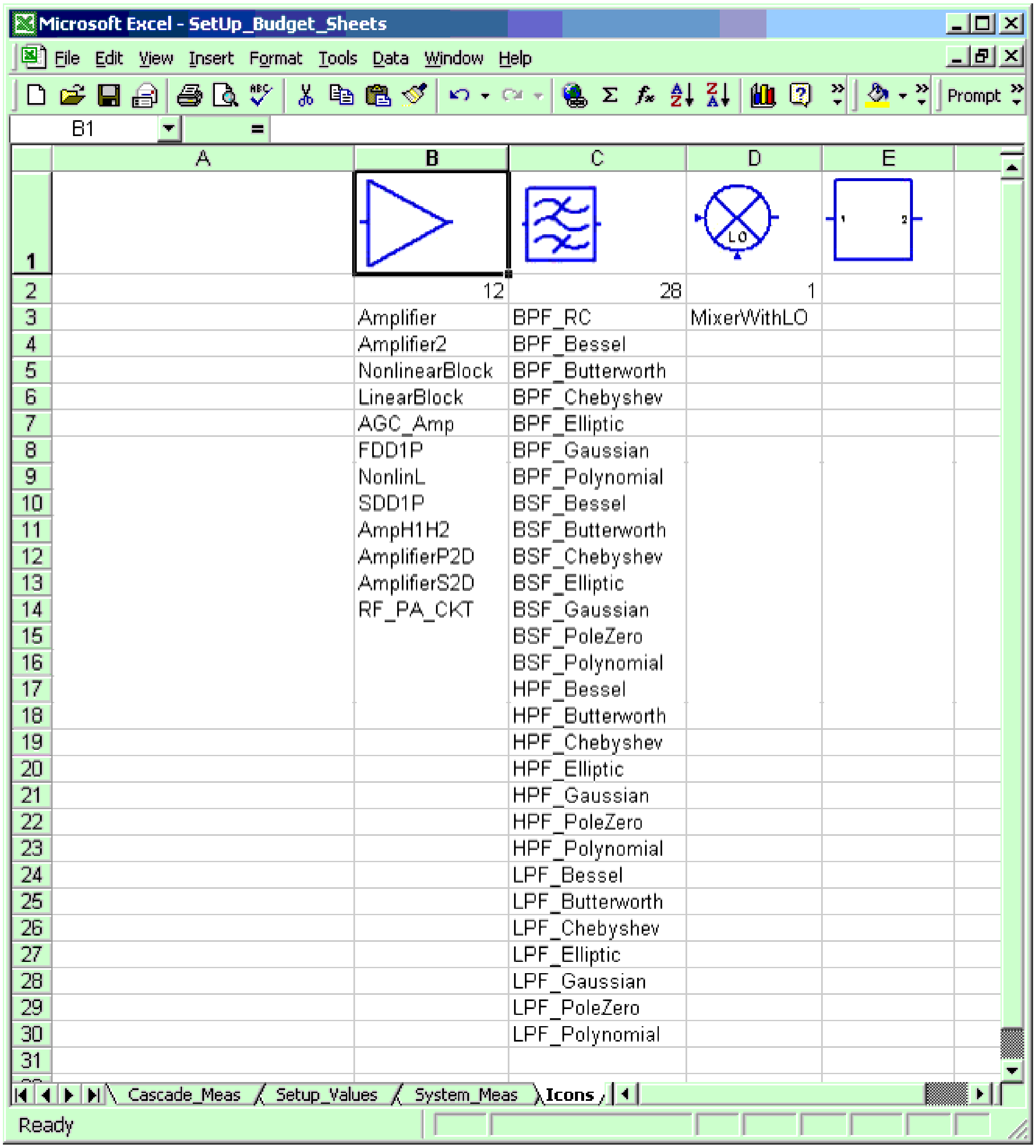
Here are additional details about using the post-processing command:

- You can define a command on any supported platform. When specifying an executable or shell script, use either its full path or a path relative to the *data* directory of the currently open ADS workspace.
- A typical use on a Windows PC is to run Excel at the end of the simulation to open the CSV file. A typical use on UNIX or Linux platforms is to run a script written in a scripting language to reformat the CSV file into a format that's easier to use.
- The system command specified in the Budget controller is executed at the end of the simulation.
- The CSV file will be overwritten after each simulation.
- The Budget controller automatically appends the name of the CSV file to the command string. For example, if the command string is
  `C:\Program Files\Microsoft Office\Office12\Excel.exe`
  then the actual command executed is
  `C:\Program Files\Microsoft Office\Office12\Excel.exe` *<design_name>*`.csv`

Example Excel Spreadsheet

ADS includes an example of a user-defined Excel spreadsheet. It contains a macro that you can use to post-process an exported CSV file. This Excel macro will process the CSV file into formatted tables and plots for each measurement. The spreadsheet is named *SetUp_Budget_Sheets.xls* and it is located in
$HPEESOF_DIR/examples/Tutorial/RF_Budget_Examples_wrk
The following figure shows *SetUp_Budget_Sheets.xls* opened to the *Icons* worksheet.

Important
Technical support is not provided for this spreadsheet. This Excel spreadsheet is included only to demonstrate how to use a user-defined macro to post-process exported results from a budget simulation. This sample spreadsheet has been tested only with Microsoft Excel 2000, version 9.0.7616 SP3. It has been found that the system command and/or spreadsheet macro fail to execute with earlier versions of Microsoft Excel.



	A	B	C	D	E
1					
2		12	28	1	
3		Amplifier	BPF_RC	MixerWithLO	
4		Amplifier2	BPF_Bessel		
5		NonlinearBlock	BPF_Butterworth		
6		LinearBlock	BPF_Chebyshev		
7		AGC_Amp	BPF_Elliptic		
8		FDD1P	BPF_Gaussian		
9		NonlinL	BPF_Polynomial		
10		SDD1P	BSF_Bessel		
11		AmpH1H2	BSF_Butterworth		
12		AmplifierP2D	BSF_Chebyshev		
13		AmplifierS2D	BSF_Elliptic		
14		RF_PA_CKT	BSF_Gaussian		
15			BSF_PoleZero		
16			BSF_Polynomial		
17			HPF_Bessel		
18			HPF_Butterworth		
19			HPF_Chebyshev		
20			HPF_Elliptic		
21			HPF_Gaussian		
22			HPF_PoleZero		
23			HPF_Polynomial		
24			LPF_Bessel		
25			LPF_Butterworth		
26			LPF_Chebyshev		
27			LPF_Elliptic		
28			LPF_Gaussian		
29			LPF_PoleZero		
30			LPF_Polynomial		
31					

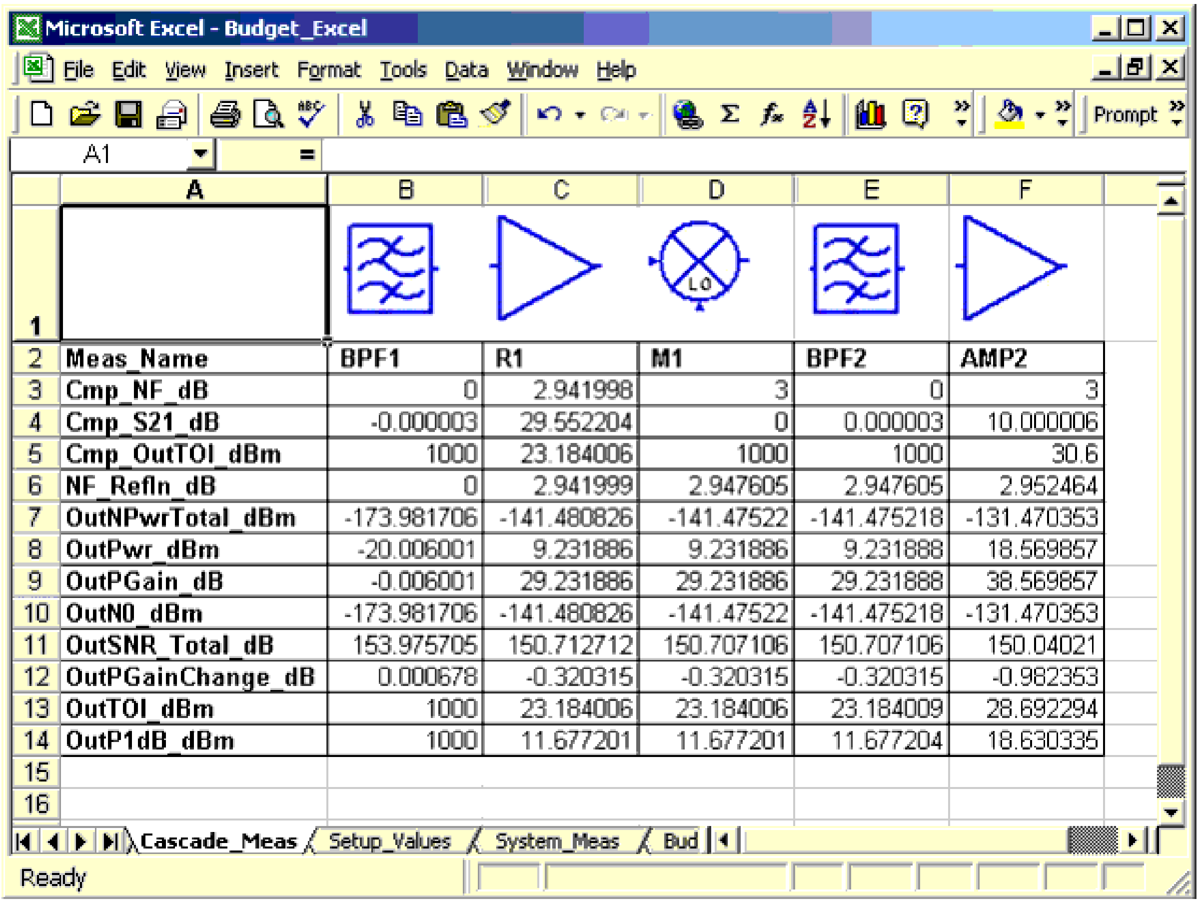
To use the sample spreadsheet:

1. Copy the file *SetUp_Budget_Sheets.xls* from the folder *$HPEESOF_DIR/examples/Tutorial/RF_Budget_Examples_wrk*.
2. Paste the *.xls* file into the *Office12\XLStart* folder. For example, if the *Excel.exe* executable's location is *C:\Program Files\Microsoft Office\Office12\Excel.exe*

then the *XLStart* folder is at
C:\Program Files\Microsoft Office\Office12\XLStart.

> **Note**
> Any Microsoft Excel spreadsheet in the *Office12\XLStart* folder will be opened any time Microsoft Excel is launched, even independent of ADS. To avoid this, delete the file *SetUp_Budget_Sheets.xls* from the *Office12\XLStart* folder after your requirement to use it for budget analysis is complete.

3. When the Budget controller launches Excel at the end of the simulation, it opens the CSV file containing the simulation data. When the CSV file opens in Excel, the macro is available in the background.
   Run the macro using the keyboard shortcut **Ctrl-R**. The following figure shows the CSV file after running the macro, opened to the *Cascade_Meas* worksheet. Additional worksheets are available named after each measurement, and containing a plot of the data for that measurement.



	A	B	C	D	E	F
1						
2	Meas_Name	BPF1	R1	M1	BPF2	AMP2
3	Cmp_NF_dB	0	2.941998	3	0	3
4	Cmp_S21_dB	-0.000003	29.552204	0	0.000003	10.000006
5	Cmp_OutTOI_dBm	1000	23.184006	1000	1000	30.6
6	NF_RefIn_dB	0	2.941999	2.947605	2.947605	2.952464
7	OutNPwrTotal_dBm	-173.981706	-141.480826	-141.47522	-141.475218	-131.470353
8	OutPwr_dBm	-20.006001	9.231886	9.231886	9.231888	18.569857
9	OutPGain_dB	-0.006001	29.231886	29.231886	29.231888	38.569857
10	OutN0_dBm	-173.981706	-141.480826	-141.47522	-141.475218	-131.470353
11	OutSNR_Total_dB	153.975705	150.712712	150.707106	150.707106	150.04021
12	OutPGainChange_dB	0.000678	-0.320315	-0.320315	-0.320315	-0.982353
13	OutTOI_dBm	1000	23.184006	23.184006	23.184009	28.692294
14	OutP1dB_dBm	1000	11.677201	11.677201	11.677204	18.630335
15						
16						

4. Customize the Excel spreadsheet *SetUp_Budget_Sheets.xls* and the macro it contains for your own needs.

Reference Measurements and Models for RF System Budget Analysis

This section provides the details about the measurements and component models used by the Budget controller:

- RF Budget Cascade Measurements
- RF Budget Summary Measurements
- RF Budget Analysis Component Models

RF Budget Cascade Measurements

You can select Budget Cascade Measurements of interest from the Budget controller's Measurements tab. These measurements produce a measurement value at each system node. For example, a system with five components will produce five values for each cascade measurement. These measurements are grouped as follows, and are described in the following sections:

- Component Measurements are for individual components. The *Cmp_Ctrb* type measurements are for the overall system without contributions of the individual component. The other *Cmp* type measurements are without contributions from the other system components.
- Noise Figure Measurements are system noise figure measurements that are calculated either from the system input to each component output (RefIn), or from each component input to the system output (RefOut).
- System Measurements at Component Inputs are for the subsystems defined from the component input to the system output.
- System Measurements at Component Outputs are for the subsystems defined from the system input to the component output.

