Agilent Technologies

Advanced Design System 2011

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Load Pull DesignGuide

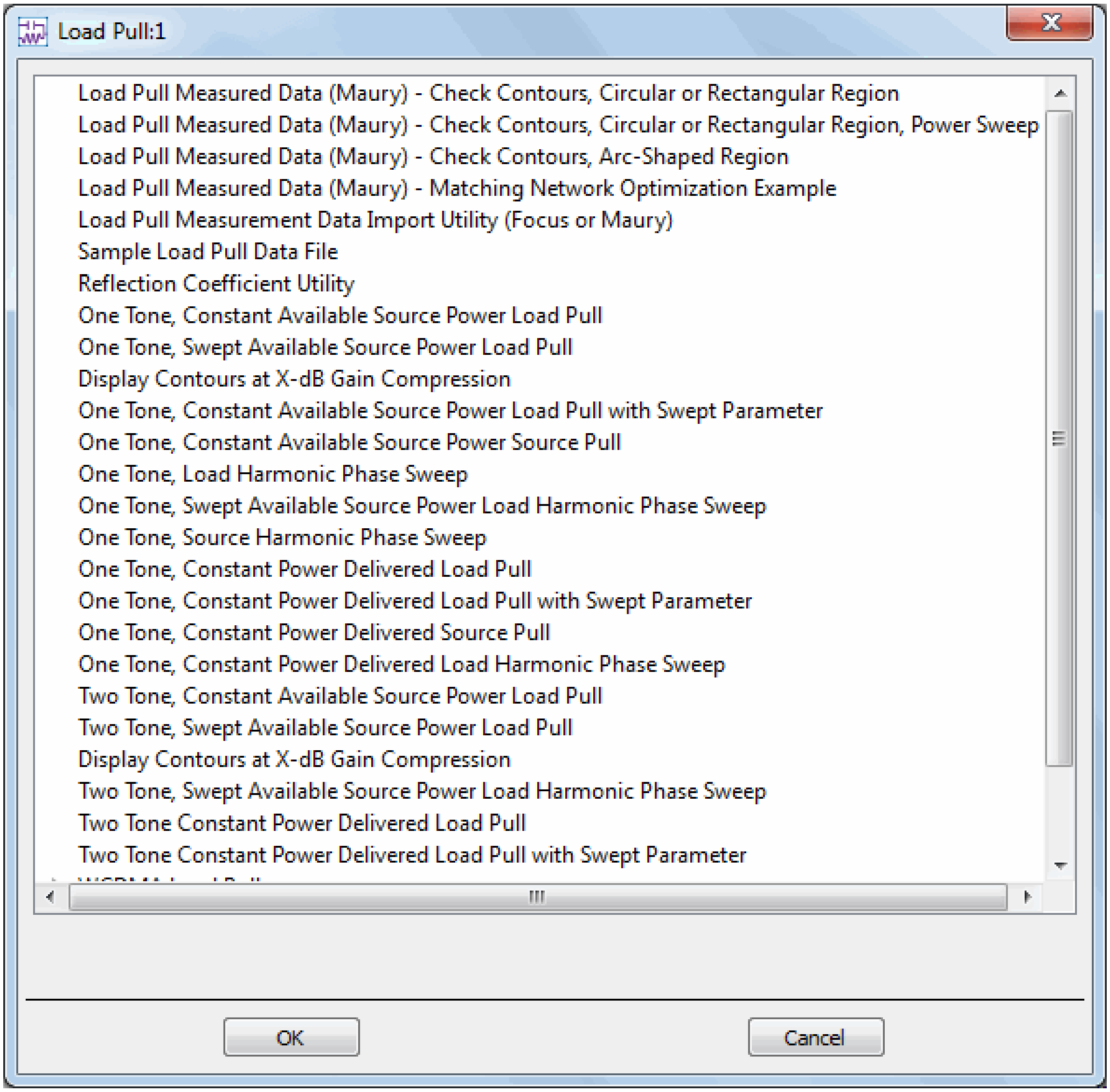
Acknowledgments

About Load Pull DesignGuide

Load Pull simulation is frequently used by power amplifier designers to determine, which load impedance to present to a device or amplifier in order to achieve a particular power delivered, power-added efficiency, inter-modulation distortion level, adjacent-channel leakage ratio, and other specifications.

The Load Pull DesignGuide has simulation setups for working with measured load pull data files and with nonlinear device models. The first three selections, that begin with **Load Pull Measured Data (Maury) - Check Contours...**, enable you to specify a region of the Smith Chart and verify that the measured data file generates the contours you expect. These are useful for determining approximately the optimal load impedance. The fourth selection, **Load Pull Measured Data (Maury) – Matching Network Optimization...**, shows an example of optimizing an impedance matching network. The first four selections each utilize the **DataBasedLoadPull** component. This component simulates the S-parameters of the network connected to it, and uses S11 as an index into the measured load pull data file to read out (possibly with interpolation and extrapolation) the corresponding measured data.
The *Load Pull Measurement Data Import Utility (Focus or Maury)* (dgutil) uses the Load Pull Utility, which is unchanged from earlier ADS releases. This is necessary because the **DataBasedLoadPull** component does not yet work with Focus data files.

The remaining selections in this Load Pull DesignGuide are all for running various different types of load and source pulls on nonlinear device or amplifier models.
From a Schematic window, Select **DesignGuide > Load Pull** where you can see different options in the Load Pull dialog box.



When you click on one of the options in the Load Pull dialog box, for example, OneTone, Constant Available Source Power Load Pull, a simulation schematic and the corresponding data display file are copied into your working workspace directory. You modify the schematic by deleting the sample device, inserting your device, editing the parameters on the load pull instrument to set voltages as needed, and specifying the circular region of the Smith Chart for the load reflection coefficients. Then you run the simulation and view the results in the corresponding data display file. Following are the load pull simulations:

- Load Pull Measured Data (Maury) – Check Contours
- One Tone Simulation
- Two Tone Simulation
- *WCDMA Signal Simulation* (dgldpull)

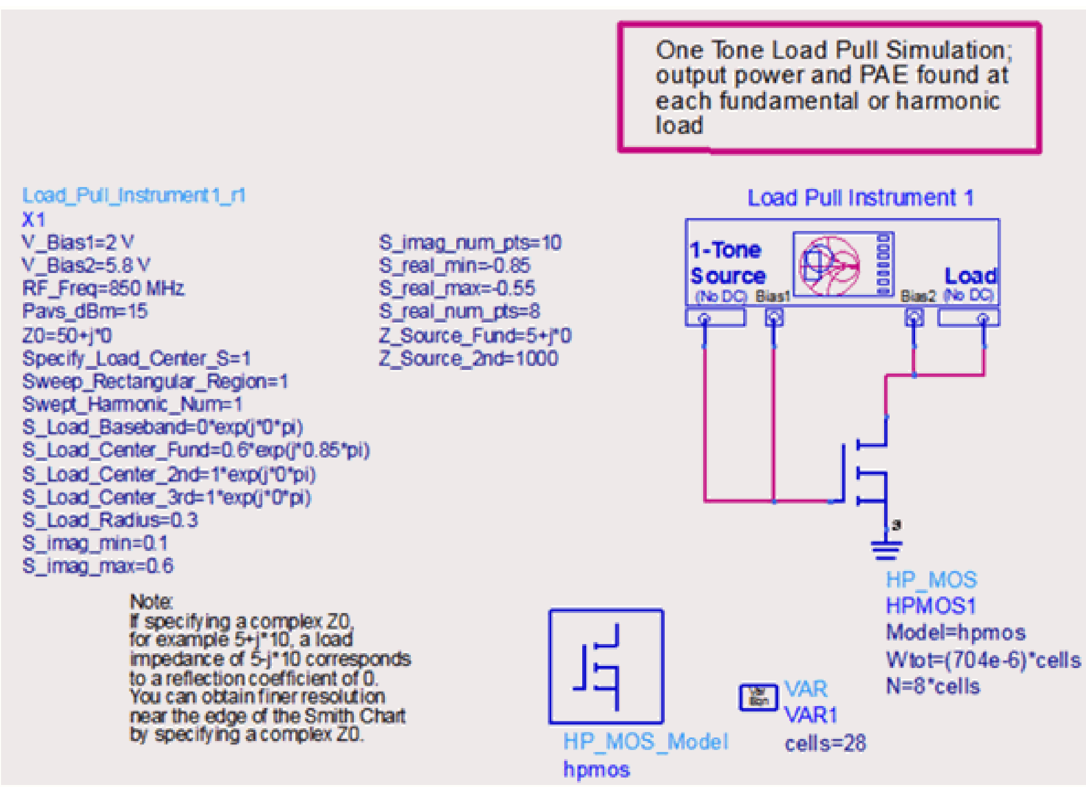
The constant power delivered simulations are achieved using an optimization, and include one-tone, two-tone, and WCDMA input signals.

One Tone Simulation

Contents

One Tone, Constant Available Source Power Load Pull

This setup simulates the device or amplifier with a constant available source power while the load reflection coefficient is swept in a circular or rectangular region of the Smith Chart. This simulation is the fastest, simplest one. It just runs a load pull simulation at a single available source power level. This is useful for seeing the power, gain, and PAE contours of a particular device at a single input power level. It does not provide information about how far into compression the device is. However, you can quickly change the settings in the schematic and see if you are getting the performance you are expecting.



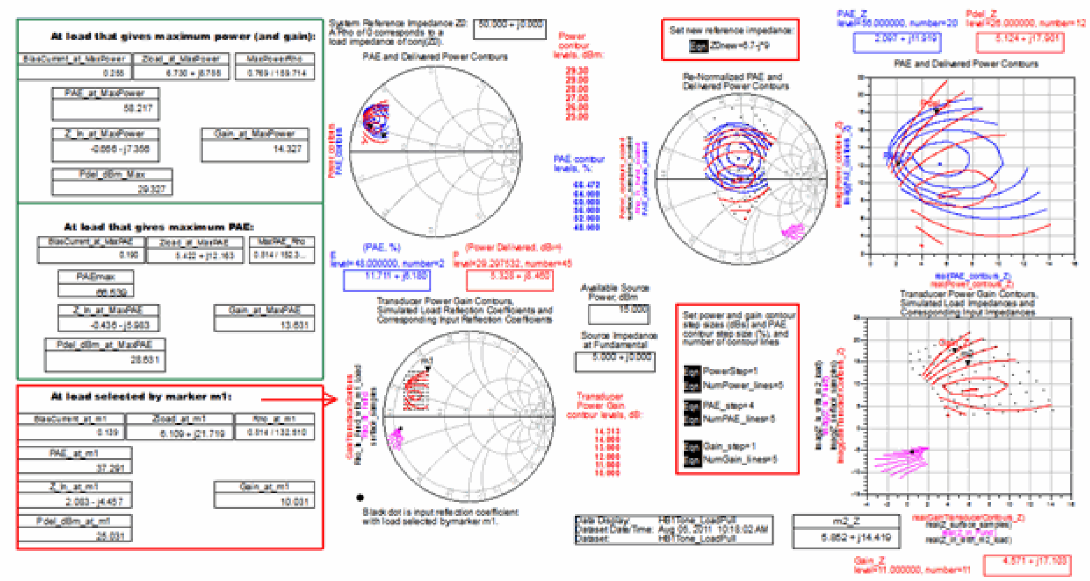
You need to specify multiple things while using this schematic, such as:

1. Replace the device with your device or amplifier.
2. Set the bias voltages `V_Bias1` and `V_Bias2` or modify the bias network in the Load_Pull_Instrument1 subcircuit, as needed. However, the DC power consumption is computed in an equation within the subcircuit, assuming current probe *Is_1* is connected to supply voltage node *Vs_1* and current probe *Is_2* is connected to supply voltage node *Vs_2*. If you delete any of these or re-name them, you must update the *Pdc* equation so the DC power consumption is computed correctly.
3. Specify the available source power *Pavs_dBm* and input frequency `RF_Freq`, source impedances at the fundamental Z_Source_Fund_, and 2nd harmonic Z_Source_2nd frequencies.
4. If you want to sweep a rectangular region of the Smith Chart, set *Sweep_Rectangular_Region = 1*. In this case, the rectangular region of reflection coefficients will be specified by the *S_imag_** and *S_real_** variables. Note that the loads at the unswept harmonic frequencies (and fundamental if sweeping a harmonic load) are specified using the *S_Load_Center_** or *Z_Load_Center_** variables.
5. If you want to sweep a circular region of the Smith Chart, set *Sweep_Rectangular_Region = 0*. In this case, there are three main ways to specify the circular region of the Smith Chart that will be sampled by the load pull:
    1. Set the reference impedance Z0 to 50, and set *Specify_Load_Center_S=1*. In this case, the center of the circle of simulated reflection coefficients (and harmonics) will be set by the *S_Load_Center_** parameters, which are reflection coefficients.
    2. Set the reference impedance Z0 to 50, and set *Specify_Load_Center_S=0*. In this case, the center of the circle of simulated reflection coefficients (and harmonics) will be set by the *Z_Load_Center_** parameters, which are impedances.
    3. Set the reference impedance Z0 to the complex conjugate of the impedance at the center of the circle of reflection coefficients you want to simulate. In this case, you could set *Specify_Load_Center_S=1* and use the *S_Load_Center_** parameters. Remember that in this case, a reflection coefficient of 0 corresponds to setting the load impedance to the complex conjugate of the reference impedance.
6. If sweeping a circular region of the Smith Chart, specify the radius of the circle of the reflection coefficients *S_Load_Radius* and the number of points *Num_Points*.