In the following, power measurements use transducer power gain. Transducer power gain is dependant on all S-parameters of a network (s11, s12, s21, s22) along with the network source reflection coefficient (gs) and load reflection coefficient (gl). The standard expression for transducer power gain, g0, is

$$g0 = \frac{(1 - |gs|^2) \times (1 - |gl|^2) \times |s21|^2}{|(1 - s11 \times gs) \times (1 - s22 \times gl) - (s12 \times s21 \times gl \times gs)|^2}$$

Measurements that involve power use source and load coefficients along with the S-parameters of the subnetwork being measured. Thus, power delivered into the system load at component *n* input is based on the transducer power gain for the subnetwork defined from the system input through component *n*-1, the system source reflection coefficient, the system load reflection coefficient into component *n* , and the system input power. The system load reflection coefficient at component *n* input is based on the subnetwork defined from component *n* to the system output and on the system output load reflection coefficient. The system load reflection coefficient at component *n* output is based on the subnetwork defined from component *n*+1 to the system output and on the system output load reflection coefficient.

Component Measurements

The formulas in the following table reference the raw data defined in *Raw Data Generated for an RF Budget Analysis* (rfsysbudget).

Component Measurements

Measurement	**Units**	**Formula**	**Description**
Cmp_Ctrb_SysNF_NoImage_dB	dB	Cmp_Ctrb_SysNF_NoImage[n]	System noise figure improvement if component contributes no noise; excludes system image noise
Cmp_Ctrb_SysTOI_dB	dB	Cmp_Ctrb_SysTOI[n]	System output 3rd-order intercept improvement if component is linear
Cmp_LS_GainChange_dB	dB	(G_ss[n] - PG_ss[n-1]) - (PG_ls[n] - PG_ls[n-1])	Difference between component effective small-signal gain and large-signal gain within system
Cmp_NF_dB	dB	Cmp_NF[n]	Component noise figure with source and load impedance of 50 ohms
Cmp_OutN0_dBm	dBm	30 + Cmp_NF[n] + Cmp_S21[n,0]	Component output noise power density (per Hz) with source and load impedance of 50 ohms
Cmp_OutP1dB_dBm	dBm	Cmp_OutP1[n]	Component output 1 dB gain compression power level with source reflection coefficient equal to the real part of the component small signal S11 and the load reflection coefficient equal to the real part of the component small signal S22
Cmp_OutSOI_dBm	dBm	Cmp_OutSOI[n]	Component output 2nd-order intercept
Cmp_OutTOI_dBm	dBm	Cmp_OutTOI[n]	Component output 3rd-order intercept with source reflection coefficient equal to the real part of the component small signal S11 and the load reflection coefficient equal to the real part of the component small signal S22
Cmp_S11_dB	dB	Cmp_S11[n, 0]	Component 50 ohm S11 in dB
Cmp_S11_mag	-	Cmp_S11[n, 1]	Component 50 ohm S11 magnitude
Cmp_S11_phase	degrees, radians	Cmp_S11[n, 2]	Component 50 ohm S11 phase
Cmp_S12_dB	dB	Cmp_S12[n, 0]	Component 50 ohm S12 in dB
Cmp_S12_mag	-	Cmp_S12[n, 1]	Component 50 ohm S12 magnitude
Cmp_S12_phase	degrees, radians	Cmp_S12[n, 2]	Component 50 ohm S12 phase
Cmp_S21_dB	dB	Cmp_S21[n, 0]	Component 50 ohm S21 in dB
Cmp_S21_mag	-	Cmp_S21[n, 1]	Component 50 ohm S21

			magnitude
Cmp_S21_phase	degrees, radians	Cmp_S21[n, 2]	Component 50 ohm S21 phase
Cmp_S22_dB	dB	Cmp_S22[n, 0]	Component 50 ohm S22 in dB
Cmp_S22_mag	-	Cmp_S22[n, 1]	Component 50 ohm S22 magnitude
Cmp_S22_phase	degrees, radians	Cmp_S22[n, 2]	Component 50 ohm S22 phase
Cmp_SS_MismatchLoss_dB	dB	Cmp_S21[n,0] - (PG_ss[n] - PG_ss[n-1])	Difference between component 50 ohm small-signal gain and small-signal transducer power gain within system
Cmp_SS_PGain_dB	dB	PG_ss[n] - PG_ss[n-1]	Component small-signal transducer power gain within system

Noise Figure Measurements

The formulas in the following table reference the raw data defined in *Raw Data Generated for an RF Budget Analysis* (rfsysbudget).

Noise Figure Measurements

Measurement	Units	Formula	Description
NF_RefIn_NoImage_dB	dB	NF_refin_no_image[n]	Noise figure from system input to component output with image noise excluded and with 50-ohm source and load resistance. This is not the true system noise figure when the system contains mixers. This measurement is provided for user reference when their own noise figure calculations exclude system image noise. Use NF_RefIn_dB for the true system noise figure when the system contains mixers.
NF_RefIn_dB	dB	NF_refin[n]	Noise figure from system input to component output with 50-ohm source and load resistance
NF_RefOut_NoImage_dB	dB	NF_refout_no_image[n]	Noise figure from component input to system output with image noise excluded and with 50-ohm source and load resistance. This is not the true system noise figure when the system contains mixers. This measurement is provided for user reference when their own noise figure calculations exclude system image noise. There is no NF_RefOut_dB measurement available that would show the true system noise figure when the system contains mixers.
NFactor_RefIn	-	10{^}(NF_refin[n]/10)	Noise factor from system input to component output with 50-ohm source and load resistance

System Measurements at Component Inputs

The formulas in the following table reference the raw data defined in *Raw Data Generated for an RF Budget Analysis* (rfsysbudget).

System Measurements at Component Inputs

Measurement	**Units**	**Formula**	**Description**
InFreq	Hz	F[n-1]	Frequency at component input
InNPwrTotal_dBm	dBm	NPwr[n-1]	Noise power per noise simulation frequency span centered at the RF fundamental frequency for noise power delivered into system load at component input
InP1dB_dBm	dBm	P1dB_in[n]	1 dB gain compression power delivered into system load at component input
InPGain_SS_dB	dB	PG_ss[n-1]	Transducer power gain for power delivered into system load at component input, small-signal analysis
InPGain_dB	dB	PG_ls[n-1]	Transducer power gain for power delivered into system load at component input
InPwrInc_SS_dBm	dBm	P_ss[n]	Power incident into component input referenced to 50 ohms, small-signal analysis
InPwrInc_dBm	dBm	P_ls[n]	Power incident into component input referenced to 50 ohms
InPwrRefl_SS_dBm	dBm	Q_ss[n]	Power reflected by component input referenced to 50 ohms, small-signal analysis
InPwrRefl_dBm	dBm	Q_ls[n]	Power reflected by component input referenced to 50 ohms
InPwr_SS_dBm	dBm	PwrS + PG_ss[n-1]	Power delivered into system load at component input, small-signal analysis
InPwr_dBm	dBm	PwrS + PG_ls[n-1]	Power delivered into system load at component input
InReflCoeff_SS_dB	dB	G_ss[n, 0]	Reflection coefficient in dB at component input referenced to 50 ohms, small-signal analysis
InReflCoeff_SS_mag	-	G_ss[n, 1]	Reflection coefficient magnitude at component input referenced to 50 ohms, small-signal analysis
InReflCoeff_SS_phase	degrees, radians	G_ss[n, 2]	Reflection coefficient phase at component input referenced to 50 ohms, small-signal analysis
InReflCoeff_dB	dB	G_ls[n, 0]	Reflection coefficient in dB at component input referenced to 50 ohms
InReflCoeff_mag	-	G_ls[n, 1]	Reflection coefficient magnitude at component input referenced to 50 ohms
InReflCoeff_phase	degrees, radians	G_ls[n, 2]	Reflection coefficient phase at component input referenced to 50 ohms
InSNR0_dB	dB	PwrS + PG_ls[n-1] - (NPwr0[n-1] - 10*log10(ResBW))	Ratio of power to noise power density delivered into system load at component input
InSOI_dBm	dBm	SOI_in[n]	2nd-order intercept power delivered into system load at component

			input
InTE_NoImage_K	K	290 * (10{^}(NF_refout_no_image[n]/10.) - 1)	Equivalent noise temperature at component input evaluated for the subnetwork from component input to system output with 50-ohm source and load resistance; excludes system image noise
InTOI_dBm	dBm	TOI_in[n]	3rd-order intercept power delivered into system load at component input
InVSWR	-	(1/G_ls[n, 1]+1)/(1/G_ls[n, 1]-1)	Voltage standing wave ratio at component input referenced to 50 ohms

System Measurements at Component Outputs

The formulas in the following table reference the raw data defined in *Raw Data Generated for an RF Budget Analysis* (rfsysbudget).

System Measurements at Component Outputs

Measurement	**Units**	**Formula**	**Description**
OutCDR_ResBW_dB	dB	P1dB_out[n] - NPwr0[n]	Compressive dynamic range from system 1 dB gain compression power to noise power per resolution bandwidth at component output
OutCDR_Total_dB	dB	P1dB_out[n] - NPwr[n]	Compressive dynamic range from system 1 dB gain compression power to total noise power at component output
OutFreq	Hz	F[n]	Frequency at component output
OutIM2_dBm	dBm	SOI_out[n] - 2 * (SOI_out[n] - PG_ls[n] - PwrS)	2nd-order IM product power delivered into system load at component output; for each ouput tone for system input 2 tone signal with each input tone at PwrS power level
OutIM3_dBm	dBm	TOI_out[n] - 3 * (TOI_out[n] - PG_ls[n] - PwrS)	3rd-order IM product power delivered into system load at component output; for each ouput tone for system input 2 tone signal with each input tone at PwrS power level
OutN0_dBm	dBm	NPwr0[n] - 10*log10(ResBW)	Noise power density delivered into system load at component output
OutNBW	Hz	NBW[n]	Noise bandwidth at component output derived from total noise power delivered into system load at component output
OutNPwrResBW_dBm	dBm	NPwr0[n]	Noise power per noise simulation resolution bandwidth centered at the RF fundamental frequency delivered into system load at component output
OutNPwrTotal_dBm	dBm	NPwr[n]	Noise power per noise simulation frequency span centered at the RF fundamental frequency for noise power delivered into system load at component output
OutP1dB_dBm	dBm	P1dB_out[n]	1 dB gain compression power delivered into system load at component output
OutPGainChange_dB	dB	PG_ls[n] - PG_ss[n]	Transducer power gain change from small-

			signal at component output
OutPGain_dB	dB	PG_ls[n]	Transducer power gain for power delivered into system load at component output
OutPwr_dBm	dBm	PwrS + PG_ls[n]	Power delivered into system load at component output
OutSFDR_ResBW_dB	dB	2/3 * (TOI_out[n] - NPwr0[n])	Spurious free dynamic range from 3rd-order intercept power level to noise power per resolution bandwidth for power delivered into system load at component output
OutSFDR_Total_dB	dB	2/3 * (TOI_out[n] - NPwr[n])	Spurious free dynamic range from 3rd-order intercept power level to total noise power for power delivered into system load at component output
OutSNR0_dB	dB	PwrS + PG_ls[n] - (NPwr0[n] - 10*log10(ResBW))	Ratio of signal power to noise power density for power delivered into system load at component output
OutSNR_ResBW_dB	dB	PwrS + PG_ls[n] - NPwr0[n]	Ratio of signal power to noise power per resolution bandwidth for power delivered into system load at component output
OutSNR_Total_dB	dB	PwrS + PG_ls[n] - NPwr[n]	Ratio of signal power to total noise power for power delivered into system load at component output
OutSOI_dBm	dBm	SOI_out[n]	2nd-order intercept power delivered into system load at component output
OutS_IM3_dB	dB	(PwrS + PG_ls[n]) - (TOI_out[n] - 3 * (TOI_out[n] - PG_ls[n] - PwrS))	Ratio of signal power to 3rd-order product power level for power delivered into system load at component output; for each output tone for system input 2 tone signal with each input tone at PwrS power level
OutTOI_dBm	dBm	TOI_out[n]	3rd-order intercept power delivered into system load at component output
OutVGainInc_SS_dB	dB	VGI_ss[n, 0]	Voltage gain in dB for wave incident on 50-ohm load at component output, small-signal analysis
OutVGainInc_SS_mag	-	VGI_ss[n, 1]	Voltage gain magnitude for wave incident on 50-ohm load at component output, small-signal analysis
OutVGainInc_SS_phase	degrees, radians	VGI_ss[n, 2]	Voltage gain phase for wave incident on 50-ohm load at component output, small-signal analysis
OutVGainInc_dB	dB	VGI_ls[n, 0]	Voltage gain in dB for wave incident on 50-ohm load at component output
OutVGainInc_mag	-	VGI_ls[n, 1]	Voltage gain magnitude for wave incident on 50-ohm load at component output
OutVGainInc_phase	degrees, radians	VGI_ls[n, 2]	Voltage gain phase for wave incident on 50-ohm load at component output
OutVGainRefl_SS_dB	dB	VGR_ss[n, 0]	Voltage gain in dB for wave reflected by 50-ohm load at component output, small-signal analysis
OutVGainRefl_SS_mag	-	VGR_ss[n, 2]	Voltage gain magnitude for wave reflected by 50-ohm load at component output, small-signal analysis
OutVGainRefl_SS_phase	degrees, radians	VGR_ss[n, 1]	Voltage gain phase for wave reflected by 50-ohm load at component output, small-signal analysis
OutVGainRefl_dB	dB	VGR_ls[n, 0]	Voltage gain in dB for wave reflected by 50-

			ohm load at component output
OutVGainRefl_mag	-	VGR_ls[n, 1]	Voltage gain magnitude for wave reflected by 50-ohm load at component output
OutVGainRefl_phase	degrees, radians	VGR_ls[n, 2]	Voltage gain phase for wave reflected by 50-ohm load at component output

RF Budget Summary Measurements

The System Summary Measurements define overall system performance from input to output.

The formulas in the following table reference the raw data defined in *Raw Data Generated for an RF Budget Analysis* (rfsysbudget).

System Summary Measurements

Measurement	Units	Formula	Description
SystemInN0_dBm	dBm	NPwr0[-1] - 10*log10(ResBW)	System input noise power density (per Hz)
SystemInNPwr_dBm	dBm	NPwr[-1]	System input noise power per simulation bandwidth
SystemInP1dB_dBm	dBm	P1dB_in[0]	System input 1-dB gain compression power
SystemInSOI_dBm	dBm	SOIs_in[0]	System input 2nd-order intercept power
SystemInTOI_dBm	dBm	TOIs_in[0]	System input 3rd-order intercept power
SystemNF_dB	dB	NF_refin[N-1]	System noise figure
SystemOutN0_dBm	dBm	NPwr0[N-1] - 10*log10(ResBW)	System output noise power density (per Hz)
SystemOutNPwr_dBm	dBm	NPwr[N-1]	System output noise power per simulation bandwidth
SystemOutP1dB_dBm	dBm	P1dB_out[0]	System output 1-dB gain compression power
SystemOutSOI_dBm	dBm	SOIs_out[N-1]	System output 2nd-order intercept power
SystemOutTOI_dBm	dBm	TOI_out[N-1]	System output 3rd-order intercept power
SystemPGain_SS_dB	dB	PG_ss[N-1]	System small-signal transducer power gain
SystemPGain_dB	dB	PG_Is[N-1]	System transducer power gain
SystemPOut_dBm	dBm	PwrS+PGain_Is[N-1]	System output power
SystemS11_dB	dB	G_Is[0, 0]	System S11 in dB with 50-ohm source and load
SystemS11_mag	-	G_Is[0, 1]	System S11 magnitude with 50-ohm source and load
SystemS11_phase	degrees, radians	G_Is[0, 2]	System S11 phase with 50-ohm source and load
SystemS12_dB	dB	System_S12[0]	System S12 in dB with 50-ohm source and load
SystemS12_mag	-	System_S12[1]	System S12 magnitude with 50-ohm

			source and load
SystemS12_phase	degrees, radians	System_S12[2]	System S12 phase with 50-ohm source and load
SystemS21_dB	dB	VGI_Is[N-1, 0]	System S21 in dB with 50-ohm source and load
SystemS21_mag	-	VGI_Is[N-1, 1]	System S21 magnitude with 50-ohm source and load
SystemS21_phase	degrees, radians	VGI_Is[N-1, 2]	System S21 phase with 50-ohm source and load
SystemS22_dB	dB	System_S22[0]	System S22 in dB with 50-ohm source and load
SystemS22_mag	-	System_S22[1]	System S22 magnitude with 50-ohm source and load
SystemS22_phase	degrees, radians	System_S22[2]	System S22 phase with 50-ohm source and load
System_AnalysisType	-	System_AnalysisType	Analysis type (0=linear, 1=nonlinear)
System_NoiseResBW	Hz	ResBW	Noise analysis resolution bandwidth
System_NoiseSimBW	Hz	SimBW	Noise analysis simulation bandwidth
System_NoiseSimFStep	Hz	SimFStep	Noise analysis simulation frequency step
System_PilotFreq	Hz	FreqPilot	System source pilot tone frequency for AGC loops
System_PilotPwr_dBm	dBm	PwrPilot	System source pilot tone power
SystemRefR	ohms	RefR	System reference resistance
System_SourceFreq	Hz	FreqS	System source frequency
System_SourcePwr_dBm	dBm	PwrS	System source power
System_SourceTemp	° C	TempS	System source temperature

RF Budget Analysis Component Models

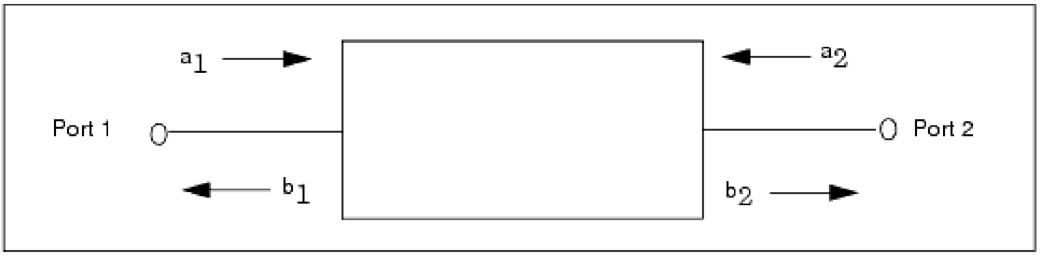
This section describes the component models used for RF budget analysis.

Two-Port, Two-Pin Small-Signal S-Parameter Definitions

Scattering parameters (S-parameters) are used to define the signal properties of a two-port, two-pin circuit component at a single frequency. The S-parameters over a range of frequencies define the component's performance for all defined spectral tones.

S-parameter definitions can be found in any textbook on circuit theory. The following discussion is for a two-port, two-pin component.

A two-port, two-pin circuit component signal wave representation can be shown in block diagram form. See the following figure.



Two-port, two-pin signal wave

where:

a_1= wave into port 1
b_1= wave out of port 1
a_2= wave into port 2
b_2= wave out of port 2

The S-parameters for this conventional component are defined in standard microwave text books as follows:

$b_1 = a_1 s_{11} + a_2 s_{12}$
$b_2 = a_1 s_{21} + a_2 s_{22}$

where:

s_{11}= port 1 reflection coefficient: $s_{11} = b_1/a_1$; $a_2 = 0$
s_{22}= port 2 reflection coefficient: $s_{22} = b_2/a_2$; $a_1 = 0$
s_{21}= forward transmission coefficient: $s_{21} = b_2/a_1$; $a_2 = 0$
s_{12}= reverse transmission coefficient: $s_{12} = b_1/a_2$; $a_1 = 0$

S-parameters are defined with respect to a reference impedance that is typically 50 ohms. For 50-ohm S-parameters, and with the two-port, two-pin component terminated with 50 ohms at each port, the s_{21} parameter is simply the voltage gain of the component from port 1 to port 2.

These equations can be solved for b_1 and a_1 in terms of a_2 and b_2 to yield the transmission (T) parameters as follows:

$b_1 = a_2 t_{11} + b_2 t_{12}$
$a_1 = a_2 t_{21} + b_2 t_{22}$

The T-parameters are related to the S-parameters as follows:

$$\begin{bmatrix} t11 & t12 \\ t12 & t22 \end{bmatrix} = \begin{bmatrix} \left(s12 - s11\dfrac{s22}{s21}\right) & \dfrac{s11}{s21} \\ -\dfrac{s22}{s21} & \dfrac{1}{s21} \end{bmatrix}$$

S-Parameter Definitions for Components with Spectral Inversions

A spectral inversion (SI) component is a component whose output signal is derived from the conjugate phase of the input signal. This typically occurs for down converting mixers with an LO frequency greater than the input RF frequency.

The frequency inversion of signals through a spectral inverting component brings about a conjugate transformation to the transmitted wave. This transformation makes use of the property of the mixer which can be modeled as a multiplier of the input and local oscillator waveforms:

$V_{in(t)}$= cos(wi • t + Phi)

$V_{LO(t)}$= cos(wlo • t); assume wlo > wi

$V_{o(t)}$ = Vin * VLO

$V_{o(t)}$ = 0.5 cos((wlo-wi) t - Phi) + 0.5 cos((wlo+wi) t + Phi)

As shown, the lower sideband component, wlo-wi, has a phase component which is the conjugate of the input phase.

The S-parameter definitions for a spectral inverting component must account for the spectral inversion that occurs at the output. Therefore, the S-parameters for a spectral inverting component are slightly different than those of a conventional component (see references 10, 11, and 12 in *References for RF System Budget Analysis* (rfsysbudget)).

(* in the following represents conjugate):

s_{11} is the port 1 reflection coefficient: $s_{11} = b_1/a_1$; $a_2 = 0$

s_{22} is the port 2 reflection coefficient: $s_{22} = b_2/a_2$; $a_1 = 0$

s_{21} is the forward transmission coefficient: $s_{21} = b_2/a_1{*}$; $a_2 = 0$

s_{12} is the reverse transmission coefficient: $s_{12} = b_1/a_2{*}$; $a_1 = 0$

Note that s_{21} and s_{12} account for the conjugate of the incident wave. The definitions for s_{11} and s_{12} above are slightly different from the convention used in reference 10 (in *References for RF System Budget Analysis* (rfsysbudget)) in which $s_{11}= b_1{*}/a_1{*}$ and $s_{12}= b_1{*}/a_2$.

The reverse transmission wave, b_1, and forward transmission wave, b_2, are as follows:

$$b_1 = a_1 s_{11} + a_2 * s_{12}$$

$$b_2 = a_1 * s_{21} + a_2 s_{22}$$

Two-Port, Two-Pin Noise Parameter Definitions

Noise parameters are used to define the noise properties of a circuit component at a single frequency. The noise parameters over a range of frequencies define the component's performance for all noise power spectral density spectral tones defining an incident noise.

Noise parameter definitions can be found in any textbook on circuit theory. Noise wave parameters are used by the program to define the noise properties of any circuit component. The following discussion is for a two-port, two-pin component.

The two-port, two-pin component noise wave representation may use two noise waves at the component input (see section (b) in the next figure; see reference 1 in *References for RF System Budget Analysis* (rfsysbudget)). Otherwise, it may use one noise wave at the component input and one at the component output (see section (c) in the next figure; see reference 2 in *References for RF System Budget Analysis* (rfsysbudget)).

In the following noise discussions, the spot noise in a bandwidth of 1 Hz is assumed.

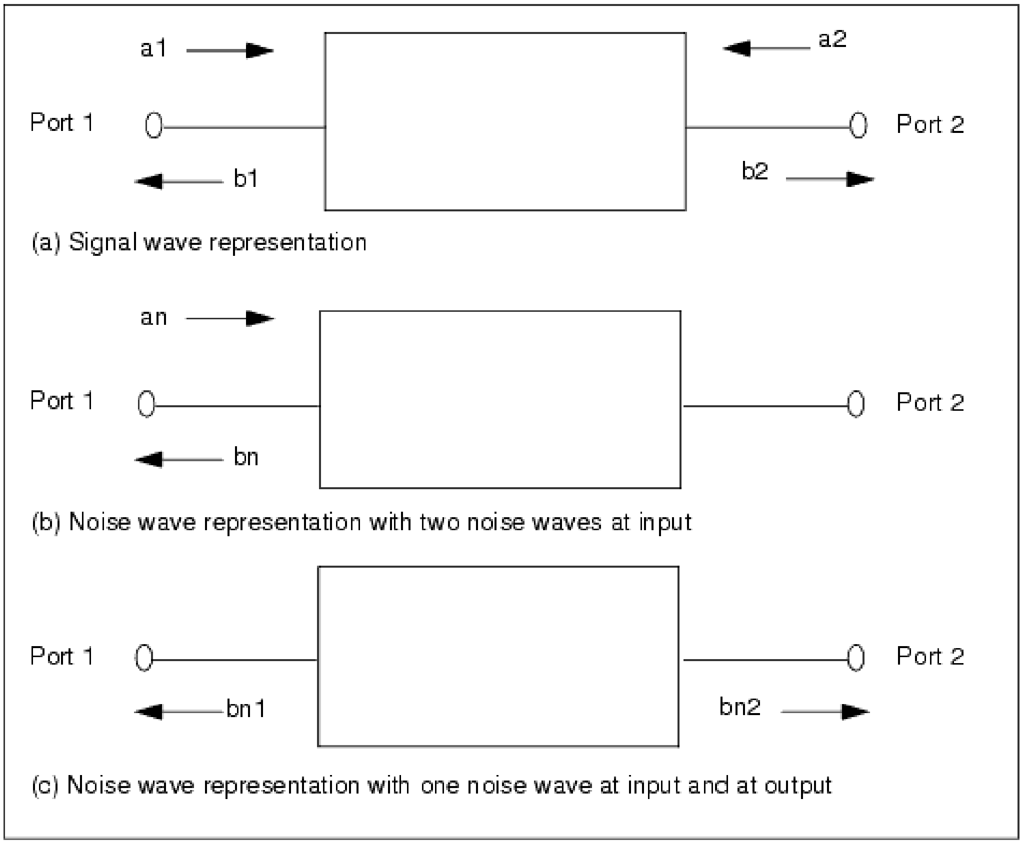
A two-port, two-pin component noise wave representation with two noise waves at the component input is shown in section (b) in the following figure; (also see reference 1 in *References for RF System Budget Analysis* (rfsysbudget)).

The noise correlation matrix, [N], is defined as follows:

$$[N] = \begin{bmatrix} N11 & N12 \\ N21 & N22 \end{bmatrix} = \begin{bmatrix} \langle bn\, bn^* \rangle & \langle bn\, an^* \rangle \\ \langle bn^*\, an \rangle & \langle an\, an^* \rangle \end{bmatrix}$$

where the noise is considered to be within a 1 Hz bandwidth and * represents the complex conjugate.

A two-port, two-pin component noise wave representation with one noise wave at the component input and at the component output is shown in section (c) in the following figure (also see reference 2 in *References for RF System Budget Analysis* (rfsysbudget)).



(a) Signal wave representation

(b) Noise wave representation with two noise waves at input

(c) Noise wave representation with one noise wave at input and at output

Component signal and noise wave representations

The noise correlation matrix, [A], is defined as follows:

$$[A] = \begin{bmatrix} A11 & A12 \\ A21 & A22 \end{bmatrix} = \begin{bmatrix} \langle bn1\ bn1^* \rangle & \langle bn1\ bn2^* \rangle \\ \langle bn1^*\ bn2 \rangle & \langle bn2\ bn2^* \rangle \end{bmatrix}$$

where the noise is considered to be within a 1 Hz bandwidth.

These noise waves, bn1 and bn2, are related to the first pair of noise waves, an and bn, as follows:

bn1 = an s11 + bn	an = bn2/s21
bn2 = an s21	bn = bn1 - bn2 s11/s21

This results in the following relationship between the [A] and [N] noise correlation parameters:

A11 = N22 |s11|2 + N21 s11 + N12 s11* + N11
A12 = N22 s11 s21* + N12 s21*
A21 = N22 s11* s21 + N21 s21
A22 = N22 |s21|2
N11 = A11 + A22 |s11|2/|s21|2 - A12 s11*/s21* - A12* s11/s21
N12 = A12/s21* - A22 s11/|s21|2
N21 = A21/s21 - A22 s11*/|s21|2
N22 = A22/|s21|2

Linear Component Noise Models

A two-port, two-pin linear circuit component has a mathematical model defined by a 2x2 S-parameter matrix and a 2x2 noise wave parameter matrix. The linear component may be passive or active.