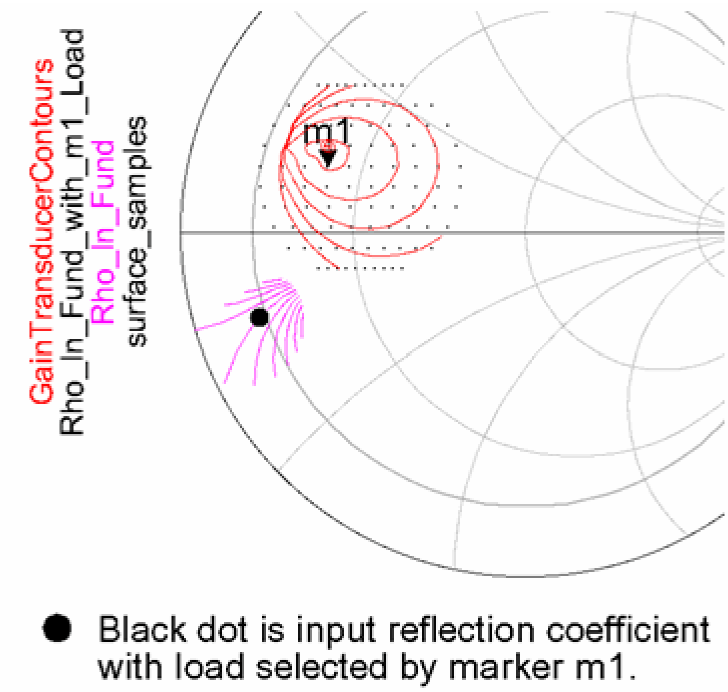
If the device or amplifier is potentially unstable and the circle of reflection coefficients that you specify includes the unstable region, the simulation may run into convergence problems. This would be due to the device wanting to oscillate. A solution to this problem is to add stabilizing components at the input, output, or in parallel with the device. You may want to use a simulation setup for this purpose, **DesignGuide > Amplifier > S-Parameter Simulations > Feedback Network Optimization** to Attain Stability. Another solution is to specify the circle or rectangle of reflection coefficients such that the unstable region is avoided.

You can select **DesignGuide > Load Pull > Reflection Coefficient Utility** to see a data display with a graphical tool to help you see the circle that corresponds to particular values of the s11_rho and s11_center variables.

Run the simulation just as you would any other. When it finishes, open the HB1Tone_LoadPull data display.

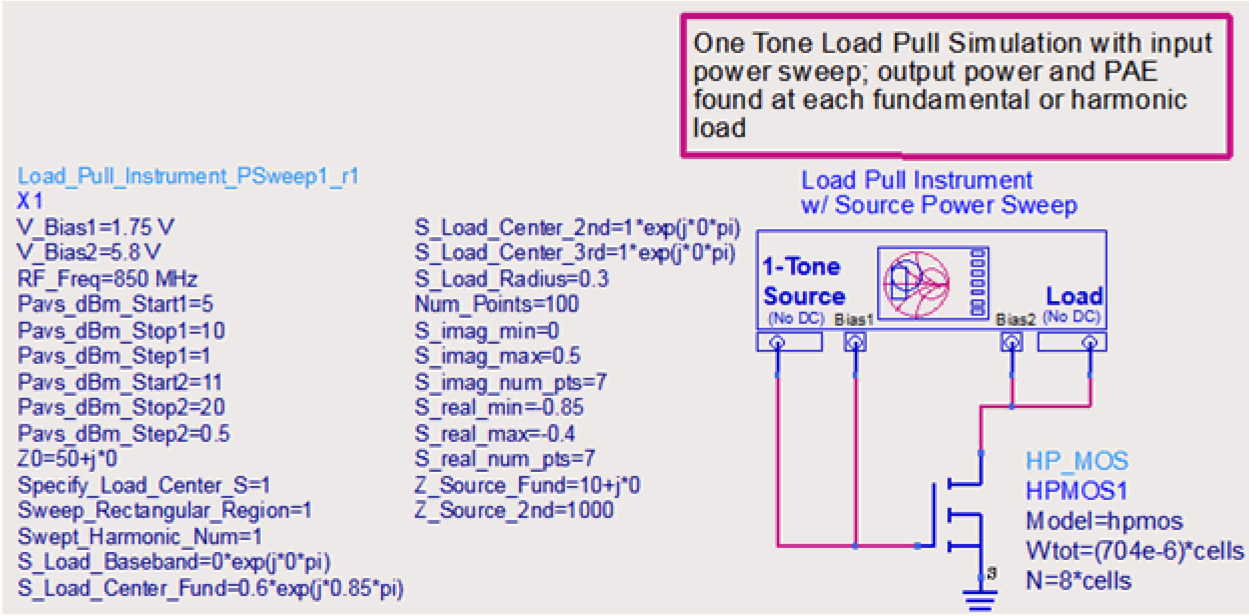


This shows the contours of power delivered, PAE, and gain. You may want to change the step sizes between and the number of contour lines. The boxes on the left show that you get slightly different performance results depending on whether you choose the load to maximize power delivered or PAE. The lower Smith Chart shows how the input reflection coefficients vary as a function of the load reflection coefficients. The impedance plots on the right make it easy to read off optimal load impedances even when the optimal loads are near a short circuit.



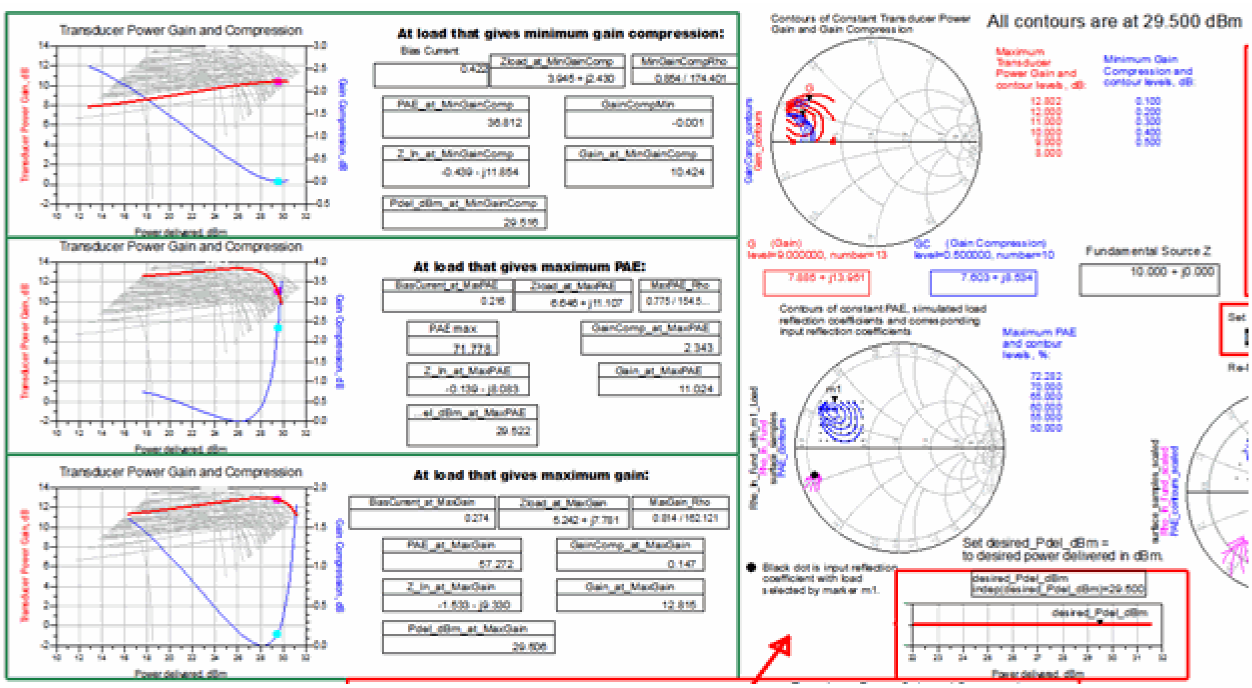
One Tone, Swept Available Source Power Load Pull

The **One Tone, Swept Available Source Power Load Pull** setup adds a sweep of the available source power for each value of the load reflection coefficient. It enables you to see how the contours change as the device is driven from small signal to large signal into compression. The schematic has an additional parameter sweep for the available source power variable *Pavs_dBm*.



In addition to the various settings done in the **HB1Tone_LoadPull** schematic, you also have to specify the sweep limits for the *Pavs_dBm* variable. Here we have two ranges, one with a coarser step (assumed to be the linear region) and one with a finer step (in the compressed region.)

After running the simulation, open the **HB1Tone_LoadPull_PSweep** data display and make sure the default dataset name is set to the name of the dataset generated by the simulation.



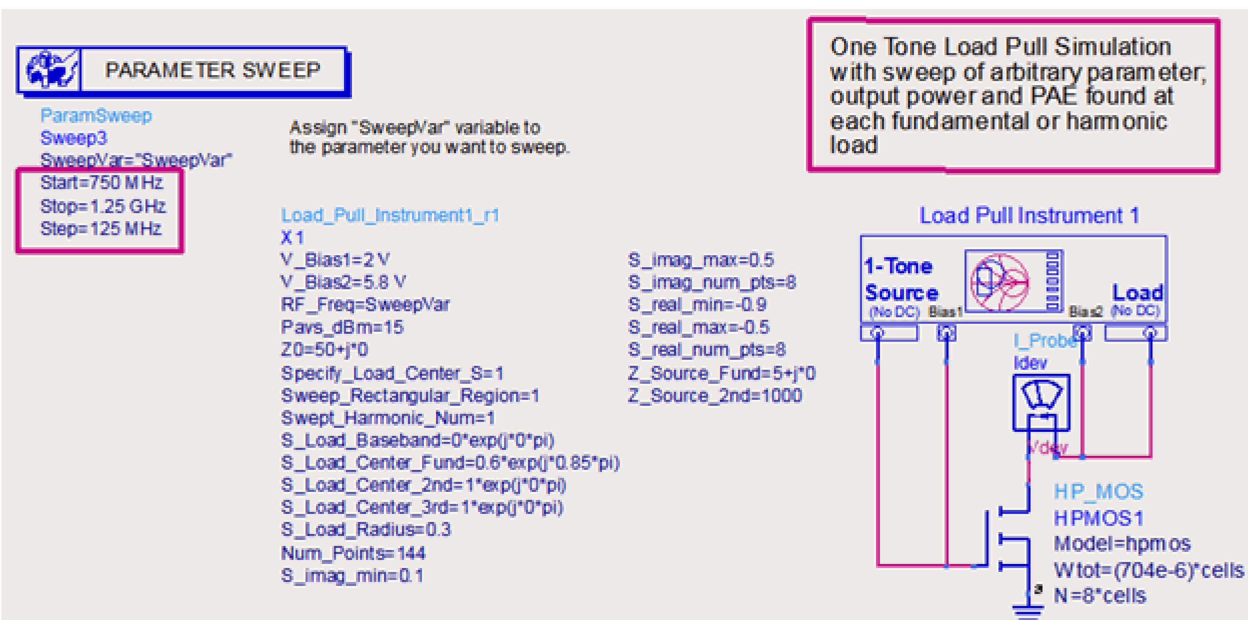
The data display shows the transducer power gain, gain compression, power delivered, and PAE contours for a particular power delivered to the load that you select using the desired_Pout_dBm marker. The gain and gain compression curves that correspond to several optimal load points (for minimum gain compression, maximum PAE, and maximum gain) are also shown.

The data from the simulation is interpolated to find the values that correspond to the desired output power. Note that the gain compression is computed relative to the maximum gain point. You may specify that the gain at the lowest input signal power be used as the reference by setting the Use_Max_Gain_For_GComp_Reference variable to 0 on the Equations page.