A passive component has S-parameters that satisfy the energy conservation requirement for port index *i* from 1 to N:

$$\sum_{i=1}^{N} \left|S_{ij}\right|^2 \le 1$$

The noise wave parameters for a linear passive component are derived from the component S-parameters and its physical temperature as follows:

For an n-port passive component the noise correlation matrix is given by reference 3 in *References for RF System Budget Analysis* (rfsysbudget):

$[A] = k \bullet Tphys \bullet \{[I] - [s][s^*]^T\}$

where:

k = Boltzmann's constant
Tphys = physical temperature in K
[I] = the identity matrix
[s] = the component's S-parameter matrix
$[s^*]^T$ = the transpose of the conjugate of the [s] matrix

For a two-port, two-pin component:

$$\begin{bmatrix} A11 & A12 \\ A21 & A22 \end{bmatrix} = k \bullet Tphys \bullet \left\{ \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} - \begin{bmatrix} s11 & s12 \\ s21 & s22 \end{bmatrix} \begin{bmatrix} s11^* & s21^* \\ s12^* & s22^* \end{bmatrix} \right\}$$

The [N] noise correlation matrix may be derived from this [A] matrix.

All active linear components within the program are two-port, two-pin components with noise wave parameters that are related to the more common noise parameters of NFmin, Gopt, and Rn (minimum noise figure (dB)), optimum source reflection coefficient for NFmin, equivalent input normalized noise resistance, respectively) as follows (see reference 1 in *References for RF System Budget Analysis* (rfsysbudget)):

N11 = k Tb T0
N12 = k Tc T0 (cos(phi) + j sin(phi))
N21 = k Tc T0 (cos(phi) - j sin(phi))
N22 = k Ta T0

where:

k = Boltzmann's constant
T0 = reference temperature = 290 K
Ta = Fmin - 1 + Td |Gopt| ^{2}
Tb = Td - Fmin + 1
Tc = Td |Gopt|
phi = PI - angle(Gopt)
Td = 4 Rn/ | 1 + Gopt | ^{2}
Fmin = 10 $^{(NFmin\ /\ 10)}$
angle(Gopt) = angle of Gopt
Z0 = reference resistance

These noise correlation parameters, Nij, can be converted back to the standard noise parameters as follows:

k Td = 0.5 {(N22+N11) + sqrt((N22+N11) ^{2} - 4 |N12| ^{2})}
NFmin = 10 log10(Td + 1 - N11/k)
|Gopt| = |N12/k|/(Td)
angle(Gopt) = PI - angle(N12/k)
Rn = Td/4 | 1+Gopt| ^{2}

The component noise is dependent on the source reflection coefficient, Gams, as follows (see reference 1 in *References for RF System Budget Analysis* (rfsysbudget)):

NF = 10 log10(nf)

where:

$$nf = 1 + \frac{N22 + N11|Gams|^2 + 2|Gams|\ \ |N12|\cos(angle(Gams) + angle(N12))}{k(1 - |Gams|^2)}$$

There is a physical realizability requirement for the noise parameters of an active two-port, two-pin component. This requirement may be expressed with respect to the common noise parameters of NFmin, Gopt, and Rn (minimum noise in dB, optimum source reflection coefficient for NFmin, equivalent input normalized noise resistance, respectively) as follows:

$$Rn \ge (Fmin\text{-}1)\ |1{+}Gopt|^2\ (1 - |S11|^2)\ /\ (4 \times |1 - S11\ Gopt|^2)$$

This is based on the requirement that the component's combined noise wave power at port 1 not be negative.

Any active component has its noise parameters checked against this physical requirement. If the noise parameters supplied by the user in any component are such that the Rn value supplied is less than this minimum, then the specific component model will either error out and quit with error message to the user, or will proceed by setting the Rn value to this limit value.

Nonlinear Component Models

All nonlinear circuit components are two-port, two-pin components with a mathematical model defined by a 2x2 S-parameter matrix versus input power at port 1 and port 2, and a 2x2 noise wave parameter matrix derived at small-signal conditions.

In general, all S-parameters (s11, s12, s21, s22) vary as a function of input power. The parameters s11 and s21 are defined as a function of power incident at port 1 with no power incident at port 2; whereas s12 and s22 are defined as a function of power incident at port 2 with no power incident at port 1 (see reference 5 in *References for RF System Budget Analysis* (rfsysbudget)). The dataset for this nonlinear model is readily measured for a nonlinear RF two-port, two-pin in a hardware measurement lab.

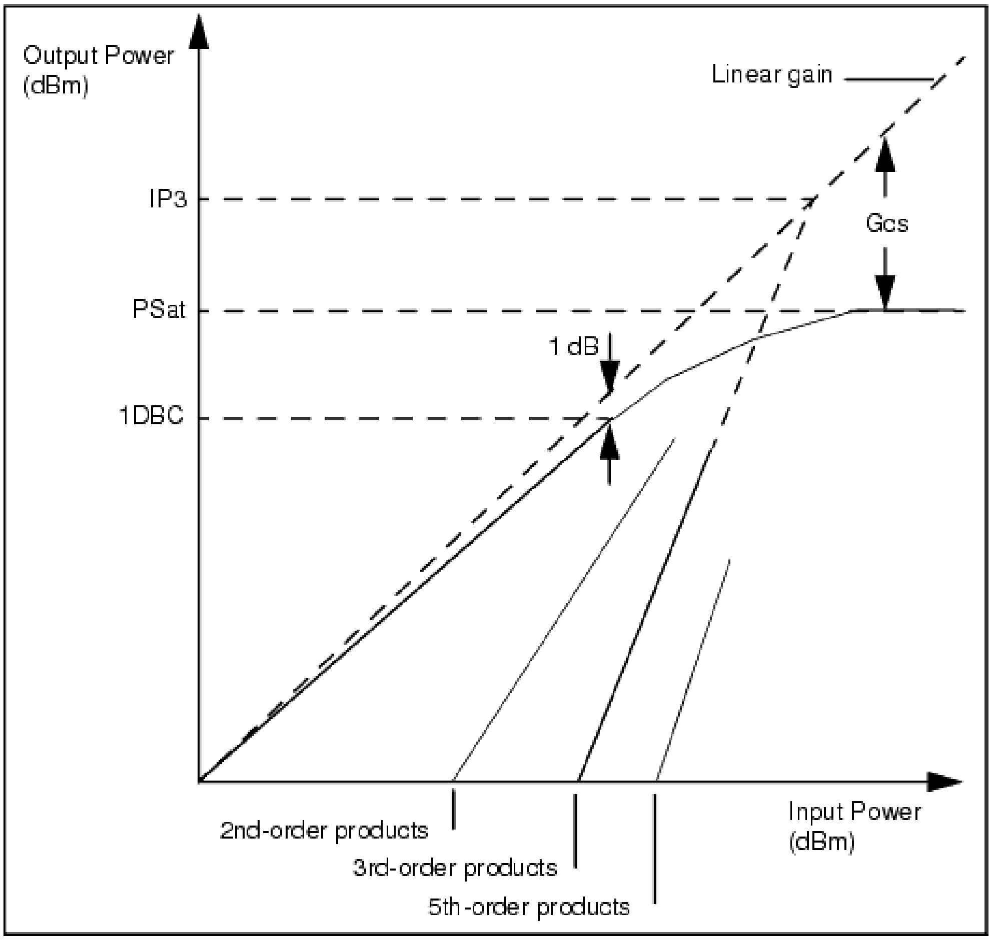
This dataset has been accepted as a convenient means of characterizing nonlinear devices by their large-signal S-parameters and have been successfully used for designing power amplifiers, oscillators, etc. (see references 6, 7, and 8 in *References for RF System Budget Analysis* (rfsysbudget)).

This general model for a circuit component nonlinearity is derived during a system simulation for a nonlinear component. For details about the P2D data file format, see *P2D Format* (cktsim).

The noise wave parameters for an electrical nonlinearity are the same as those defined for an active linear component in Linear Component Noise Models.

Characterization of Component Nonlinearities

In general, nonlinear two-port, two-pin amplifiers have an output power versus input power characteristic as shown in the following figure.



Nonlinear component characterization for power out versus power in

As shown, the nonlinear characteristic includes:

- Fundamental small-signal linear gain
- 2nd-order products
- 3rd-order products
- 5th and higher order products
- 3rd-order intercept point (IP3, also called TOI)
- 2nd-order intercept (IP2, also called SOI)
- 1 dB gain compression point (1DBC)
- Power saturation point (PSat)
- Gain compression at saturation (Gcs)

For budget analysis, nonlinear two-port, two-pin amplifiers are modeled using one of the following modeling techniques:

- Nonlinear models with S-parameters versus power used for all nonlinear measurements except for SOI and TOI measurements.
- Nonlinear models with defined SOI used for SOI measurements.
- Nonlinear models with defined TOI used for TOI measurements.
- Nonlinear models with no explicitly defined TOI used for TOI measurements.

All nonlinear models represent zero memory nonlinearities.

Nonlinear models with S-parameters versus power

This nonlinear model is used for all nonlinear measurements except for SOI and TOI measurements. It is based on the large-signal S-parameter (P2D) dataset for each nonlinear component. This dataset is obtained for each nonlinear component during budget analysis set-up. In this dataset, all S-parameters (S11, S21, S12, S22) can vary as a function of frequency and power. This dataset is linearly interpolated and used for budget analysis.

The P2D data for a nonlinear component is collected at the component input frequency and for a power range that is dependant on whether the user has selected any budget measurements that require the 1 dB power compression point (P1dB), SOI, or TOI for each component.

When no P1dB, SOI, and TOI measurements are selected The maximum component input power used to collect the P2D data for a nonlinear component is equal to the component large-signal incident power (P_LS_inc) plus 5 dB (P_LS_inc+5dB). The large-signal incident power is determined by analyzing the system to determine the system large-signal gain from the system source output to the evaluated nonlinear component input. This maximum power level (P_LS_inc+5dB) must be less than or equal to the *CmpMaxPin* value (Component maximum input power in dBm). You can set *CmpMaxPin* in the Budget controller's setup dialog box, on the Setup tab.

When any P1dB, SOI, or TOI measurement is selected The maximum component input power used to collect the P2D data for a nonlinear component is equal to the component small-signal incident power (P_SS_inc) that places the nonlinear component into at least 5 dB gain compression (P_SS_inc_5dB). The small-signal incident power is determined by analyzing the system to determine the system small-signal gain from the system source output to the evaluated nonlinear component input. This maximum power level (P_LS_inc_5dB) must be less than or equal to the *CmpMaxPin* value (Component maximum input power in dBm). You can set *CmpMaxPin* in the Budget controller's setup dialog box, on the Setup tab. The P1dB measurements are any of the following: Cmp_OutP1dB_dBm, InP1dB_dBm, OutCDR_ResBW_dB, OutCDR_Total_dB, OutP1dB_dBm.

Given the component maximum input power from the above conditions (P_LS_inc+5dB or P_SS_inc_5dB), the P2D data (S11, S12, S21, S22 versus power) is obtained for the nonlinear component over a 100 dB range below this maximum input power in 1 dB steps.

During budget analysis, the P2D data for each nonlinear component is linearly interpolated in an iterative process to obtain the overall system operating points at each nonlinear component input and output. All P2D S-parameters (S11, S12, S21, S22) are used in this analysis.

Nonlinear models with defined SOI used for SOI measurements

This nonlinear model is used only for components Amplifier, Amplifier2, and AGC_Amp, and *only* when these models are at the top level of the RF System design being analyzed. If these models are within a nonlinear subnetwork design, then the subnetwork is considered to not have any defined SOI and the nonlinear subnetwork is modeled as described in the section Nonlinear models with S-parameters versus power.

For components Amplifier, Amplifier2 and AGC_Amp, SOI can only be used if TOI is also specified.

The SOI value for these nonlinear amplifiers is used directly in the Budget SOI measurements Cmp_OutSOI_dBm, InSOI_dBm, OutIM2_dBm, OutSOI_dBm.

For a definition of these measurements, see sections Component Measurements, System Measurements at Component Inputs and System Measurements at Component Outputs.

Nonlinear models with defined TOI used for TOI measurements

This nonlinear model is used only for components Amplifier, Amplifier2 and AGC_Amp and *only* when these models are at the top level of the RF system design being analyzed. If these models are within a nonlinear subnetwork design, then the nonlinear subnetwork is modeled as described in the section for Nonlinear model with no explicitly defined TOI used for TOI measurements.

The TOI value for these nonlinear amplifiers is used directly in the Budget TOI measurements Cmp_OutTOI_dBm, InTOI_dBm, OutIM3_dBm, OutTOI_dBm, OutSFDR_ResBW_dB, OutSFDR_Total_dB, OutS_IM3_dB.

For definition of these measurements, see sections Component Measurements, System Measurements at Component Inputs, and System Measurements at Component Outputs.

Nonlinear model with no explicitly defined TOI used for TOI measurements

This nonlinear model is used for any nonlinear component with no defined TOI or for any nonlinear subnetwork for which TOI measurements are to be made.

The TOI value for these nonlinear amplifiers is derived from their P2D dataset for S21 versus power, and then these models are treated the same as for those described in Nonlinear models with defined TOI used for TOI measurements.

The TOI value is obtained by curve fitting the component S21 data versus power to a third order polynomial expression evaluated under low power conditions. It is presumed that the nonlinear model does not contain any SOI characteristic.

The 3rd-order polynomial expression relates output RF voltage (V_{out}) to input RF voltage (V_{in}).

$$V_{out}(V_{in}) = a_1 V_{in} + a_3 V_{in}^3$$

where:

V_{in}= input signal voltage

V_{out}= output signal voltage

a_1= small-signal gain

a_3= 3rd-order gain coefficient

The S21 data versus power (V_{out}versus V_{in}) is used to find the input signal level where 0.2 dB gain compression occurs (Vin_0.2dB). It is presumed that only the 3rd-order nonlinearity dominates at this level of gain compression and that all higher order nonlinear polynomial terms are negligible.

Given the small-signal gain (a_1) and the value for Vin_0.2dB, the $a_3$coefficient (and thus the TOI value) is derived.

For details on how a_3 and TOI are related, see the section *2nd and 3rd-Order Intercept Definition* (rfsysbudget).

Limitations of RF System Budget Analysis

When using Budget analysis, various limitations prevent Budget analysis use with general system designs and topologies. Awareness of these limitations is required so that you can be more effective in addressing subsystem and system design, and simulation objectives.

Budget analysis determines the system internodal signal and noise performance for components in the top-level system network schematic. Budget analysis uses frequency-domain based S-parameter and noise wave parameter techniques for a system containing only components for which S-parameter and noise wave parameters are meaningful. The analysis is a single-tone analysis.

Error messages result in terminating the simulation. Warning messages result in proceeding with the simulation.

The notes in this section that describe the Budget analysis limitations regard the following areas, and reference the measurement groups listed in Measurement Groups Referenced by Limitation Notes:

- S-Parameter Based Measurements
- Measurements for Budget Controller without "Enable nonlinear analysis"
- Measurements for Budget Controller with "Enable nonlinear analysis"
- System Signal Source
- System Termination
- System Components
- Subnetworks
- Nonlinear Components
- Optimization

Measurement Groups Referenced by Limitation Notes

Measurement Group	**Measurements**	
SOI	Cmp_OutSOI_dBm InSOI_dBm OutIM2_dBm OutSOI_dBm	
TOI	Cmp_Ctrb_SysTOI_dB Cmp_OutTOI_dBm InTOI_dBm OutIM3_dBm OutSFDR_ResBW_dB OutSFDR_Total_dB OutS_IM3_dB OutTOI_dBm	
P1 dB	Cmp_OutP1dB_dBm InP1dB_dBm OutCDR_ResBW_dB OutCDR_Total_dB OutP1dB_dBm	
50-ohm S-parameter	Cmp_S11_* Cmp_S12_* Cmp_S21_* Cmp_S22_* Cmp_SS_MismatchLoss_dB	InPwrInc_* InPwrRefl_* InReflCoeff_* InVSWR OutVGainInc_* OutVGainRefl_*
General power, noise, and frequency	Cmp_Ctrb_SysNF_NoImage_dB Cmp_LS_GainChange_dB Cmp_NF_dB Cmp_OutN0_dBm Cmp_SS_PGain_dB InFreq InNPwrTotal_dBm InPGain_SS_dB InPGain_dB InPwr_SS_dBm InPwr_dBm InSNR0_dB InTE_NoImage_K NF_RefIn_NoImage_dB	NF_RefIn_dB NF_RefOut_NoImage_dB NFactor_RefIn OutFreq OutN0_dBm OutNBW OutNPwrResBW_dBm OutNPwrTotal_dBm OutPGainChange_dB OutPGain_dB OutPwr_dBm OutSNR0_dB OutSNR_ResBW_dB OutSNR_Total_dB

S-Parameter Based Measurements

- The measurements in the 50-ohm S-parameter measurement group are meaningful with respect to 50-ohm source and load reference resistances.
- For system internal nodes at which the user is interested in non-50 ohm reference resistances, then these measurements will not produce results expected for non-50 ohm use.

Measurements for Budget Controller without "Enable nonlinear analysis"

- All measurements for this Budget controller usage are obtained without any nonlinear analysis; small-signal techniques are used for all measurements.

- Measurements in the SOI, TOI, and P1dB measurement groups will result in default values of 1000 since these measurements are dependant on nonlinear analysis.

Measurements for Budget Controller with "Enable nonlinear analysis"

- All power and noise measurements from the general power, noise, and frequency measurement group and SOI, TOI, and P1dB measurement groups use transducer power gain under larger signal conditions in their measurement definition. These measurements are independent of the individual component reference resistance since transducer power gain deals with power delivered into the actual loads at each system internal node.
- Each nonlinearity is characterized using 50-ohm source and load resistances and measuring the resultant nonlinearity P2D data over a power range. The maximum power level is set by the Budget controller so that at least 5 dB component transducer power gain compression occurs with the nonlinear component input source reflection coefficient equal to the real part of s11 and output load reflection coefficient equal to the real part of s22.

System Signal Source

- The system input signal source must have an output resistance of 50 ohms, but may have a user-defined temperature. Not using 50 ohms for output resistance will result in an error message.
- The signal source has a single fundamental frequency defined for system budget analysis. An optional second fundamental frequency may be defined for control of system AGC loops. The second tone is not used for two-tone analysis. It is used independently from the first tone for control of the AGC loops. More than two frequency tones will result in an error message.

System Termination

- The system output termination load must be 50 ohms and is assumed to be noiseless. Not using 50 ohms for output termination will result in an error message. However, if you enable resistor noise, then Budget analysis will turn the noise off and issue a warning message.

System Components

- The system network and all top-level system components must have only two ports (with two pins), with the only exceptions being: *AGC_Amp*, *AGC_PwrControl*, *S2P* (with pin 3 tied to ground), *PathSelect2*, and *R* (with pin 2 tied to ground). This means that other two-port components with three pins or four pins are not allowed as top-level components. Budget analysis will trap for these disallowed components and display a suitable error message.

> **Note**
> Components not allowed directly at the top-level schematic can still be included in subnetworks to create circuit designs usable as two-pin subnetworks with two ports in the top level schematic.

- Various other two-port components (with two pins) are also excluded from use as top level components because they do not provide meaningful S-parameter representations. This includes such components as two-port signal sources, modulators, demodulators, diodes, and more. Budget analysis will trap for these disallowed two-port components and display a suitable error message.

Subnetworks

- Nonlinear subnetworks may contain even- and/or odd-order nonlinearities. For all cases, the Vout vs. Vin characteristic is represented by extracted P2D data. However, the modeling approach used by Budget analysis for TOI analysis interprets the P2D data as an odd-order nonlinearity. Budget analysis interprets all nonlinear subnetwork components as odd order nonlinearities. If a subnetwork exhibits even order nonlinearities, then the SOI measurements may be in error.
- All subnetworks must result in a single frequency tone at its output that is the same as the frequency at the subnetwork input. Thus, Budget analysis does not support subnetworks with input to output frequency conversion.

Nonlinear Components

- For linear blocks, or when SOI, TOI, and 1 dB compression measurements are not allowed, the default value for SOI, TOI, and 1 dB compression measurements is 1000.
- Second-order nonlinearities are included for SOI measurements only when SOI is used with specific components at the top-level schematic. These components are *Amplifier*, *Amplifier2*, and *AGC_Amp*.
- Nonlinearities cannot be characterized if the Budget analysis setting for *CmpMaxPin* is too low. *CmpMaxPin* must be set to a value greater enough to result in driving the nonlinear component 5 dB into gain compression. Budget analysis will trap for low settings of *CmpMaxPin* and display a suitable error message.
- If nonlinearity is expansive, then Budget analysis will not be able to compute SOI and TOI measurements, and all SOI and TOI measurement values will be set to 1000. Additionally, if gain is expansive and also does not achieve more than 5 dB gain compression at higher input power levels, then Budget analysis will not be able to compute 1 dB compression and all 1 dB compression measurement values will be set to 1000. Budget analysis will trap for expansive nonlinearities and display a suitable warning message.
- All nonlinearities have noise analysis performed under small-signal conditions. This implies that the noise characteristic is not dependant on the nonlinear operating point.
- All nonlinear components are assumed to be memory-less nonlinearities. This means that their nonlinear characteristic is not dependant on the time history of the input signal.

- All nonlinear components are assumed to be bandpass nonlinearities for which harmonics through the amplifier are ignored and thus any harmonics do not affect other nonlinear amplifiers in the cascade. However, the fundamental tone characteristics of the amplifier do impact the nonlinear characteristics of other nonlinear amplifiers in the cascade.
- All nonlinear components are defined based on the compression effects on a single fundamental RF tone input. This implies that LO and image frequencies do not impact the nonlinear characteristics for the single fundamental RF tone.
- All nonlinearities are assumed to be Class A, B, or AB amplifiers; that is, they have a small-signal linear region for input signal amplitudes less than that for onset on gain compression. For definitions of the various classes of RF power amplifiers, see the following table, which defines each class in terms of the device conduction angle and/or the type of device operation.

Class	**Description**
A	Linear operation, 360 conduction angle
B	Linear operation, 180 conduction angle
AB	Linear operation, conduction angle less than 360 but more than 180
C	Fixed drive, less than 180 conduction angle
D	Switched operation, conduction angle may vary with time from 0 to 360 or may be fixed

Optimization

- Budget cannot be used with the following optimization types:
  - Gradient
  - Gradient Minmax
  - Quasi-Newton
  - Least path
  - Minmax
  - Hybrid
  - Sensitivity

Parameters for RF System Budget Analysis

The recommended way to setup a budget analysis is by using the Budget controller set up dialog box. To open this dialog box, double-click the Budget controller instance from the ADS schematic design. The Budget dialog box includes three tabs, enabling you to define aspects of the simulation listed in the following table:

Tab Name	**Description**	**For details, see...**
Setup	Provides simulation setup and results/display setup features.	Setting up a Budget Analysis
Measurements	Provides measurement descriptions, selection, save and recall features.	Selecting Measurements
Display	Control the visibility of simulation parameters on the Schematic.	*Displaying Simulation Parameters on the Schematic* (cktsim)

Setting up a Budget Analysis

The Setup tab enables you to set up the simulation for linear or nonlinear analysis specify the frequency for noise simulation, and to specify how results are output. Names used in netlists and ADS Schematics appear under *Parameter Name*.

RF Budget Simulation Setup Parameters

Setup Dialog Name	**Parameter Name**	**Description**
Simulation - Set up linear/nonlinear simulation		
Nonlinear Analysis		
Enable nonlinear analysis	NonlinearAnalysis	Select the checkbox to enable nonlinear analysis. Leave the checkbox unselected to enable linear analysis.
Harmonic order	NonlinearHarmonicOrder	Harmonic order used for P2D analysis of components that require S-parameter characterization
Max. component input power (dBm)	CmpMaxPin	Maximum component input power
Noise Simulation - Set up noise simulation		
Frequency span	NoiseFreqSpan	The frequency span used for noise simulations
Frequency step	NoiseFreqStep	The frequency step used for noise simulations. In the dialog box, entering a value for *Frequency step* automatically calculates the value for *Frequency points* based on the value for *Frequency span*.
Frequency points		Optionally, define the number of points and Frequency span to determine the Frequency step. In the dialog box, entering a value for *Frequency points* automatically calculates the value for *Frequency step* based on the value for *Frequency span*.
Resolution bandwidth	NoiseResolutionBW	Resolution bandwidth used for noise simulations
Results - Set up the format and options for displaying results after analysis		
Components in	TableComponentFormat	Formats output table with measurements in columns or rows
Angle unit	MeasurementAngleUnit	Determines the angle for output measurements in radians or degrees
Frequency unit	MeasurementFrequencyUnit	Determines the frequency units for output measurements in Hz, kHz, MHz, GHz, THz, or PHz
Auto format display with overwrite	AutoFormatDisplay	When selected, the output to the Data Display is formatted in tables and plots such that: - Components are ordered as in the system from first to last (source to term) - Measurements are ordered as listed in the Measurement tab - New data overwrites the existing *.dds* file for the current design
Output results as comma separated values (CSV) to file	OutputCSVFile	Measurement data written as comma-separated values to *.csv* file
Run command after analysis	RunCommand	When *Output results as comma separated values (CSV) to file* is selected, enabling this parameter runs a user-defined command after analysis. The command is entered in the System Command field, and typically is used for post processing the *.csv* file data.
System command	SystemCommand	When *Run command after analysis* is selected, enter a command to run, such as running Excel on a PC platform. See Exporting and Post-Processing Results.

Selecting Measurements

The Measurement tab enables you to select the system cascade measurements that are evaluated per component in the schematic design. Names used in netlists and ADS Schematics appear under *Parameter Name*.

Note
Measurements also include a set of built-in system summary measurements, that evaluate overall system performance. These are single value system measurements and are not for each component. They are not selectable, and are always written to the CSV file and the ADS dataset.

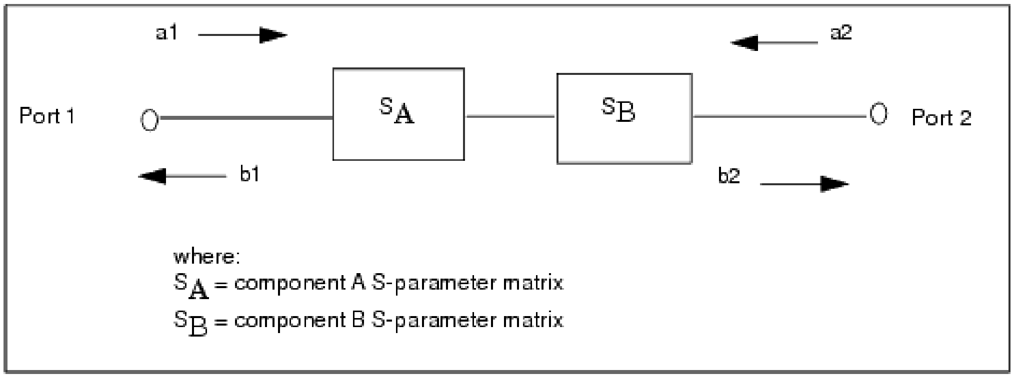
Setup Dialog Name	**Parameter Name**	**Description**
Recall selected measurements from file		Populates the list of Selected Measurements from a file
Available Measurements		Select from list of available measurements to include in analysis. These are system cascade measurements for each component, or at each component input or output.
Selected Measurements	Measurement[n]	An ordered list determines the order in which measurements are written to the CSV file and Data Display. To change the order: ▪ *Raise* moves the selected measurement up ▪ *Lower* moves the selected measurement down ▪ *Delete* moves selected measurement(s) to the Available Measurements list
Description		Displays description of selected measurement
Save selected measurements to file		Saves the list of selected measurement to a text file

Theory of Operation for RF System Budget Analysis

This section describes the budget analysis process.