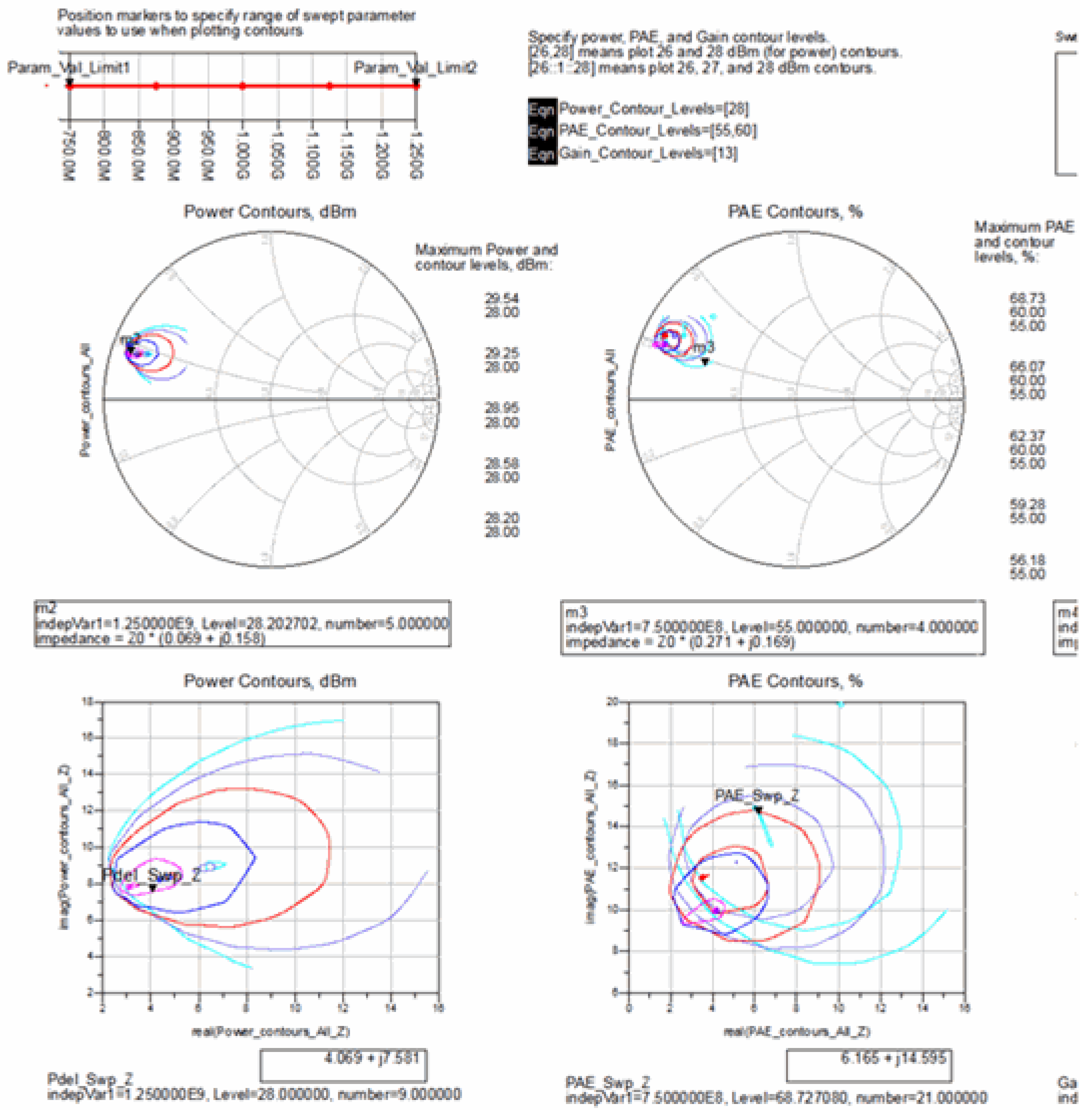
One Tone, Constant Available Source Power Load Pull with Swept Parameter

The **One Tone, Constant Available Source Power Loadpull with Swept Parameter** simulation allows you to see how the contours and performances vary with some arbitrary swept parameter (such as a bias voltage and the input frequency). However, the available source power is held constant.

This setup adds the sweep of an arbitrary parameter to the simplest constant available source power load pull simulation. You have to assign the parameter *SweepVar* to some component or variable on the schematic. In this case it is assigned to the input signal frequency `RF_Freq`.



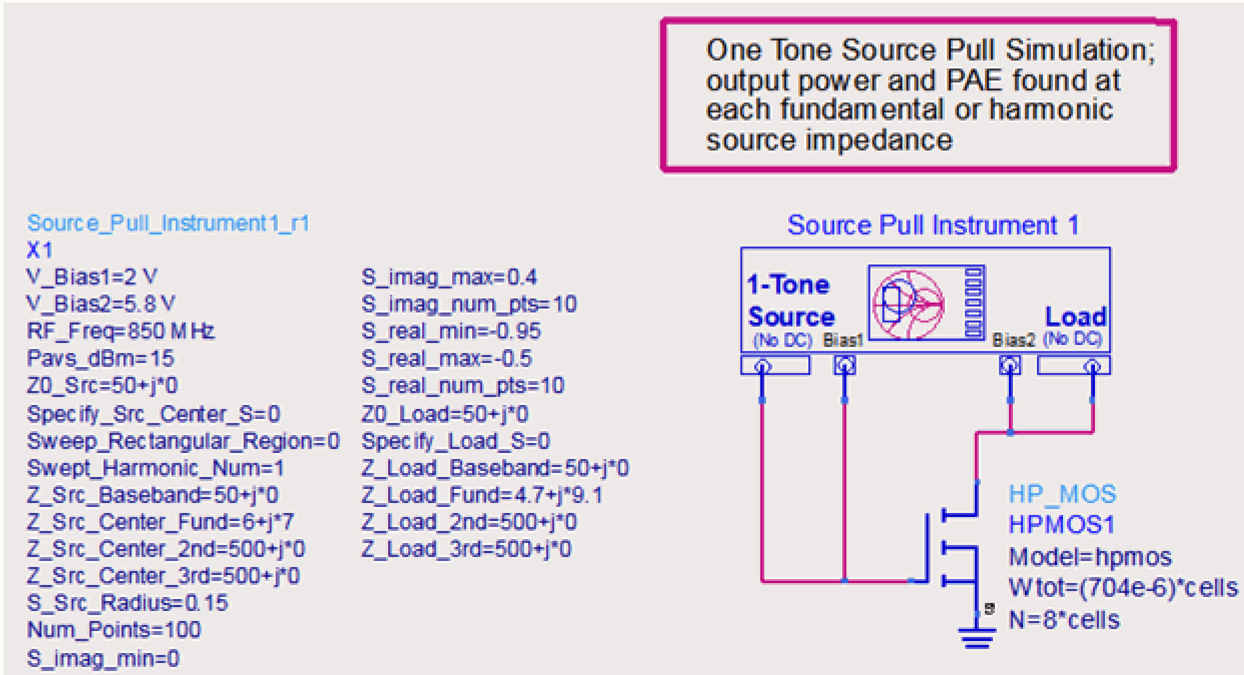
The above figure specifies the limits of the swept variable, *SweepVar*, and assigning it to `RF_Freq`. The corresponding data display has plots similar to the ones shown earlier, but it also has a page with contours at multiple values of the swept parameter.



The above plots show how the region of load impedances required to obtain 28 dBm power delivered gets much smaller as the input frequency increases. When plotting contour lines as a function of a swept parameter, they may be easier to interpret if just one or two contour levels are specified.

One Tone, Constant Available Source Power Source Pull

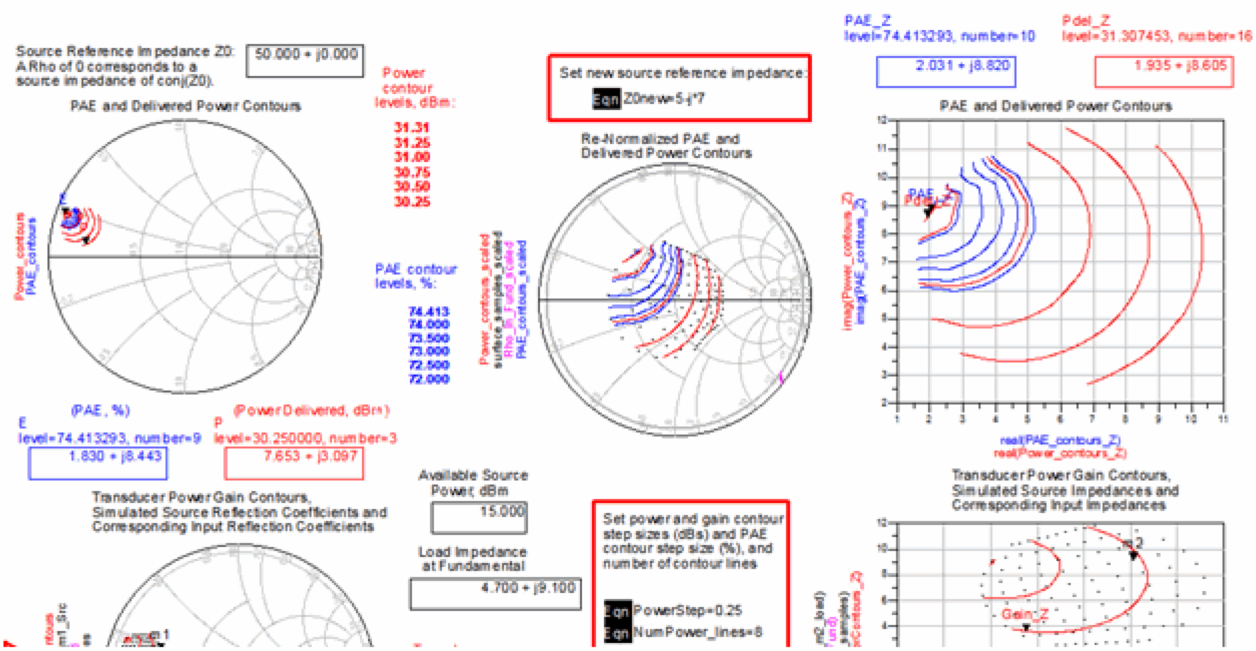
This setup simulates the device or amplifier with a constant available source power while the source reflection coefficient is swept in a circular or rectangular region of the Smith Chart. This simulation is the fastest, simplest one. It just runs a source pull simulation at a single available source power level. This is useful for seeing the power, gain, and PAE contours of a particular device at a single input power level. It does not provide information about how far into compression the device is. However, you can quickly change the settings in the schematic and see if you get the performance you expect.



In this case, since the *Sweep_Rectangular_Region=0*, sweep a circular region of the Smith Chart. Also, since *Specify_Src_Center_S=0*, we are using the *Z_Src_Center_** to specify the impedances at the fundamental and harmonic frequencies. Since *Swept_Harmonic_Num=1*, we are sweeping the reflection coefficient at the fundamental frequency.

Because the optimal source impedance is usually close to the edge of the Smith Chart, you may want to set the reference impedance for the source *Z0_Src* to a value that is near the complex conjugate of what you expect will be the optimum.

The right Smith Chart below shows much better resolution of the contour lines because its center corresponds to **5+j*8** Ohms. An alternative is to just view the contours on the rectangular impedance plots.