S-Parameters for the Cascade of Two, Two-Port, Two-Pin Components

The cascaded two-port, two-pin network signal wave representation used for the network S-parameter derivations can be represented in block diagram form as shown in the following figure.



Signal wave-representations used for network S-parameter derivations

The S-parameters resulting from cascading two two-port, two-pin components, A and B, can be expressed as the following: (see reference 9 in *References for RF System Budget Analysis* (rfsysbudget))

$$\begin{bmatrix} s11 & s12 \\ s21 & s22 \end{bmatrix} = \begin{bmatrix} sA11 & 0 \\ 0 & sB22 \end{bmatrix} + \begin{bmatrix} sA12 & 0 \\ 0 & sB21 \end{bmatrix} \left(\begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix} - \begin{bmatrix} sA22 & 0 \\ 0 & sB11 \end{bmatrix} \right)^{-1} \begin{bmatrix} sA21 & 0 \\ 0 & SB12 \end{bmatrix}$$

The T-parameters resulting from cascading two two-port, two-pin components, A and B, can also be derived and are expressed as follows:

$$\begin{bmatrix} t11 & t12 \\ t21 & t22 \end{bmatrix} = \begin{bmatrix} tA11 & tA12 \\ tA21 & tA22 \end{bmatrix} \begin{bmatrix} tB11 & tB12 \\ tB21 & tB22 \end{bmatrix}$$

When A is a spectral inverting component, but not B, then their cascade is defined as follows (* in the following represents conjugate):

$$\begin{bmatrix} s11^* & s12^* \\ s21 & s22 \end{bmatrix} = \begin{bmatrix} sA11^* & 0 \\ 0 & sB22 \end{bmatrix} + \begin{bmatrix} sA12^* & 0 \\ 0 & sB21 \end{bmatrix} \left(\begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix} - \begin{bmatrix} sA22 & 0 \\ 0 & sB11 \end{bmatrix} \right)^{-1} \begin{bmatrix} sA21 & 0 \\ 0 & sB12 \end{bmatrix}$$

When B is a spectral inverting component, but not A, then their cascade is defined as follows (* in the following represents conjugate):

$$\begin{bmatrix} s11^* & s12^* \\ s21 & s22 \end{bmatrix} = \begin{bmatrix} sA11^* & 0 \\ 0 & sB22 \end{bmatrix} + \begin{bmatrix} sA12^* & 0 \\ 0 & sB21 \end{bmatrix} \left(\begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix} - \begin{bmatrix} sA22^* & 0 \\ 0 & sB11^* \end{bmatrix} \right)^{-1} \begin{bmatrix} sA21^* & 0 \\ 0 & sB12^* \end{bmatrix}$$

When both A and B are spectral inverting components, then their cascade is defined as follows (* in the following represents conjugate):

$$\begin{bmatrix} s11 & s12 \\ s21 & s22 \end{bmatrix} = \begin{bmatrix} sA11 & 0 \\ 0 & sB22 \end{bmatrix} + \begin{bmatrix} sA12 & 0 \\ 0 & sB21 \end{bmatrix} \left(\begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix} - \begin{bmatrix} sA22^* & 0 \\ 0 & sB11^* \end{bmatrix} \right)^{-1} \begin{bmatrix} sA21^* & 0 \\ 0 & sB12^* \end{bmatrix}$$

S-Parameters for a Nonlinear Channel

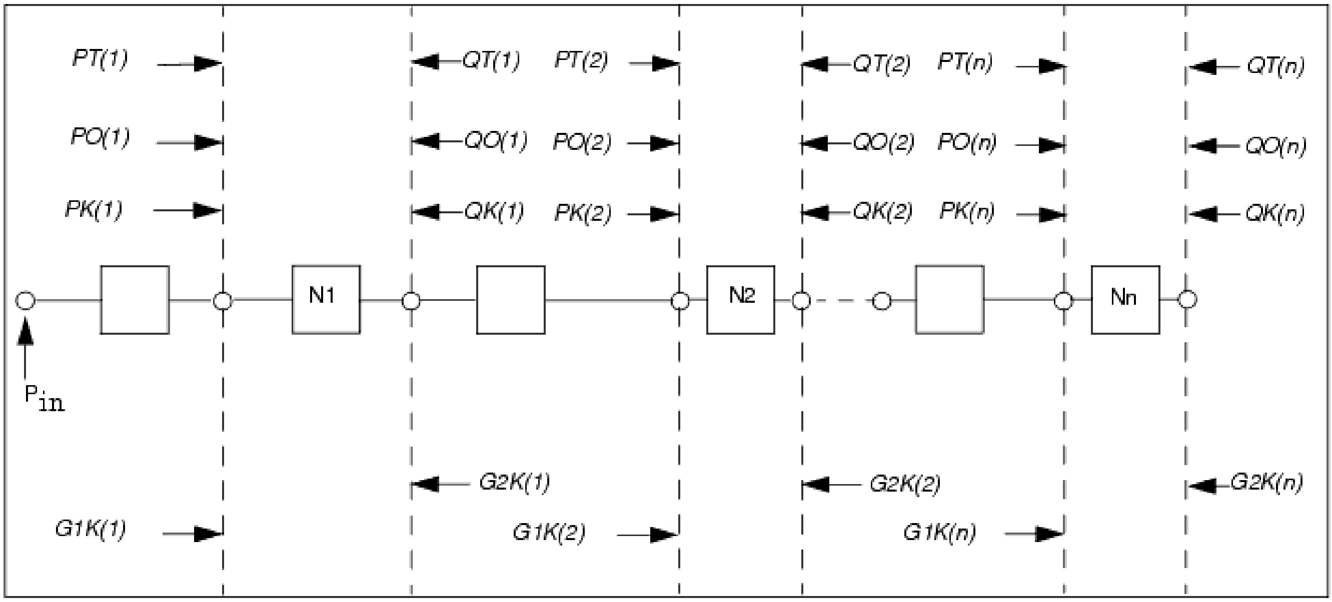
A nonlinear channel with a cascade connection of a number of nonlinear and linear two-port, two-pin components will have the overall channel S-parameters at the channel input carrier frequency derived as a function of input power using an iterative algorithm (see reference 5 in *References for RF System Budget Analysis* (rfsysbudget)).

The derivation of these S-parameters only address the carrier frequency throughout the channel and ignore any harmonics generated by the nonlinearities. This is a reasonable assumption because the nonlinearities are characterized with respect to the input to output fundamental carrier with harmonics filtered out. Also, the input signal is assumed to be narrowband.

The S-parameters of each nonlinear two-port, two-pin under large-signal conditions are assumed to be measured as a function of power level incident at only one port; the s11 and s21 parameters are a function of power incident at port 1, and the s12 and s22 parameters are a function of power incident at port 2.

A general nonlinear channel may be composed of alternating linear and nonlinear components as shown in the following figure. In general, the operating point for each nonlinearity is dependent on the operating point of all other nonlinearities.

The S-parameters for each nonlinearity in the channel are interpolated between their given power-dependent values during the iteration process to estimate the intermediate power levels that are incident at the input and output ports of each nonlinear two-port, two-pin component.



Cascade connection of alternately connected linear and nonlinear two-port, two-pin components

In this figure:

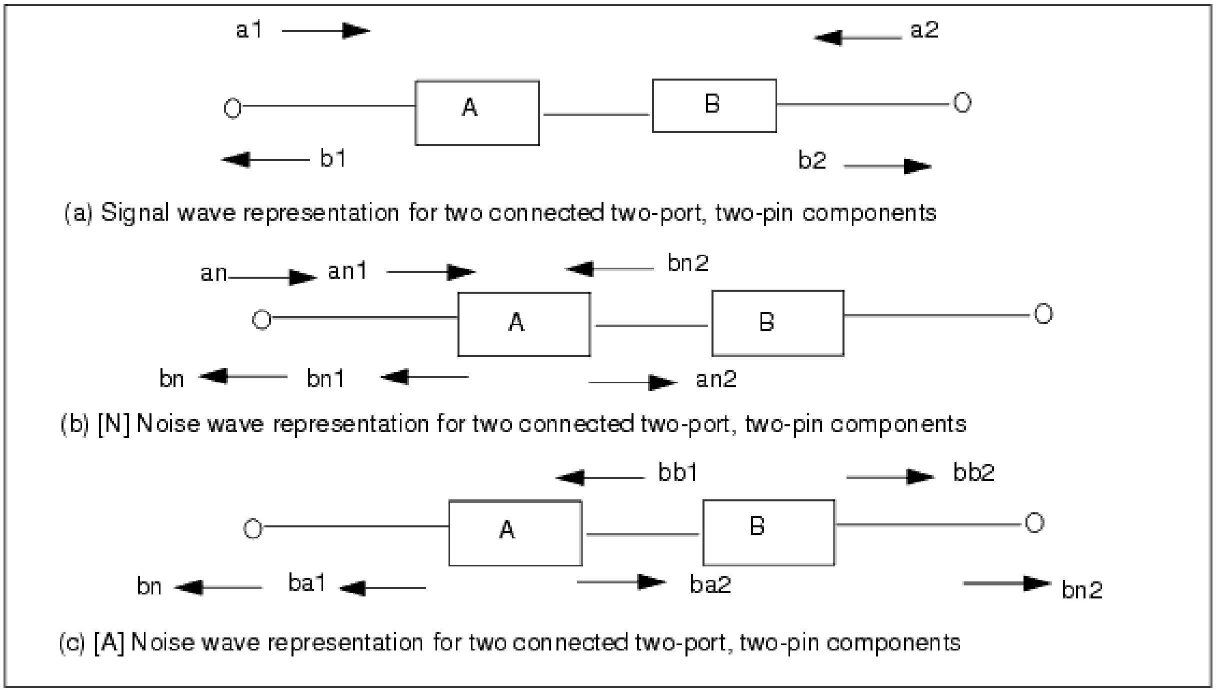
- P_{in} is the power incident at the channel input (at a given carrier frequency).
- *PO(n)* and *QO(n)* are the initial estimates of the incident power levels at the input and output ports of the *n*'th nonlinearity obtained from an initial small-signal analysis.
- *PK(n)* and *QK(n)* are the incident power levels at the *k*'th iteration.
- *G1K(n)* and *G2K(n)* are the total reflection coefficients looking into the input and output ports of *n*'th nonlinearity calculated at the *k*'th iteration.
- The (*k+1*) terms are derived from the *k* estimates.
- *PT(n)* and *QT(n)* are the operating power levels incident at port 1 and port 2 of the *n* 'th nonlinearity obtained after the final iteration.

The iterative process is continued until the change in *PT* and *QT* is below a predetermined threshold. S-parameters for each nonlinearity are then obtained for the *PT* (*n*) and *QT* (*n*) values and the overall channel S-parameters are derived as in the linear case.

The greatest advantage of this technique is its ability to incorporate all the interstage mismatches and to handle any number of embedded linear and nonlinear two-port, two-pin components.

Noise Parameters for the Interconnection of Two Components

The cascaded two-port, two-pin network noise wave representation shown in section (b) of the following figure is used for the network noise correlation matrix, [N], derivation (see reference 1 in *References for RF System Budget Analysis* (rfsysbudget)).



(a) Signal wave representation for two connected two-port, two-pin components

(b) [N] Noise wave representation for two connected two-port, two-pin components

(c) [A] Noise wave representation for two connected two-port, two-pin components

Representations for the connection of two components

This derivation uses the transmission (T) parameters of component A.

Using the definition of the T-matrix for components, that is, b1 = T11 a2; (b2=0), and b1 = T12 b2; (a2=0), the resultant network noise waves an and bn are:

bn = bn1 + TA11 bn2 - TA12 an2
an = an1 - TA21 bn2 + TA22 an2

In matrix form:

$$\begin{bmatrix} bn \\ an \end{bmatrix} = \begin{bmatrix} 1 & 0 & TA11 & -TA12 \\ 0 & 1 & -TA21 & TA22 \end{bmatrix} \begin{bmatrix} bn1 \\ an1 \\ bn2 \\ an2 \end{bmatrix}$$

Using the definition of [N] and assuming noise from component A is independent and uncorrelated to the noise from component B:

$$[N] = \begin{bmatrix} bn \\ an \end{bmatrix} \begin{bmatrix} bn^* & an^* \end{bmatrix}$$

Resulting in (* in the following represents conjugate):

$$\begin{bmatrix} N11 & N12 \\ N21 & N22 \end{bmatrix} = \begin{bmatrix} NA11 & NA12 \\ NA21 & NA22 \end{bmatrix} + \begin{bmatrix} TA11 & -TA12 \\ -TA21 & TA22 \end{bmatrix} \begin{bmatrix} NB11 & NB12 \\ NB21 & NB22 \end{bmatrix} \begin{bmatrix} TA11^* & -TA21^* \\ -TA12^* & TA22^* \end{bmatrix}$$

When A is a spectral inverting component, but not B, or when both A and B are spectral inverting components, then:

bn = bn1 + TA11* bn2* - TA12* an2*

an = an1 - TA21* bn2* + TA22* an2*

Resulting in (* in the following represents conjugate):

$$\begin{bmatrix} N11 & N12 \\ N21 & N22 \end{bmatrix} = \begin{bmatrix} NA11 & NA12 \\ NA21 & NA22 \end{bmatrix} + \begin{bmatrix} TA11* & -TA12* \\ -TA21* & TA22* \end{bmatrix} \begin{bmatrix} NB11 & NB21 \\ NB12 & NB22 \end{bmatrix} \begin{bmatrix} TA11 & -TA21 \\ -TA12 & TA22 \end{bmatrix}$$

2nd and 3rd-Order Intercept Definition

The 2nd-order intercept (SOI) and 3rd-order intercept (TOI) of a component or network is a widely accepted system design parameter because they indicate the degree of nonlinearity of a nonlinear component. The volt-out to volt-in relationship for a nonlinear component when S21, SOI, and TOI are specified can typically be described as a polynomial relationship as follows:

$$Y = \left(\frac{S21}{a1}\right)(a_1X + a_2X^2 + a_3X^3)$$

where:

X = input voltage
Y = output voltage
S_{21} = complex small-signal gain
a_1 = the fundamental small-signal gain magnitude
a_2 = 2nd-order gain coefficient
a_3 = 3rd-order gain coefficient

Given an input signal, V_{in}, with two frequency domain spectral tones (two-tones), ω1 and ω2, such that ω2 > ω1 and (ω2-ω1) << ω1, then a nonlinear component's output intermodulation products will include 2nd-order intermodulation products at (or near) twice ω1 and ω2 (2*ω1, 2*ω2, ω1+ω2), and 3rd-order intermodulation products localized about the two output fundamental tones (2*ω1-ω2, 2*ω1-ω2).