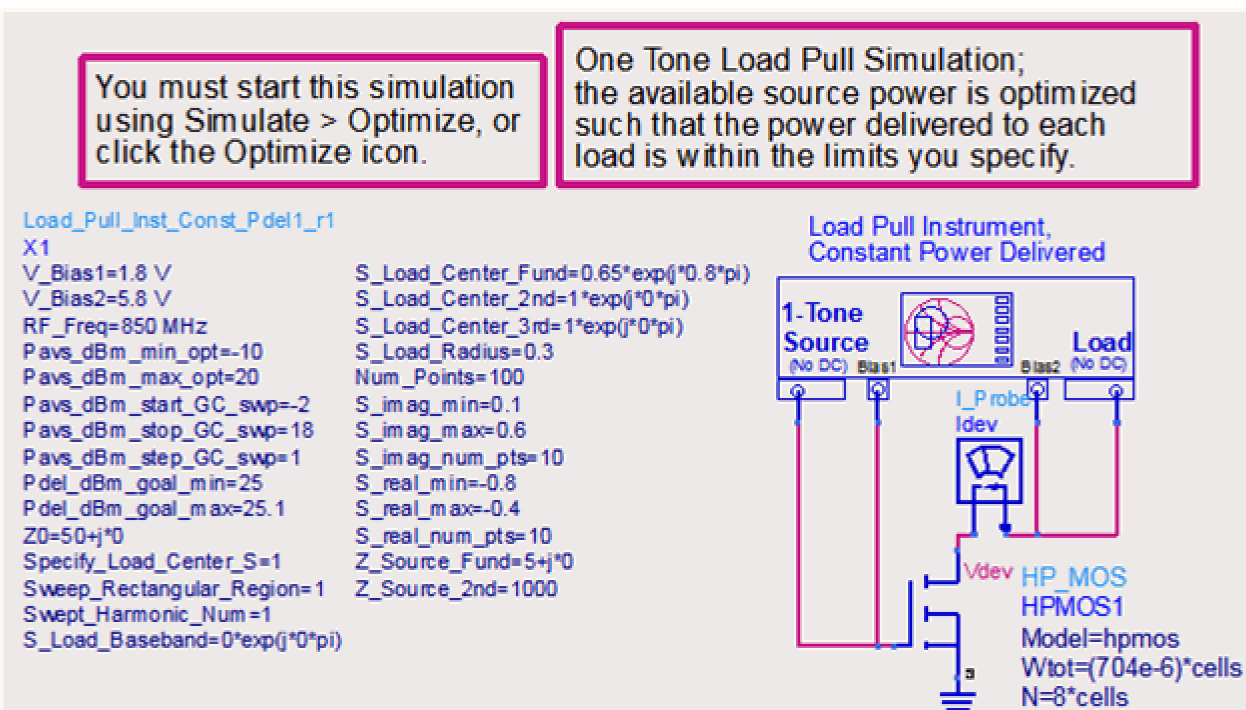


You have to be careful when selecting the source impedance. In this case, the impedance that gives the highest output power and PAE is also very close to the complex conjugate of the impedance seen looking into the device when the load impedance is set to *4.7+j*9.1* Ohms. This should be very close to satisfying the conditions for oscillation, which we want to avoid. You could add some stability network around the device or choose a source impedance that is not so close to satisfying the conditions for oscillation.

One Tone, Constant Power Delivered Load Pull

The **One Tone, Constant Power Delivered Loadpull (HB1Tone_LoadPull_ConstPdel)** simulation optimizes the available source power level until the desired power is delivered to each load reflection coefficient. You would use this if your device or amplifier needs to deliver a particular power level and you want to choose the optimum load considering other performances (such as gain, gain compression, PAE, and bias current.)

This setup sweeps the load reflection coefficient in a circular or rectangular region of the Smith Chart and optimizes the source power level for each load reflection coefficient until the desired power is delivered to the load. The data display shows contours of constant PAE, bias current, gain, and gain compression. The input reflection coefficient is also shown for a particular load that you specify. These data allow you to pick the optimal load that produces the best PAE, gain, gain compression, or bias current, or make trade-offs amongst these specifications.



You have to make the same types of edits to this schematic as with the others described above. Also, you have to specify the minimum and maximum allowed values of the available source power, Pavs_dBm_min_opt and Pavs_dBm_max_opt, respectively.

During the optimization, the available source power is adjusted within these limits until the power that you want is delivered to the load. Depending on how high a power you want delivered to the load and the gain of the device, you may have to adjust the

Pavs_dBm_max_opt limit.

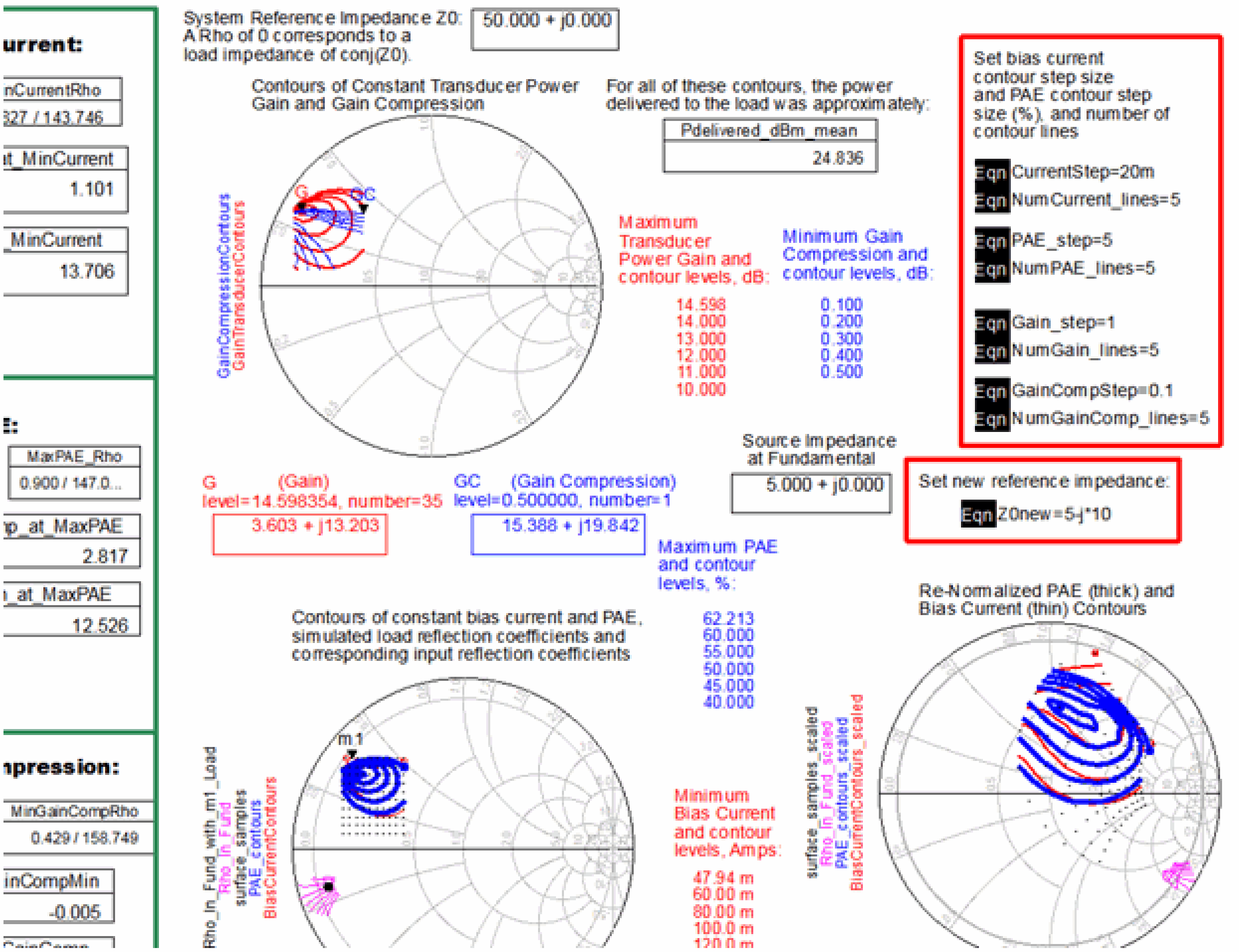
In this example, the power delivered (based on Pdel_dBm_goal_min and Pdel_dBm_goal_max) is to be between 25 and 25.1 dBm. With this value and a Pavs_dBm_max_opt value of 20 dBm, it is specified that the lowest transducer power gain accepted is 5 dB.

The gain compression at the desired output power is also computed, and the reference gain for this gain compression calculation is the maximum gain computed from a power sweep between Pavs_dBm_start_GC_swp and Pavs_dBm_stop_GC_swp. If your device or amplifier is expected to have a maximum gain at a small input power level, then you may set Pavs_dBm_start_GC_swp to a low value and set Pavs_dBm_stop_GC_swp to the same value, in which case this part of the simulation should run quickly. If your device or amplifier is expected to have gain expansion, then you should set Pavs_dBm_stop_GC_swp high enough that the sweep does include the maximum gain point. However, be aware that the further into gain compression this sweep drives the device or amplifier, the slower the simulation will be.

You may also specify different load impedances or reflection coefficients at the harmonic frequencies and (for the source) at the fundamental and harmonic frequencies.

To launch the simulation, click the *Optimize* icon . If the simulation is started by hitting the F7 key or by selecting **Simulate > Simulate**, then an optimization is not executed and the simulation results are not displayed correctly in the data display.

After running the optimization, the **HB1Tone_LoadPull_ConstPdel** data display shows the results.

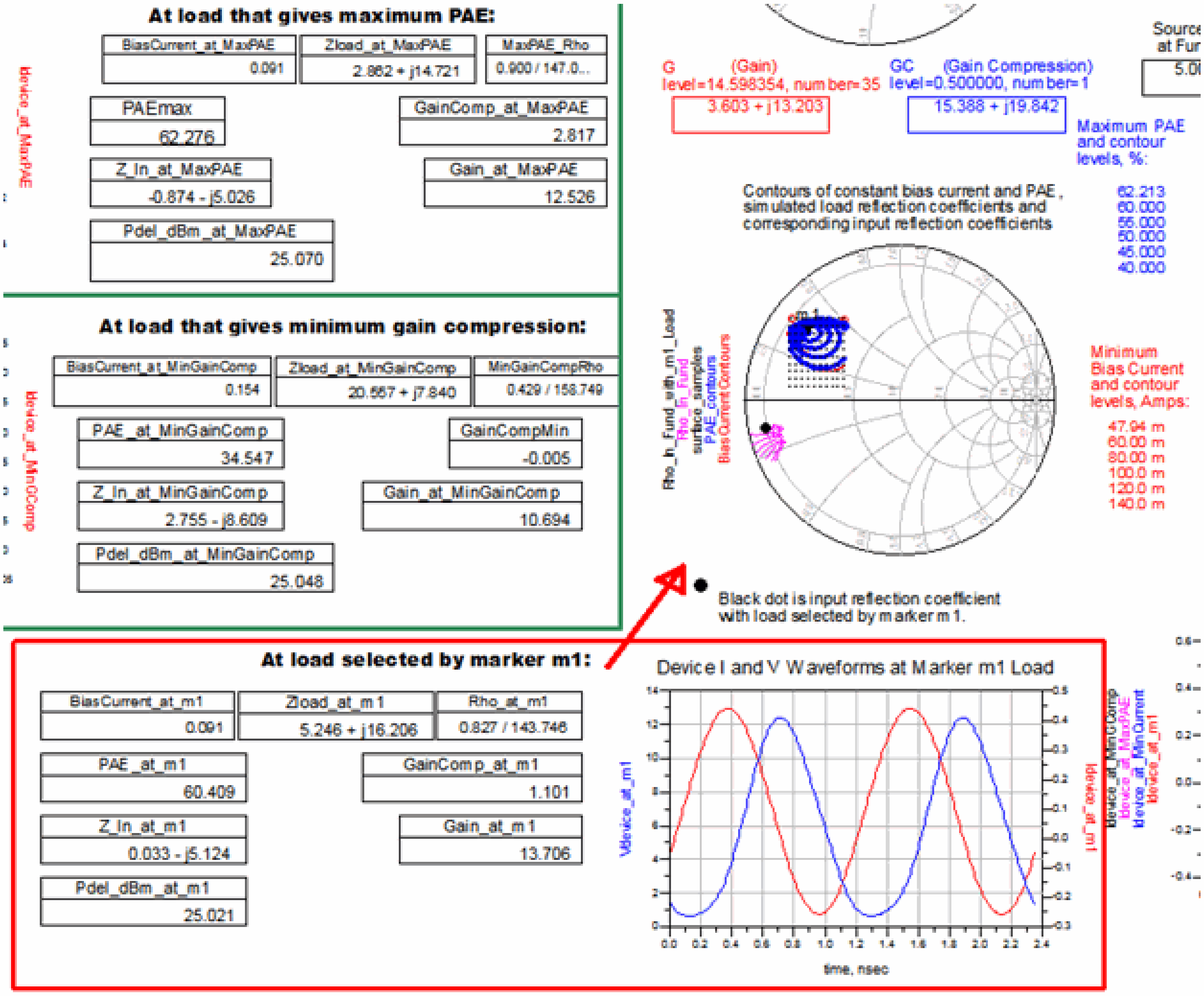


To see the contours effectively, you may need to change the `CurrentStep`, `PAE_step`, `Gain_step`, and `GainCompStep` variables. These set the step sizes between the contours.

The upper Smith Chart shows contours of constant gain and gain compression. The lower left Smith Chart shows contours of constant bias current and power-added efficiency (PAE), as well as the simulated load reflection coefficients and the corresponding input reflection coefficients.

In the green boxes on the left side are data that correspond to a particular optimal condition such as minimum bias current, maximum PAE, or minimum gain compression. However, you have to make sure that the desired power delivered was actually achieved. For some load impedances close to the edge of the Smith Chart this may be difficult.

You also have the option of selecting any of the simulated load reflection coefficients with marker m1. The corresponding data appears in a separate box.

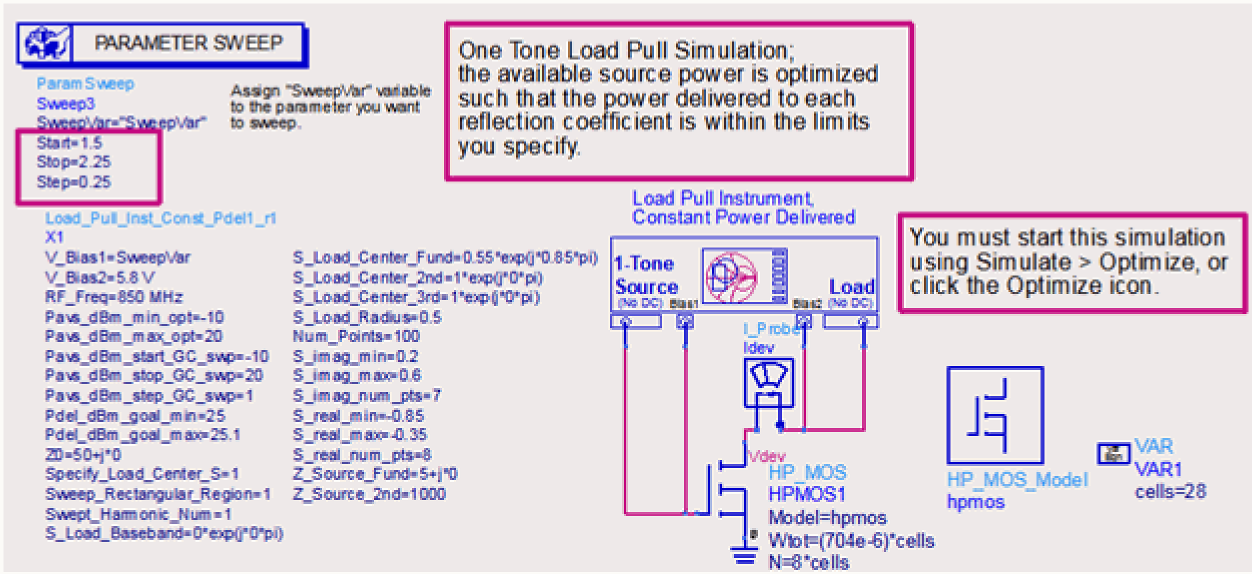


Data within the red box corresponds to the reflection coefficient selected by marker M1.

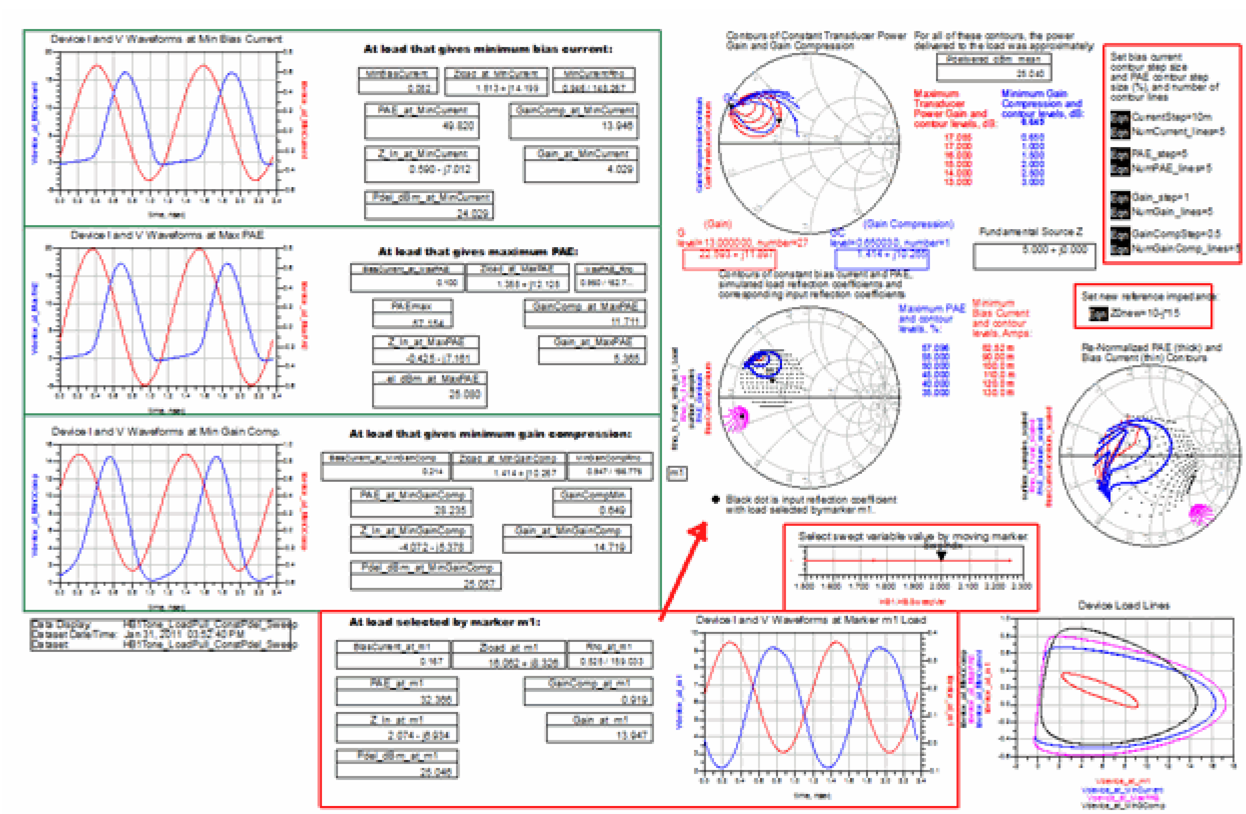
One Tone, Constant Power Delivered Load Pull with Swept Parameter

The **One Tone, Constant Power Delivered Loadpull with Swept Parameter (HB1Tone_LoadPull_ConstPdel_Sweep)** simulation adds the sweep of an arbitrary parameter. This sort of simulation is very useful if you want to see how the optimal load impedance, load pull contours, and the device performances vary versus some arbitrary parameter. For example, how does the optimal load vary with frequency and how do the power added efficiency and other parameters change with the bias voltage. If you have included some stabilization network around the device, how does the performance vary as you change one of the parameters.

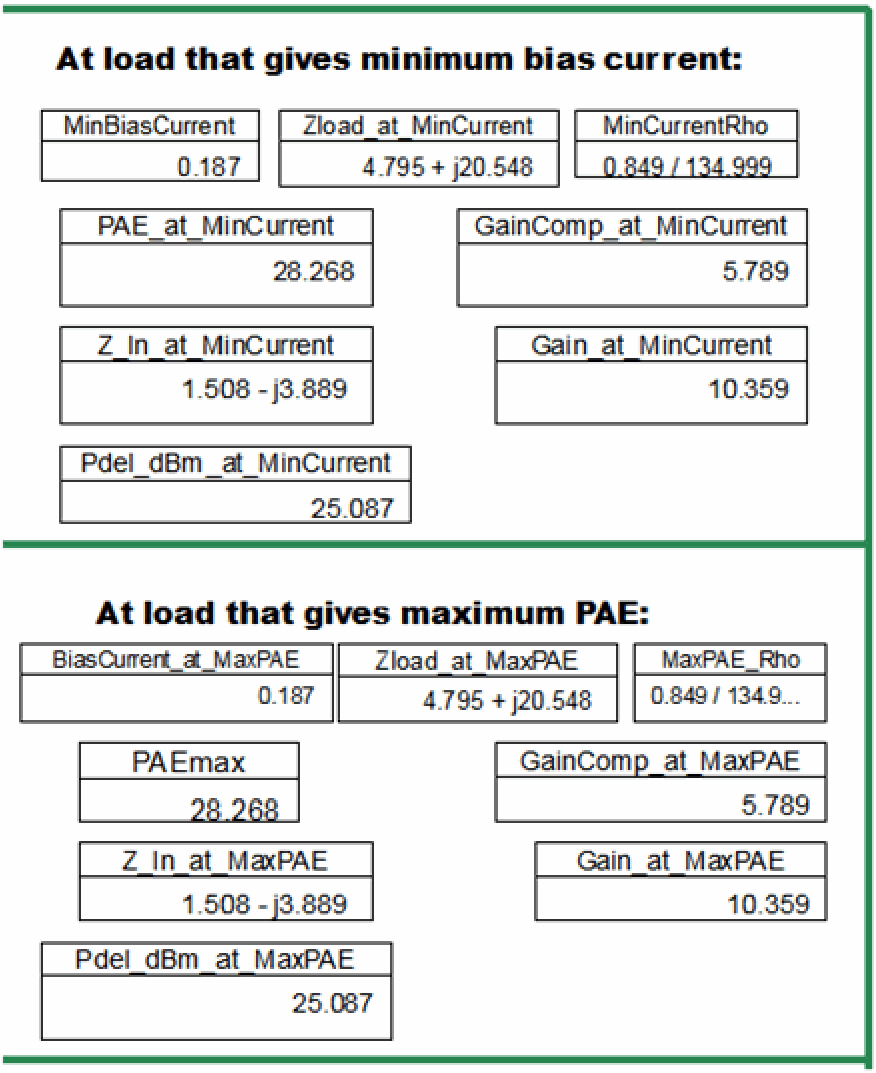
This simulation setup and data display are nearly identical to the version without the parameter sweep.



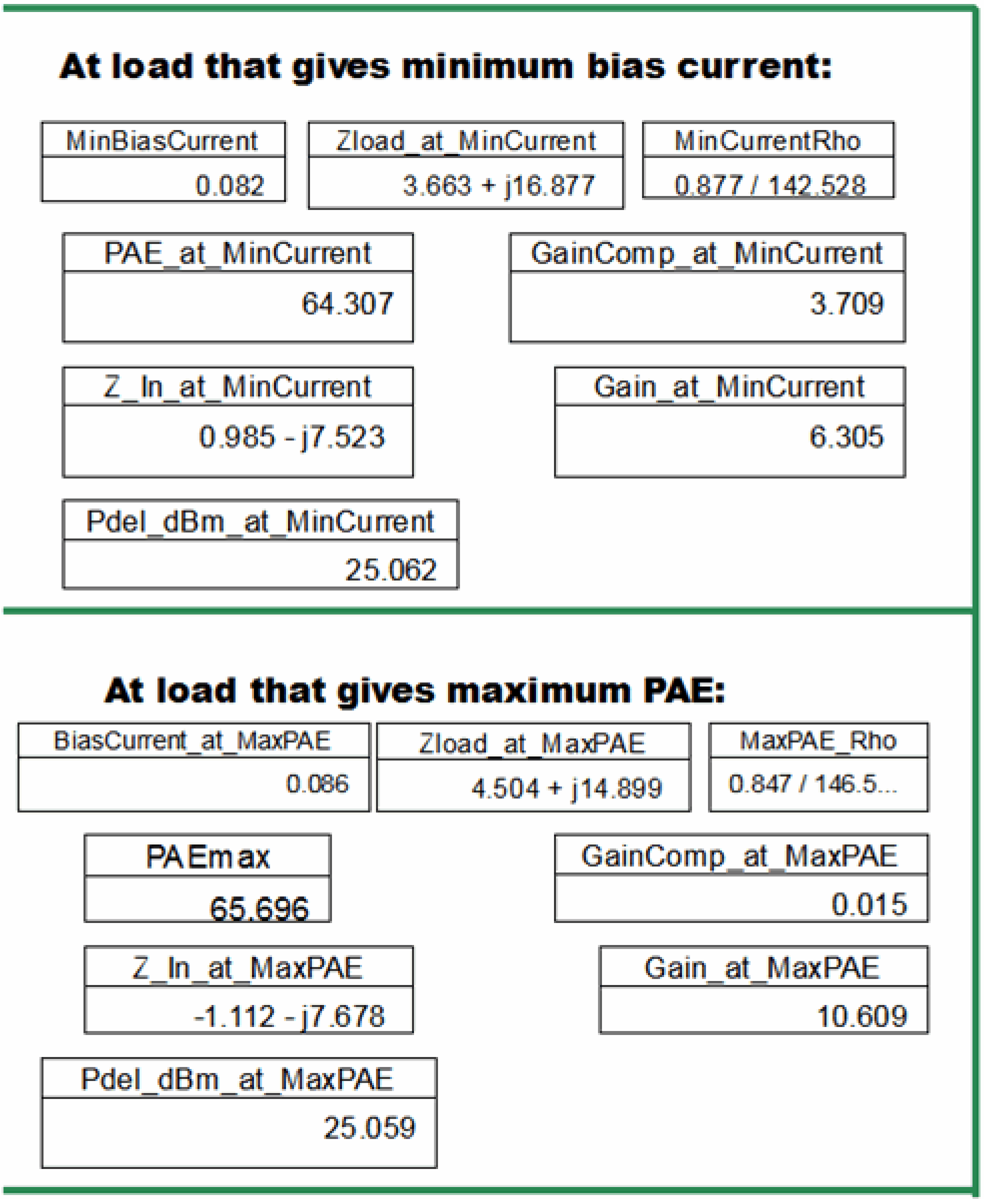
You have to assign the swept variable *SweepVar* to some parameter on the schematic as well as set its sweep limits. In this case, the gate bias voltage `V_Bias1` will be swept from 1.5 to 2.25 Volts. After running the optimization, open the **HB1Tone_LoadPull_ConstPdel_Sweep** data display and make sure the default dataset name is set to the name of the dataset the simulation just created.