For a plot of the output power versus input power for output fundamental, 2nd-order and 3rd-order tones, see the figure *Nonlinear component characterization for power out versus power in* (rfsysbudget).

The small-signal fundamental curve varies with a 1:1 slope. The small-signal 2nd-order and 3rd-order curves vary with a 2:1 and 3:1 slope respectively.

The third-order intercept is that point where the extrapolated small-signal fundamental and 3rd-order curves intersect. At this 3rd-order intercept you may be interested in the input power level, or in the output power level.

Similarly, the 2nd-order intercept is that point where the extrapolated small-signal fundamental and 2nd-order curves intersect.

The following defines the nonlinear amplifier output response for one- and two-tone inputs, and derives the relationship between a , a and SOI, TOI.

Nonlinearity Output for One- and Two-Tone Excitation

For one-tone excitation:

$$x(t) = A_1 \cos(\omega_1 t)$$

The response is:

$$y(t) = \frac{\alpha_2}{2}A_1^2 + \left(\alpha_1 A_1 + \frac{3\alpha_3}{4}A_1^3\right)\cos(\omega_1 t) + \left(\frac{\alpha_2}{2}A_1^2\right)\cos(2\omega_1 t) + \left(\frac{\alpha_3}{4}A_1^3\right)\cos(3\omega_1 t)$$

For two-tone excitation:

$$x(t) = A_1 \times \cos(\omega_1 \times t) + A_2 \times \cos(\omega_2 \times t)$$

The response is:

$$y(t) = \frac{1}{2} \times \alpha_2 \times (A_1^2 + A_2^2)$$

$$\left(\alpha_1 \times A_1 + \frac{3}{4} \times \alpha_3 \times A_1^3 + \frac{3}{2} \times \alpha_3 \times A_1 \times A_2^2\right) \times \cos(\omega_2 \times t)$$

$$+$$

$$\left(\alpha_1 \times A_2 + \frac{3}{4} \times \alpha_3 \times A_2^3 + \frac{3}{2} \times \alpha_3 \times A_2 \times A_1^2\right) \times \cos(\omega_2 \times t)$$

$$+$$

$$\frac{1}{2} \times \alpha_2 \times A_1^2 \times \cos(2 \times \omega_1 \times t)$$

$$+$$

$$\frac{1}{2} \times \alpha_2 \times A_2^2 \times \cos(2 \times \omega_2 \times t)$$

$$+$$

$$\frac{1}{4} \times \alpha_3 \times A_1^3 \times \cos(3 \times \omega_1 \times t)$$

$$+$$

$$\frac{1}{4} \times \alpha_3 \times A_2^3 \times \cos(3 \times \omega_2 \times t)$$

$$+$$

$$\alpha_2 \times A_1 \times A_2 \times \cos((\omega_1 - \omega_2) \times t)$$

$$+$$

$$\alpha_2 \times A_1 \times A_2 \times \cos((\omega_1 + \omega_2) \times t)$$

$$+$$

$$\frac{3}{4} \times \alpha_3 \times A_2 \times A_1^2 \times \cos((2 \times \omega_1 + \omega_2) \times t)$$

$$+$$

$$\frac{3}{4} \times \alpha_3 \times A_2 \times A_1^2 \times \cos((2 \times \omega_1 - \omega_2) \times t)$$

$$+$$

$$\frac{3}{4} \times \alpha_3 \times A_1 \times A_2^2 \times \cos((2 \times \omega_2 + \omega_1) \times t)$$

$$+$$

$$\frac{3}{4} \times \alpha_3 \times A_1 \times A_2^2 \times \cos((2 \times \omega_2 - \omega_1) \times t)$$

$$+$$

For practical nonlinear devices defined by SOI and TOI, there is a maximum input signal level beyond which the device is driven into saturation. The above equations are applicable only below this saturation drive level.

Below saturation, the a_2 term is dependant on SOI (and not TOI) and that the a_3 term is dependant on TOI (and not SOI).

Relating Coefficients a2 and a3 to a1, SOI and TOI

The a_2 and a_3 coefficients are derived from the nonlinear amplifier small-signal gain magnitude, a_1, and output SOI and TOI values.

Given SOI and TOI in dBm power units and given that the amplifier is defined with respect to RefR input and output resistance, they also define the following:

SOI output power level, Watts = po_soi = $10^{(\ (SOI-30)/10)}$ = vo_soi^2 /(2*RefR)
TOI output power level, Watts = po_toi = $10^{(\ (TOI-30)/10)}$ = vo_toi^2 /(2*RefR)
SOI input power level, Watts = pi_soi = po_soi/($a1^2$)
TOI input power level, Watts = pi_toi = po_toi/($a1^2$)

SOI and TOI are defined with respect to two-tone inputs with equal amplitude and with small frequency difference (Δω) such that ω1=ω0-Δω and ω2=ω0+Δω.

For SOI, the output tones of interest are at ω1+ω2=2*ω0, and ω2-ω1=2*Δω.
For TOI, the output tones of interest are at

|2*ω1-ω2| = ω0-3*Δω
or
|2*ω2-ω1| = ω0+3*Δω

The two-tone excitation response equation shows the amplitude of the 1st-order product (the fundamental) with a value of

$$\left(a_1*A_1+\frac{3*a_3}{4}*A_1^3+\frac{3*a_3}{2}*A_1*A_2^2\right)$$

At low power levels, the a_i*A_1 term is dominant (the higher-order terms are negligible):

$$a_1*A_1>>\frac{3*a_3}{4}*A_1^3+\frac{3*a_3}{2}*A_1*A_2^2$$

As a result, at low level input power levels (dBm), the 1st, 2nd, and 3rd-order output powers (dBm) vary versus input power (dBm) with ratios 1:1, 2:1, and 3:1 respectively.

By definition, the SOI and TOI points occur where the input and output power levels (dBm) are equal for the extrapolation of the small-signal power levels (dBm) for the fundamental and 2nd-order harmonics (SOI) or 3rd-order harmonics (TOI).

For example, given ω1 = 995 MHz at -30 dBm and ω2 = 1005 MHz at -30 dBm and nonlinear device with S21 = 20 dB, SOI = 50 dBm and TOI = 30 dBm, the 2nd-order and 3rd-order output tones are at (1990 MHz, 2000 MHz, 2010 MHz) and (985 MHz, 1015 MHz) respectively.

For TOI at 30 dBm, the output tones at 1005 MHz and 1015 MHz are at -10 dBm and -90 dBm respectively. TOI is related to the levels at 1005 MHz and 1015 MHz as follows:

TOI = -90 + 3/2*(-10 - (-90)) = 30 dBm

For SOI at 50 dBm, the output tones at 1990 MHz, 2000 MHz and 2010 MHz are at -76 dBm, -70 dBm and -76 dBm respectively. The 2nd-order product at 2000 MHz is the largest. SOI is related to the levels at 1005 MHz and 2000 MHz as follows:

SOI = -70 + 2*(-10 - (-70)) = 50 dBm

For SOI, and from the above equations for two-tone excitation, the maximum 2nd-order output tone of interest occurs at ω1+ω2 for which the relationship between a_2 to a_1 and SOI is as follows:

$a_2 = a_1^{\ 2}$ /sqrt(2*RefR*po_soi)

where:

po_soi = $10^{((SOI-30)/10)}$ with SOI in dBm

For TOI, and from the above equations for two-tone excitation, the 3rd-order tones at |2*ω1-ω2| or |2*ω2-ω1| are the desired 3rd-order intermod tones for which the relationship between a_3 to a_1 and TOI is as follows:

pi_toi = vi_toi^2 /(2*RefR)
a_3 = (4/3)*a_1^3 /(2*RefR*po_toi)

where:

po_toi = $10^{((TOI-30)/10)}$ with TOI in dBm

2nd and 3rd-Order Intercept for a Cascade Network

When N two-port, two-pin nonlinear components are connected in cascade, the expression for the overall output 2nd- and 3rd-order intercepts (see reference 13 in *References for RF System Budget Analysis* (rfsysbudget)) are as follows:

$$\frac{1}{vsoi} = \sum_{i=1}^{N}\left\{\frac{1}{vsoi[i]vg[i]}\right\}$$

where:

vsoi = overall output SOI in volts
vsoi[i] = i'th component output SOI in volts
vg[i] = system voltage gain (magnitude) from the i'th component output to the system output

$$\frac{1}{ptoi} = \sum_{i=1}^{N}\left\{\frac{1}{ptoi[i]pg[i]}\right\}$$

where:

ptoi = overall output TOI in watts
ptoi[i] = i'th component output TOI in watts
pg[i] = system power gain (magnitude) from the i'th component output to the system output

This expression is typically evaluated (see reference 13 in *References for RF System Budget Analysis* (rfsysbudget)) as a scalar equation by ignoring each component's reflection coefficients (s11 and s22), transmission phase characteristic (angle of s21), and reverse transmission coefficients (s12).

However, this expression becomes a close approximation to a complete complex nonlinear solution when the pg[i] and vg[i] terms include the effects of each component's reflection coefficients (s11 and s22), transmission phase characteristic (angle of s21), and reverse transmission characteristic (s12).

The preceding expressions for the network 2nd-order and 3rd-order intercepts are based on the small-signal performance of the individual components and on the extrapolated intersection of each components small-signal fundamental and 2nd-order and 3rd-order P_{out} versus P_{in} curves.

This formulation given above is used by the program to derive the network input and output 2nd and 3rd-order intercepts (InSOI, OutSOI, InTOI and OutTOI) and associated measurements utilizing these intercepts (Cmp_OutSOI_dBm, OutIM2_dBm, Cmp_OutTOI_dBm, OutIM3_dBm, OutSFDR_ResBW_dB, OutSFDR_Total_dB, OutS_IM3_dB). These measurements do not require any large-signal analysis, and thus are approximations to the network's actual large-signal performance.

Raw Data Generated for an RF Budget Analysis

The cascaded two-port, two-pin analysis described in the prior sections defined small-signal S-parameter analysis, power dependent S-parameter analysis, and noise parameter analysis. Those analyses result in raw data from which the RF budget measurements are derived. To define this raw data, several cascade system definitions are shown first:

System source definitions

- RefR = system source resistance = 50 (cannot be changed by user)
    - Source reflection coefficient, Gs = 0
- TempS = system source temperature in degrees Celsius
- FreqS (FreqPilot) = system source (AGC pilot) frequency
- PwrS, PwrS_dBm (PwrPilot) = system source (AGC pilot) available power in W, dBm

System load definitions

- RefR = system load resistance = 50 (cannot be changed by the user)
    - System load resistance, GL = 0
- TempL = system load temperature = -273.15°C (cannot be changed by the user)

Component definitions

- N = number of cascaded components
- n = component index; n = 0, 1, ..., N-1

Simulation setup parameters

- ResBW: user-defined resolution BW for noise measurements
- SimBW, SimFStep: SimBW is the user-defined BW over which noise measurements are swept in frequency with steps defined by SimFStep

Temporary data calculated during cascade analysis

- s11_ss[n], s12_ss[n], s21_ss[n], s22_ss[n], s11_ls[n], s12_ls[n], s21_ls[n], s22_ls[n]
    - S-parameters from system input to component n output for small- and large-signal analysis
- b2_ss[n], b2_ls[n]
    - System wave out from component n and incident on component n+1 based on small- and large-signal analysis
    - b2[N-1] = system wave incident on system load; define b2[-1] = 0
- a2_ss[n], a2_ls[n]
    - System wave at output of component n and reflected from component n+1 based on small- and large-signal analysis
    - a2_ss[N-1], a2_ls[N-1] = 0 because GL = 0
    - Define a2[-1] = reflection from component 0 input

System raw data

With the cascade system definition above, the system raw data is defined here where n represents the n'th component with the index starting at zero for the first component:

- F[n] = frequency (Hz) at component output
    - Let F[-1] = FreqS
    - F[N-1] = FreqL = system load frequency based on system input FreqS
- G_ss[n], G_ls[n] = reflection coefficient at component input for small- and large-signal analysis