All the data is now indexed to the swept parameter value, which you select by moving the *SweepIndx* marker. There is a change in the power-added efficiency as you change the bias voltage.



The above figure displays the data with swept variable (gate bias) set to 2.25 Volts.

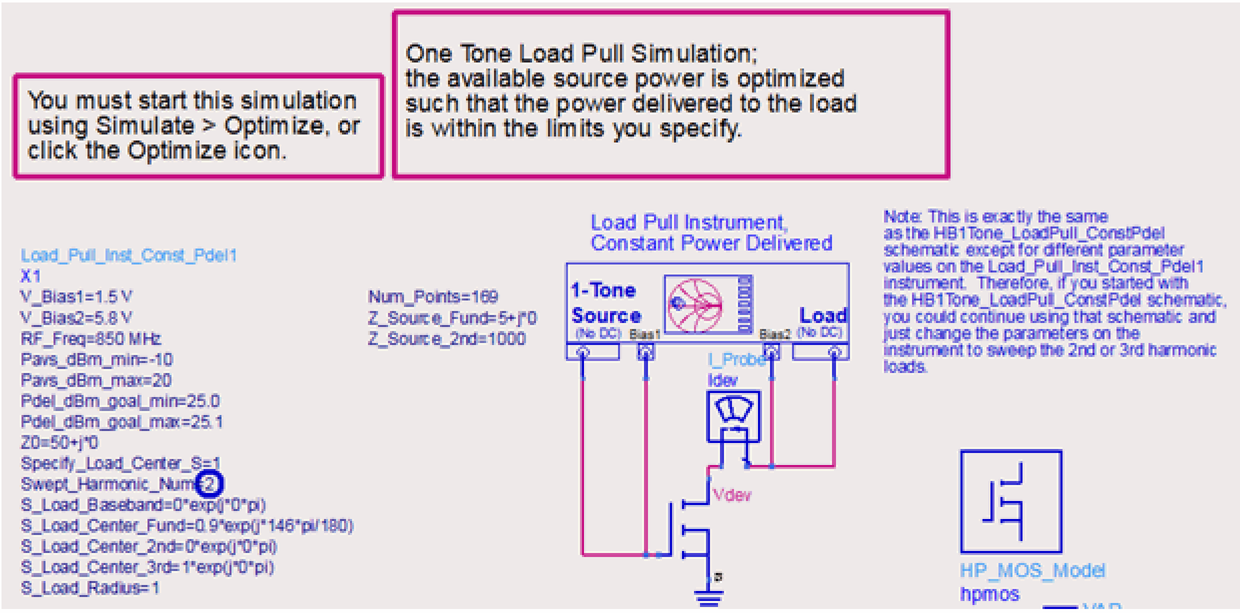


The above figure displays the data with swept variable (gate bias) set to 1.5 Volts.

When the *GainComp* values are negative, it means gain expansion is occurring. This could be because the device is biased off or at a low bias current and that this bias point shifts when a large enough signal is applied.

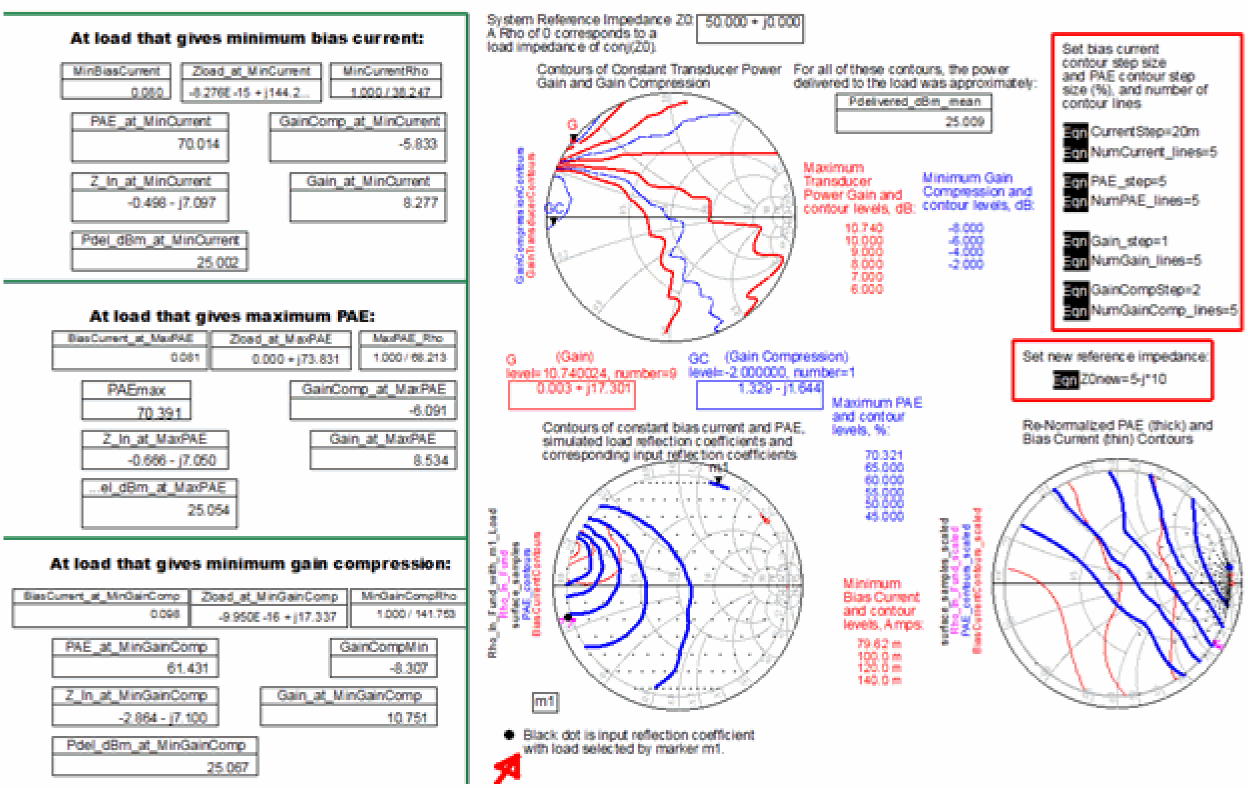
One Tone, Constant Power Delivered 2nd Harmonic Load Pull

The **One Tone, Constant Power Delivered 2nd Harmonic Loadpull (HB1Tone_2ndHarmLoadPull_ConstPdel)** simulation runs a load pull in which the load at the fundamental frequency is held constant and the load at the 2nd harmonic is allowed to vary. As above, the available source power is optimized until the desired power is delivered to the load. The second harmonic may only have a significant effect on the performances of devices being driven well into compression. This simulation is identical to other load pull simulations, except that the load impedance at the second harmonic frequency is swept.



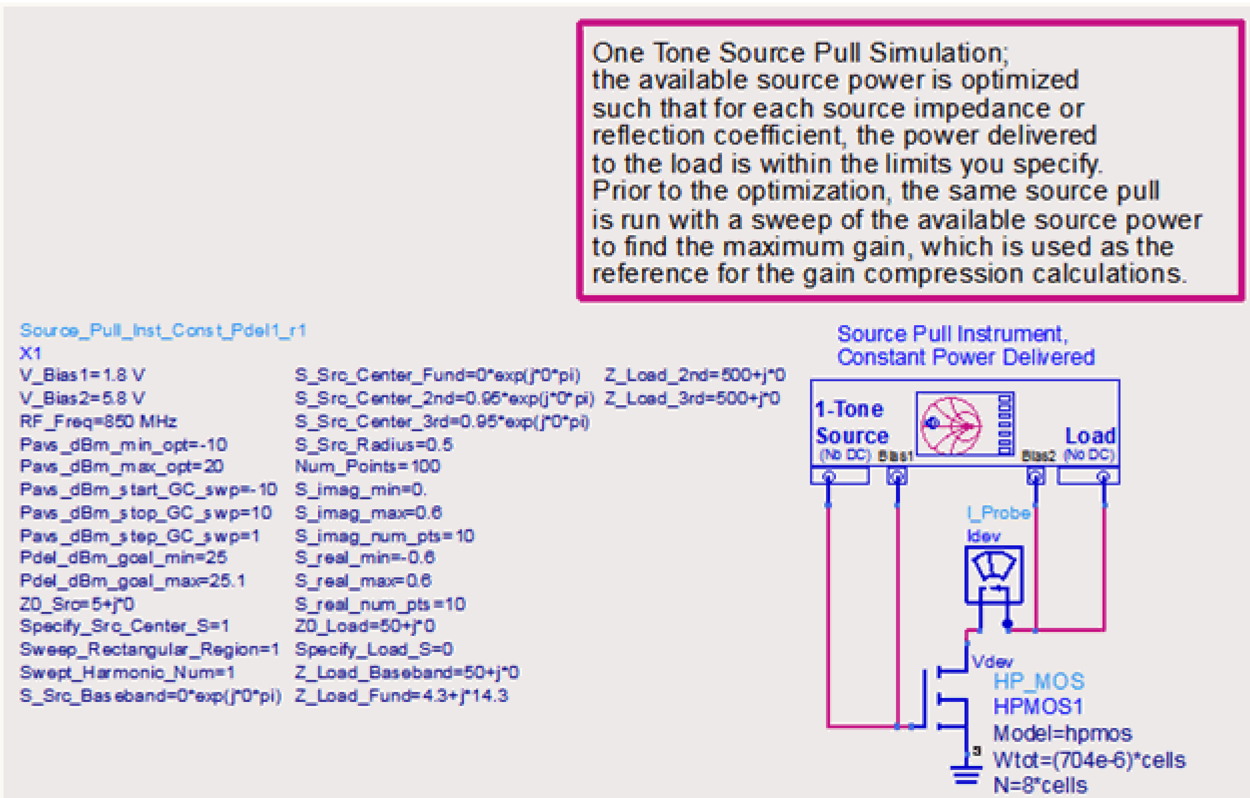
This schematic is identical to the corresponding one for a load pull at the fundamental except that now the `Swept_Harmonic_Num` variable is set to 2 instead of 1. (In fact, you could just use the schematic set up for the fundamental sweep, instead of this one.) Since we are sweeping the impedance at the second harmonic frequency, the load at the fundamental frequency will be fixed at `S_Load_Center_Fund` or `Z_Load_Center_Fund`. The further into compression the device is being driven or the more non-linearly it is operating, the larger the effect of the second harmonic impedance.

The variation in performance due to the 2nd harmonic impedance may be small.



One Tone, Constant Power Delivered Source Pull

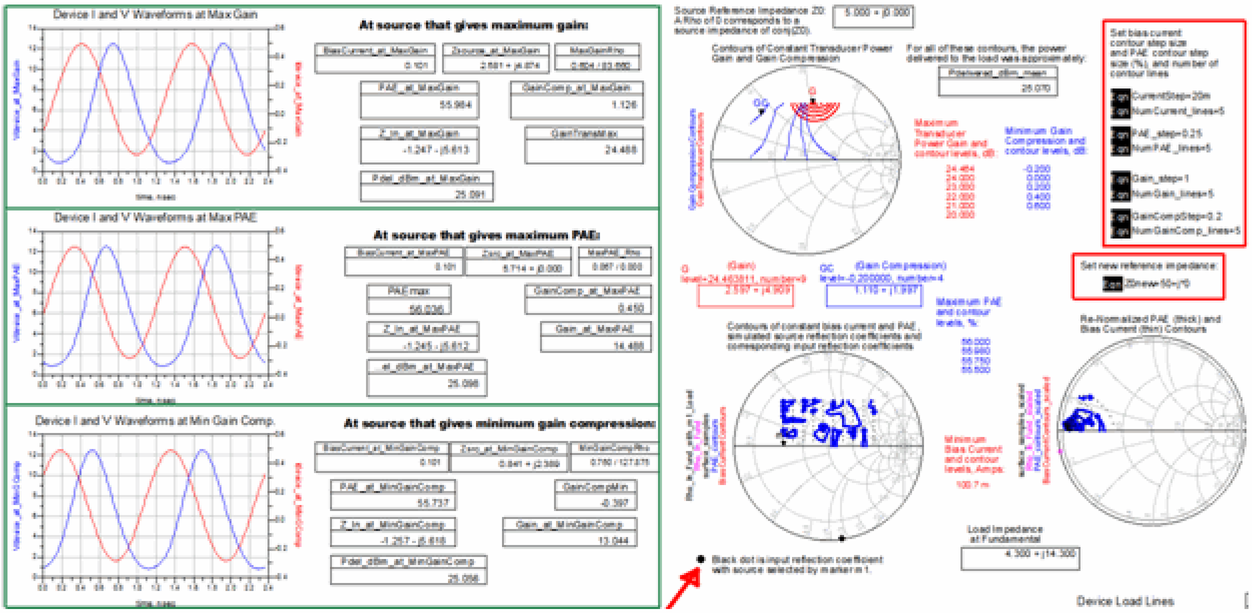
The **One Tone, Constant Power Delivered Source Pull (HB1Tone_SourcePull_ConstPdel)** simulation is most useful for determining the optimal source impedance to present to a device. The source impedance should mostly affect the gain and gain compression. This setup sweeps the source reflection coefficient in a circular or rectangular region of the Smith Chart and optimizes the source power level for each source reflection coefficient until the desired power is delivered to the load. The data display shows contours of constant PAE, gain, and gain compression. This allows you to pick the optimal source that produces the best PAE, gain, or gain compression, or make trade-offs amongst these specifications.



Relative to the other constant power delivered simulation schematics above, the only difference is that you have to specify the constant load impedance at the fundamental frequency, instead of the source impedance. You may also specify different load and source impedances at the harmonic frequencies. Typically, you would first run a load pull simulation to determine the fundamental load impedance to use here.

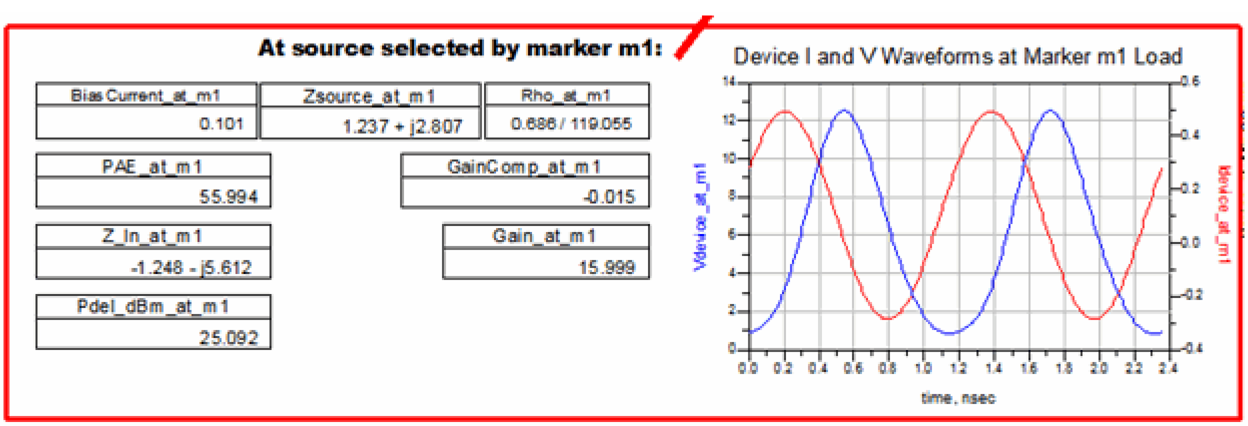
To launch the simulation, click the *Optimize*  icon. If the simulation is started by hitting the F7 key or by selecting **Simulate > Simulate**, then an optimization is not executed and the simulation results are not displayed correctly in the data display.

After running the optimization, the **HB1Tone_SourcePull_ConstPdel** data display shows the results.



To see the contours effectively, you may need to change the PAE_step, Gain_step, and GainCompStep variables. These set the step sizes between the contours.
The upper Smith Chart shows contours of constant gain and gain compression. The lower left Smith Chart shows contours of constant power-added efficiency (PAE), which may not vary much, as well as the simulated source reflection coefficients and the corresponding input reflection coefficients, which may be just a single point since they should not depend on the source impedance. The lower right Smith Chart shows the same data on a Smith Chart with a different reference impedance.
In the boxes on the left side are data that correspond to a particular optimal condition such as maximum gain, maximum PAE, or minimum gain compression. However, you have to make sure that the desired power delivered was actually achieved.

The source that corresponds to the maximum gain is very nearly satisfying the conditions for oscillation at the input (Z_In_at_MaxGain+Zsource_at_MaxGain =0, approximately), so you would want to avoid setting the source impedance to this value or you would want to add some sort of stabilization network around the device.
You also have the option of selecting any of the simulated source reflection coefficients with marker m1. The corresponding data appear in a separate box.



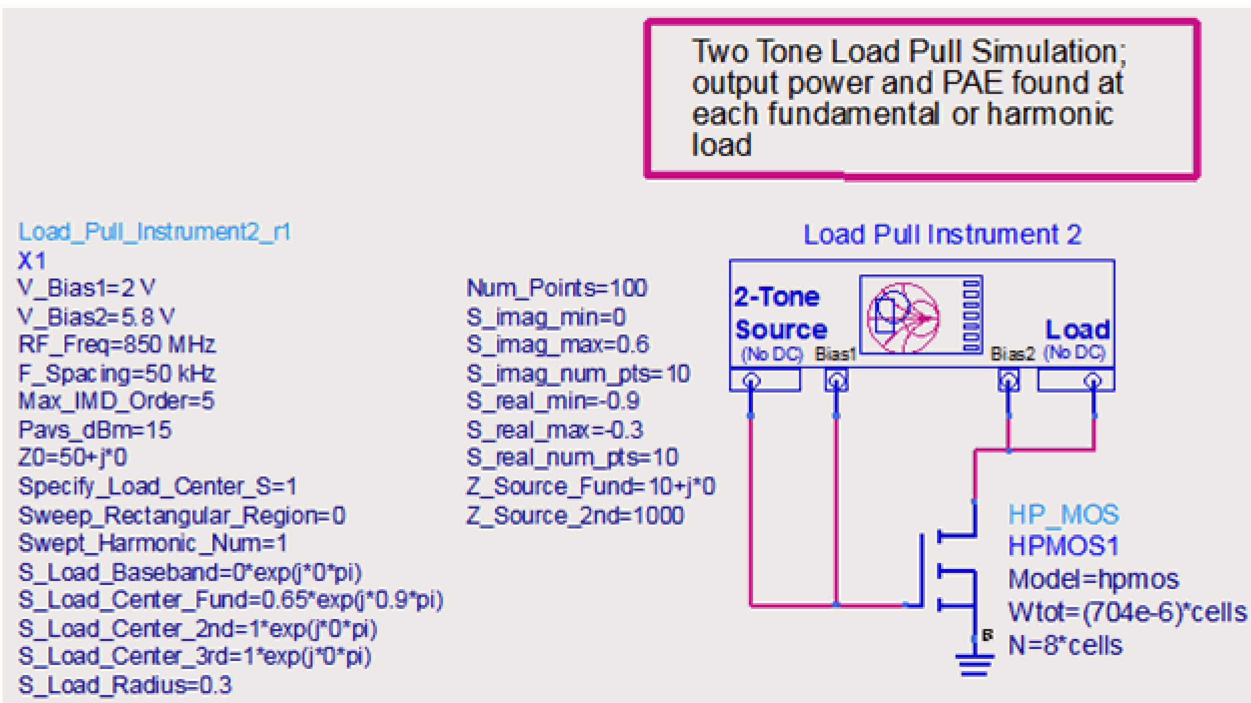
The above figure shows the performance data corresponding to the source impedance selected by marker m1. This enables you to see potential trade-offs. As you move away from the maximum gain source impedance, the gain drops rapidly.

Two Tone Simulation

Contents

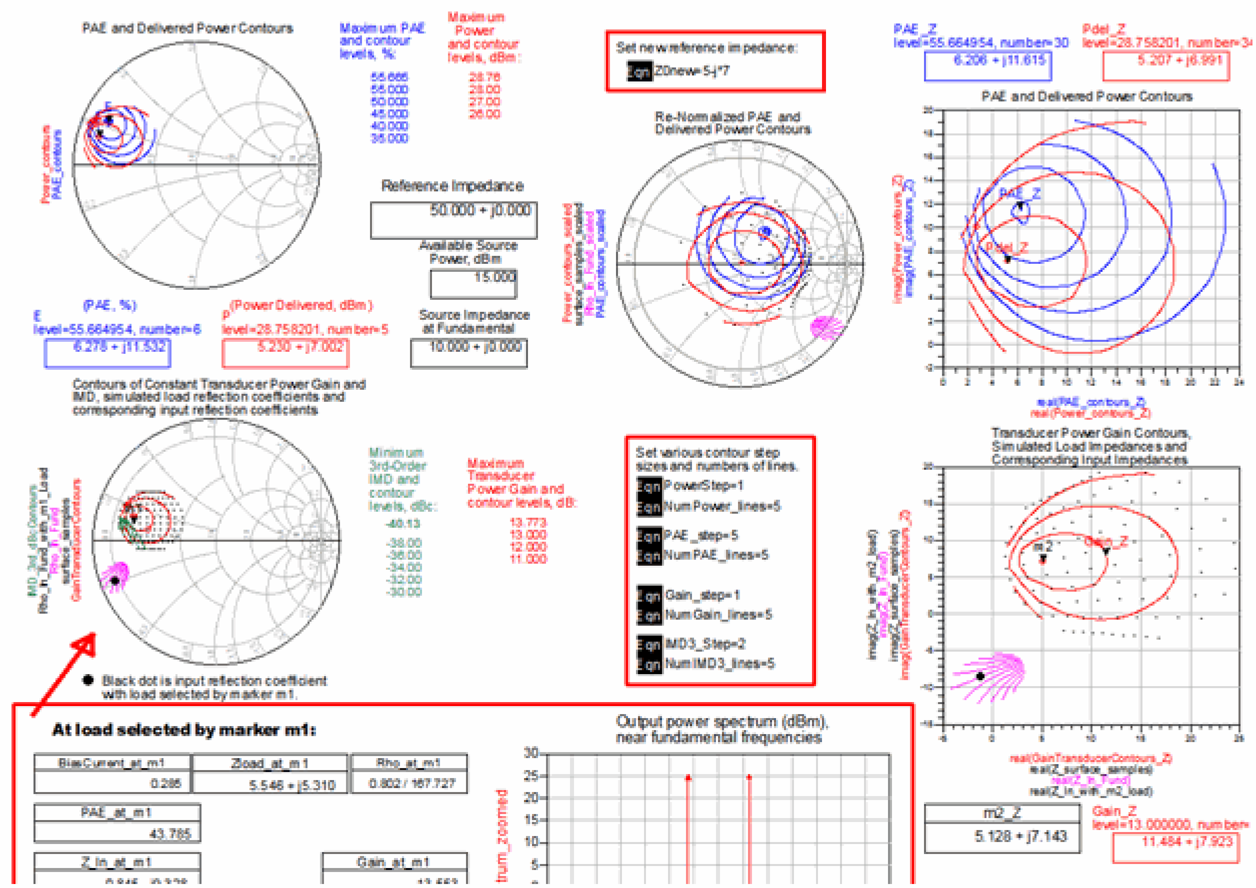
Two Tone, Constant Available Source Power Load Pull

This simulation setup and data display is identical to the "One Tone" version, except that now two tones are supplied instead of one. A two tone test signal stresses the device more because of its much higher peak-to-average ratio. The data display from this simulation shows the same information as shown in the one-tone version and also includes intermodulation distortion.