  - Let G[N] = GL = 0
- VGI_ss[n], VGI_ls[n] = voltage gain for wave incident on load at component output over system input wave for small- and large-signal analysis input wave
  - VGI[n] = b2[n]/as = s21[n]/(1 - s11[n]*Gs - s22[n]*G[n+1] - s12[n]*s21[n]*Gs*G[n+1] + s11[n]*s22[n]*Gs*G[n+1])
  - When Gs = 0: VGI[n] = s21[n]/(1 - s22[n]*G[n+1])
- VGR_ss[n], VGR_ls[n] = for wave reflected by load at component output over system input wave for small- and large-signal analysis
  - VGR[n] = a2[n]/as = G[n+1] (b2[n]/as)
  - When Gs = 0: VGR[n] = G[n+1] s21[n]/(1 - s22[n]*G[n+1])
- P_ss[n], P_ls[n], Q_ss[n], Q_ls[n] = power incident into, reflected from component input for small- and large-signal analysis
  - P[n] = PwrS|VGI[n-1]|^2
  - Q[n] = PwrS|VGR[n-1]|^2 = |G[n]|^2 P[n]
- PG_ss[n], PG_ls[n] = transducer power gain from system input to power delivered into load at component output for small- and large-signal analysis
  - PG[n] = (1-|Gs|^2)(1-|G[n+1]|^2)|s21[n]|^2 / |(1 - s11[n]*Gs)(1 - s22[n] G[n+1])- s12[n]*s21[n]*Gs*G[n+1] |^2
  - When Gs = 0:
    PG[n] = (1-|G[n+1]|^2) |s21[n]|^2 / |1 - s22[n]*G[n+1]|^2
    PG[n] = |VGI[n]|^2 - |VGR[n]|^2
- NPwr[n] = noise power, dBm, at component output

$$NPwr[n]=30+10\log\left(k\times SimFStep\times \sum_{i=0}^{M-1}\left\{\left(TempS+273.15+290\times\left(10^{\frac{NFin[n,j]}{10}}-1\right)\right)\times PGss[n,j]\right\}\right)$$

  where:

  FreqS_NBW[j] = system input frequencies contributing to component j output within its SimBW centered at its primary frequency
  j = frequency index of swept system source
  k = Boltzmann's constant
  NFin[n,j] = NF_RefIn[n] for FreqS_NBW[j]
  PGss[n,j] = PG_ss[n] for FreqS_NBW[j]
- NBW[n] = noise bandwidth at component output
  - NBW[n] = NPwr_W[n]/NPwr0_W[n]
  - NPwr0_W[j] = noise power per Hz at the center of the SimulationBW at the node
- Noise figure from system input to component output, NF_RefIn[n]
  - Derived from NPwr_NF (W/Hz): defined to be similar as NPwr, but with TempS replaced with 290 K
  - NPwr_NF[n] = (k*Ti[n]*Gi[n] + k*Ts*Gi[n])
    where:

    Gi[n] = G1[n] + G2[n] + G3[n] ... = total transducer power gain (ratio) from system input to component n output for system input fundamental and image frequencies
    G1[n] = transducer power gain from system input to the component n output at the system input frequency
    Ti[n] = T1[n] + T2[n] + T3[n] ... = total noise temperature (K) representing the system noise contribution at system input fundamental and image frequencies
    T1[n] = noise temperature representing the system noise

contribution from system input to the component n output at the system input frequency
Ts = source noise temperature = T0 = 290 K
NF_RefIn[n] = 10*log10((T[n]*Gi[n] + T0*Gi[n])/(T0*G1[n]))

The Noise Figure above is from system input to component n output and includes all system input image noise.

Noise Figure from system input to component output

The Noise Figure from system input to component output, but excluding system image noise is not the real system noise figure, but is also available for users:

- NF_RefIn_NoImage[n] = noise figure, dB, from system input to component n output, with exclusion of all image noise
  This is available for user reference to compare to their Excel spreadsheet calculations that do not include image noise.

Noise Figure from component input to system output

The Noise Figure from component input to system output available excludes system image noise:

- NF_RefOut_NoImage[n] = noise figure, dB, from component n input to system output, with exclusion of all image noise
  The Noise Figure contribution by the component to the overall system noise figure excludes system image noise.
- NF_Ctrb_NoImage[n] = component n contribution, in dB, to full system NF

Raw Data Summary for Budget Analysis

With the definitions above, the following table shows the raw data from which all measurements are related by formula.

Raw Data Name	Description	Notes
System_S12[j]	System overall S12	j=0 for dB =1 for mag =2 for phase
System_S22[j]	System overall S22	j=0 for dB =1 for mag =2 for phase
Cmp_Name[n]	Component name	n = 0 to N-1
Cmp_RefDes[n]	Component reference designator	n = 0 to N-1
Cmp_Ctrb_SysNF_NoImage[n]	System noise figure improvement in dB if component contributes no noise; excludes system input image noise	n = 0 to N-1

Cmp_Ctrb_SysTOI[n]	System output 3rd-order intercept improvement in dB if component is linear	n = 0 to N-1
Cmp_NF[n]	Component noise figure in dB	n = 0 to N-1
Cmp_OutP1[n]	Component output 1 dB compression power level in dBm	n = 0 to N-1
Cmp_OutSOI[n]	Component output 2nd-order intercept power level in dB	n = 0 to N-1
Cmp_OutTOI[n]	Component output 3rd-order intercept power level in dBm	n = 0 to N-1
Cmp_S11[n, j]	Component 50 ohm S11	n = 0 to N-1; j=0 for dB =1 for mag =2 for phase
Cmp_S12[n, j]	Component 50 ohm S12	n = 0 to N-1; j=0 for dB =1 for mag =2 for phase
Cmp_S21[n, j]	Component 50 ohm S21	n = 0 to N-1; j=0 for dB =1 for mag =2 for phase
Cmp_S22[n, j]	Component 50 ohm S22	n = 0 to N-1; j=0 for dB =1 for mag =2 for phase
G_ss[n, j]	Reflection coefficient at component input for small-signal analysis	n = 0 to N-1; j=0 for dB =1 for mag =2 for phase
G_ls[n, j]	Reflection coefficient at component input for large-signal analysis	n = 0 to N-1; j=0 for dB =1 for mag =2 for phase
VGI_ss[n, j]	Voltage gain for wave incident on load at component output over system incident input wave for small-signal analysis	n = 0 to N-1; j=0 for dB =1 for mag =2 for phase
VGI_ls[n, j]	Voltage gain for wave incident on load at component output over system incident input wave for large-signal analysis	n = 0 to N-1; j=0 for dB =1 for mag =2 for phase
VGR_ss[n, j]	Voltage gain for wave reflected by load at component output over system incident input wave for small-signal analysis	n = 0 to N-1; j=0 for dB =1 for mag =2 for phase
VGR_ls[n, j]	Voltage gain for wave reflected by load at component output over system incident input wave for large-signal analysis	n = 0 to N-1; j=0 for dB =1 for mag =2 for phase
P_ss[n]	Power in dBm incident into component input for small-signal analysis	n = 0 to N-1
P_ls[n]	Power in dBm incident into component input for large-signal analysis	n = 0 to N-1
Q_ss[n]	Power in dBm reflected from component input for small-signal analysis	n = 0 to N-1
Q_ls[n]	Power in dBm reflected from component input for	n = 0 to N-1

	large-signal analysis	
PG_ss[n]	Transducer power gain in dB from system input to power delivered into load at component output for small-signal analysis	n = -1 to N-1; -1 means at system source output
PG_ls[n]	Transducer power gain in dB from system input to power delivered into load at component output for large-signal analysis	n = -1 to N-1; -1 means at system source output
F[n]	Frequency at component output	n = -1 to N-1; -1 means at system source output
NF_refin[n]	Noise figure in dB from system input to component output	n = 0 to N-1
NF_refin_no_image[n]	Noise figure in dB from system input to component output; with exclusion of all image noise	n = 0 to N-1
NF_refout_no_image[n]	Noise figure in dB from component input to system output; with exclusion of all image noise	n = 0 to N-1
NPwr[n]	Total noise power in dBm at component output	n = -1 to N-1; -1 means at system source output
NPwr0[n]	Noise power in dBm per resolution bandwidth at component output	n = -1 to N-1; -1 means at system source output
NBW[n]	Noise bandwidth at component output	n = 0 to N-1
SOI_in[n]	2nd-order intercept power level in dBm at component input based on VGI_ls[n-1, 0]	n = 0 to N-1
SOI_out[n]	2nd-order intercept power level in dBm at component output based on VGI_ls[n, 0]	n = 0 to N-1
TOI_in[n]	3rd-order intercept power level in dBm at component input based on VGI_ls[n-1, 0]	n = 0 to N-1
TOI_out[n]	3rd-order intercept power level in dBm at component output based on VGI_ls[n, 0]	n = 0 to N-1
P1dB_in[n]	1 dB gain compression power in dBm at component input based on VGI_ls[n-1, 0]	n = 0 to N-1
P1dB_out[n]	1 dB gain compression power in dBm at component output based on VGI_ls[n, 0]	n = 0 to N-1

Troubleshooting RF System Budget Analysis

Here are some typical budget simulation problems and remedies to resolve them.

Using Components with Three or More Pins

Only two-port, two-pin components are supported by the budget simulation in the top-level schematic, except for these components: *AGC_Amp*, *AGC_PwrControl*, *S2P*, *PathSelect2*, and *R* with pin 2 tied to ground. The simulation will generate an error if any other unsupported components have three or more pins.

Using Unsupported Networks

If the topology in the design is not a simple two-port, two-pin cascaded network, an error is generated indicating more than three components pins are connected to the same node in the network. Only two-port, two-pin cascaded RF system designs can be used with the Budget controller. For example designs, see *Performing Budget Simulations* (rfsysbudget).

Using Unsupported Components

If your design contains components in the top-level schematic that are not supported in a budget analysis, an error is generated. The component may not be supported for one of the following reasons:

- The component does not have an S-parameter representation.
- The component cannot be used with the ADS P2D analysis controller. This is one of the limitations of the Budget controller, since it relies on P2D analysis to determine the nonlinear characteristics of RF system components.

Unfortunately, no workaround exists for these components. They are simply not supported in the top-level schematic for a budget simulation. However, these components can be used in subnetworks to create circuit designs that are used as two-port, two-pin subnetworks in top-level schematics.

Enabling Other Simulation Controllers in a Design

When performing a budget analysis, no other analysis can be enabled in a simulation. If other analyses are included, an error is generated indicating that the design contains an instance of another ADS simulation controller, such as *Harmonic Balance*, *DC*, *S_Param*, etc., or an ADS parent controller, such as *Sweep*, *Optim*, *Yield*, etc., that does not sweep or optimize the budget analysis instance. The Budget controller can only be used in isolation, except where parent controllers are used to sweep or optimize the budget analysis. Remove or deactivate any instances of these other ADS simulation controllers to proceed.

Instance Name Conflict in Subnetworks

The Budget analysis simulation reports an error when a top-level subnetwork reference designator (or instance name) is the same as the reference designator of a component inside the subnetwork. Use a different reference designator for one of the two instances.

Setting the CmpMaxPin Parameter

If the value for the maximum component input power parameter (*CmpMaxPin*) is set too low, the analysis cannot characterize nonlinearity. Increase the value of the Budget controller parameter *CmpMaxPin* and try again. For information about how *CmpMaxPin* is used with nonlinear models, see *Characterization of Component Nonlinearities* (rfsysbudget).

Using 1 dB Power Compression Measurements

When using the 1 dB power compression measurements, the simulator may detect conditions requiring you to consider modifying the design or changing how the measurement is set up. The following topics discuss these conditions and ways you might resolve them:

- The system nonlinear analysis may not converge while calculating 1 dBm compression points after a certain number of iterations. This means that one or more components in the system cascade have S-parameters that do not allow for the Budget iterative large signal algorithm to converge.
    - Provide more isolation between nonlinear stages by resetting one or more component S12 values to zero.
    - Look at the component P2D file in the workspace data directory for irregular power or S-parameter values. Test the component with a separate P2D analysis and look for irregular power or S-parameter values. Irregular S-parameters include S21 that decreases at a rate much greater than 1 dB per input power change. Irregular power values include P2 power levels that suddenly drop in level.
    - Turn off all P1dB measurements.
- A particular component has a power input in dBm that is greater than the component nonlinearity definition during analysis. This means that a component has large signal S-parameters that conflict with analysis power levels incident at its port 1 or port 2.
    - Look at the component P2D file in the workspace data directory for irregular power or S-parameter values. Test the component with a separate P2D analysis and look for irregular power or S-parameter values. Irregular S-parameters include S21 that decreases at a rate much greater than 1 dB per input power change. Irregular power values include P2 power levels that suddenly drop in

    level.
    - Turn off all P1dB measurements.
- A system nonlinear analysis error occurs because the overall system gain is less than -200 dB. This indicates that one or more components in the system cascade has a loss that is too large for the nonlinear analysis to proceed successfully.
    - Look for one or more components with excessive loss and reduce its loss.
    - Turn off all P1dB measurements.
- A system nonlinear analysis error occurs because the gain for a particular component output is less than -200 dB. This indicates that the component has a loss that is too large for the nonlinear analysis to proceed successfully.
    - Change the component to reduce its loss.
    - Turn off all P1dB measurements.

Error Messages During Large Signal Analysis

During large-signal analysis, the simulator may detect conditions requiring you to consider modifying the design. The following topics discuss these conditions and ways you might resolve them:

- The system small signal gain to a component output has gain that is less than -200 dB. This indicates that one or more components in the system cascade has a loss that is too large for the small signal analysis to proceed successfully.
    - Look for one or more components with excessive loss and reduce its loss.
- The system nonlinear analysis did not converge, indicating that the budget nonlinear analysis did not converge.
    - Provide more isolation between nonlinear stages by resetting one or more component S12 values to zero.
    - Look at the component P2D file in the workspace data directory for irregular power or S-parameter values. Test the component with a separate P2D analysis and look for irregular power or S-parameter values. Irregular S-parameters include S21 that decreases at a rate much greater than 1 dB per input power change. Irregular power values include P2 power levels that suddenly drop in level.
- There is a system nonlinear analysis error, indicating that an undocumented error has occurred in the budget nonlinear analysis.
    - Insufficient information is known to provide a resolution. Please contact Agilent EEsof Technical Support for further investigation. You may be asked to send the design to Agilent.

Internal Errors

If a fatal internal error occurs, please report the problem to Agilent EEsof Technical Support. Also, keep the design that is causing the error available for evaluation by Agilent EEsof.

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