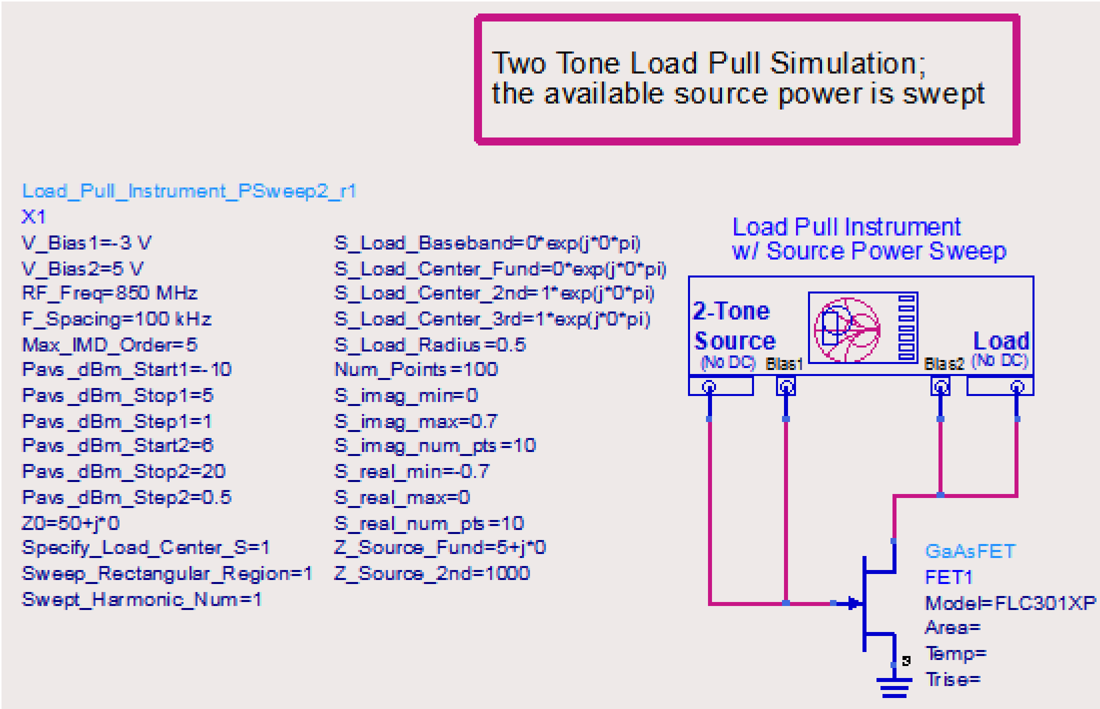
Here also you have to replace the sample device with yours and adjust the bias voltages as needed. In addition to all the other variables that you must specify as before, you need to specify the following two variables:

1. Frequency spacing between the two tones `F_Spacing`.
2. Maximum order of intermodulation distortion tones to be included in the simulation `Max_IMD_Order`.
   The simulation results include similar information as shown above, with the addition of intermodulation distortion.



Two Tone, Swept Available Source Power Load Pull

This simulation setup and data display is identical to the "One Tone" version, except that now two tones are supplied instead of one. A two tone test signal stresses the device more because of its much higher peak-to-average ratio. The data display from this simulation shows the same information as shown in the one-tone version and also includes intermodulation distortion.



Here also you have to replace the sample device with yours and adjust the bias voltages as needed. In addition to all the other variables that you must specify as before, you need to specify the following two variables:

1. Frequency spacing between the two tones `F_Spacing`.
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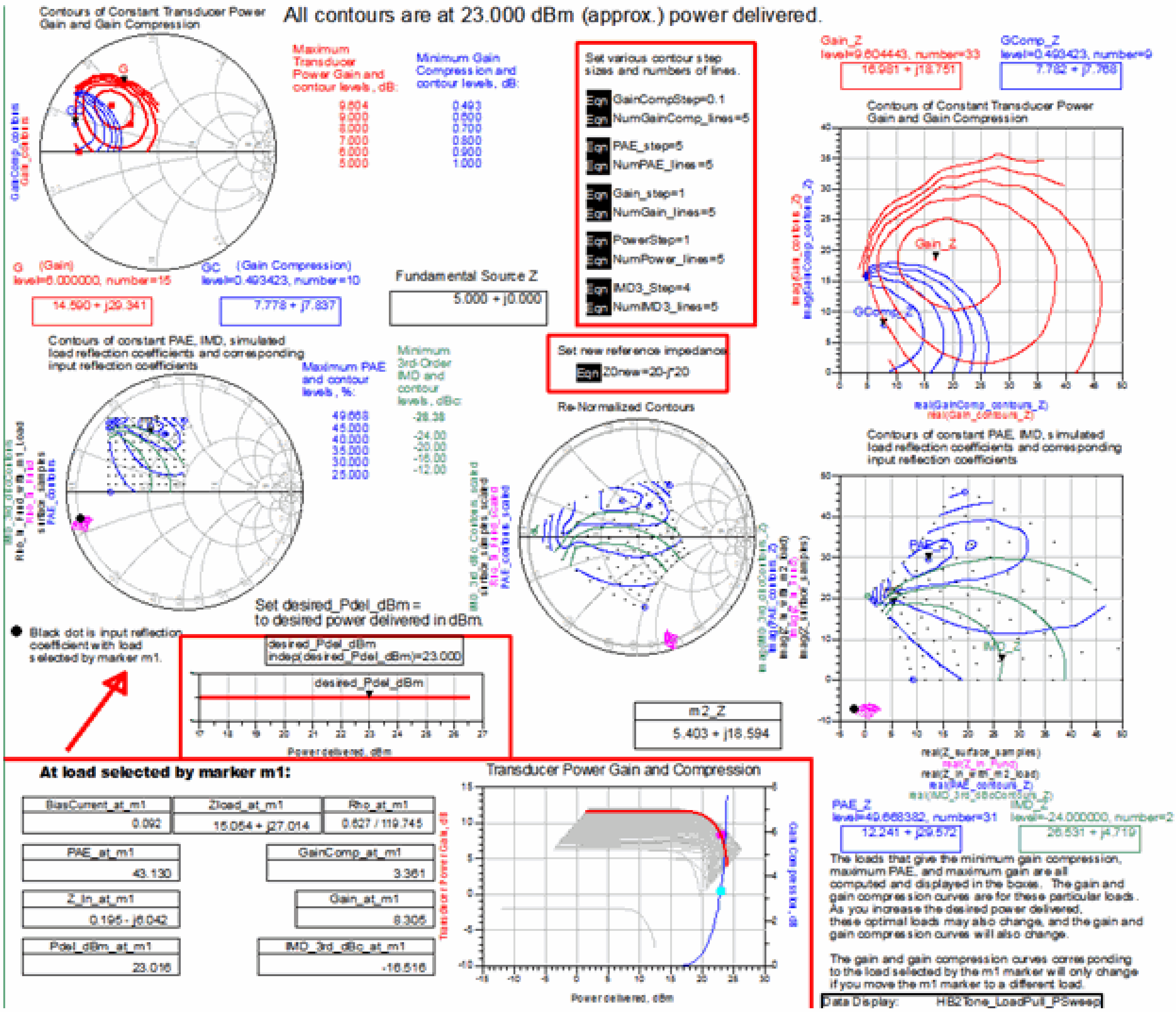
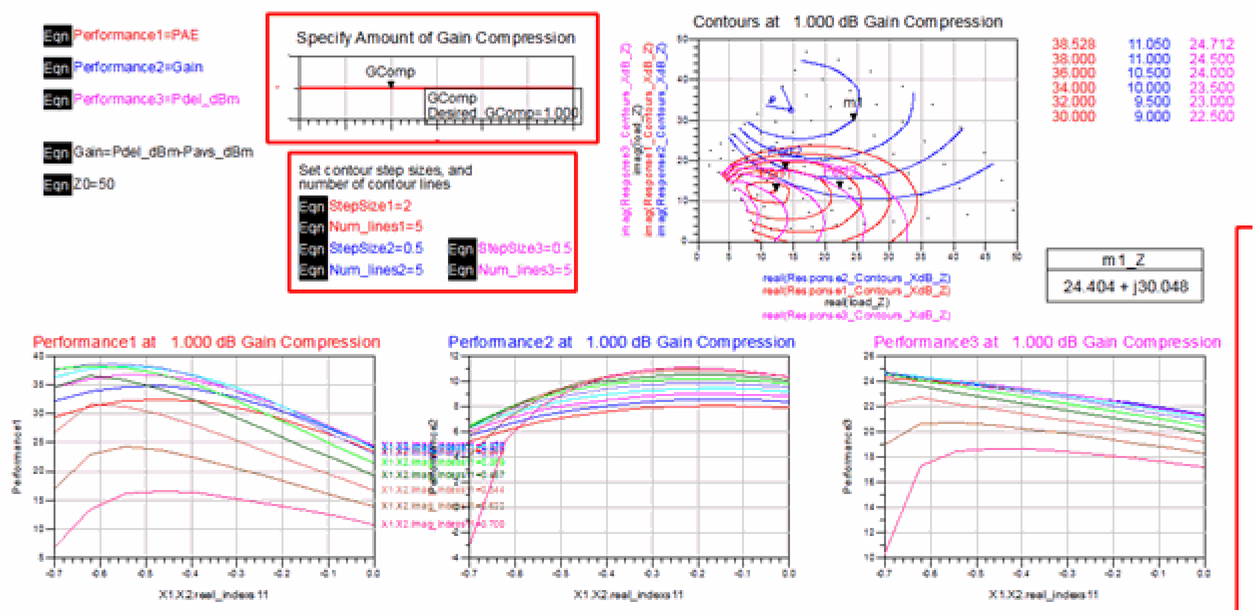
The simulation results include similar information as shown above, with the addition of intermodulation distortion.



From the same swept-power simulation results, you may see gain compression contours by selecting **DesignGuide > Load Pull > Display Contours at X-dB Gain Compression**. Note that there are two such menu picks. The lower one is for displaying results from a two-tone simulation, whereas the upper one is for a one-tone simulation.

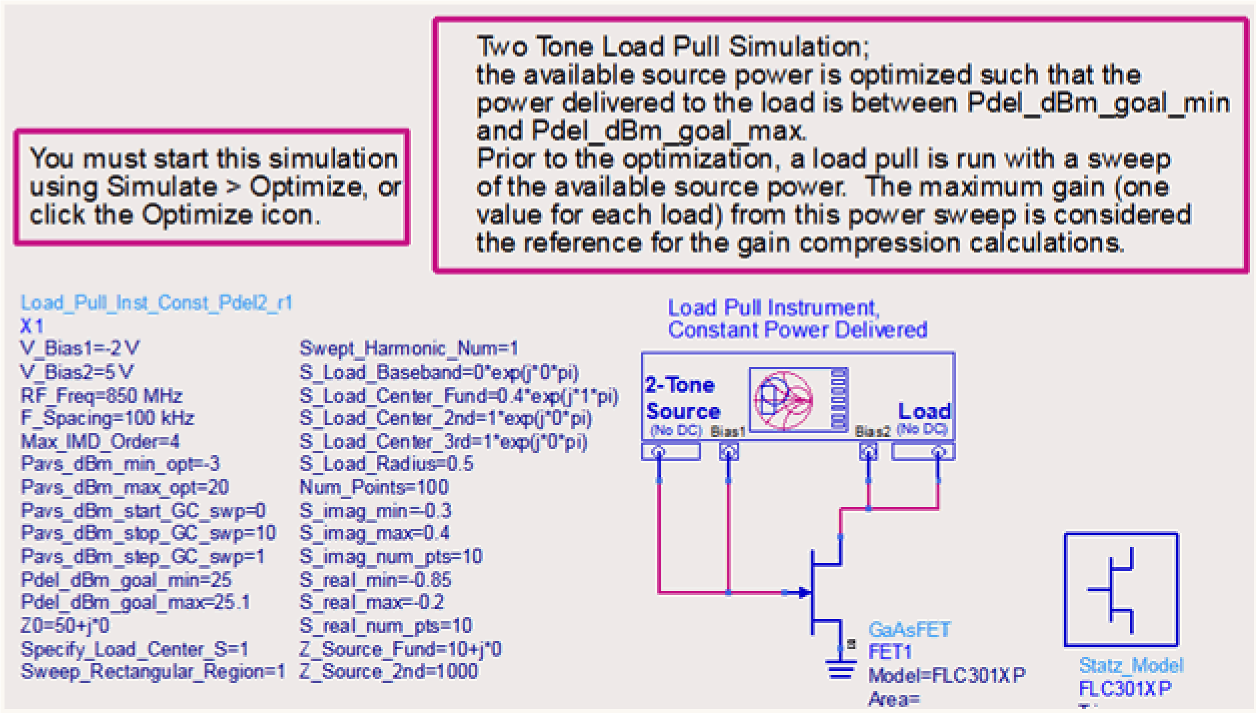


In the data display, you specify the performances (in this case, PAE, Gain, and Pdel_dBm) you want to contour, the amount of gain compression by moving the GComp marker and the step size and number of contour lines. For some reflection coefficients, the input power sweep may not produce the desired amount of gain compression. In these cases, where Allow_extrapolation=”No”, the responses are set to 0. You may deal with this situation by re-running the simulation with the input power swept to a higher level.

Two Tone, Constant Power Delivered Load Pull

This simulation setup and data display is identical to the "One Tone" version, except that now two tones are supplied instead of one. A two tone test signal stresses the device more because of its much higher peak-to-average ratio. The data display from this simulation shows the same information as shown in the one-tone version and also includes intermodulation distortion.

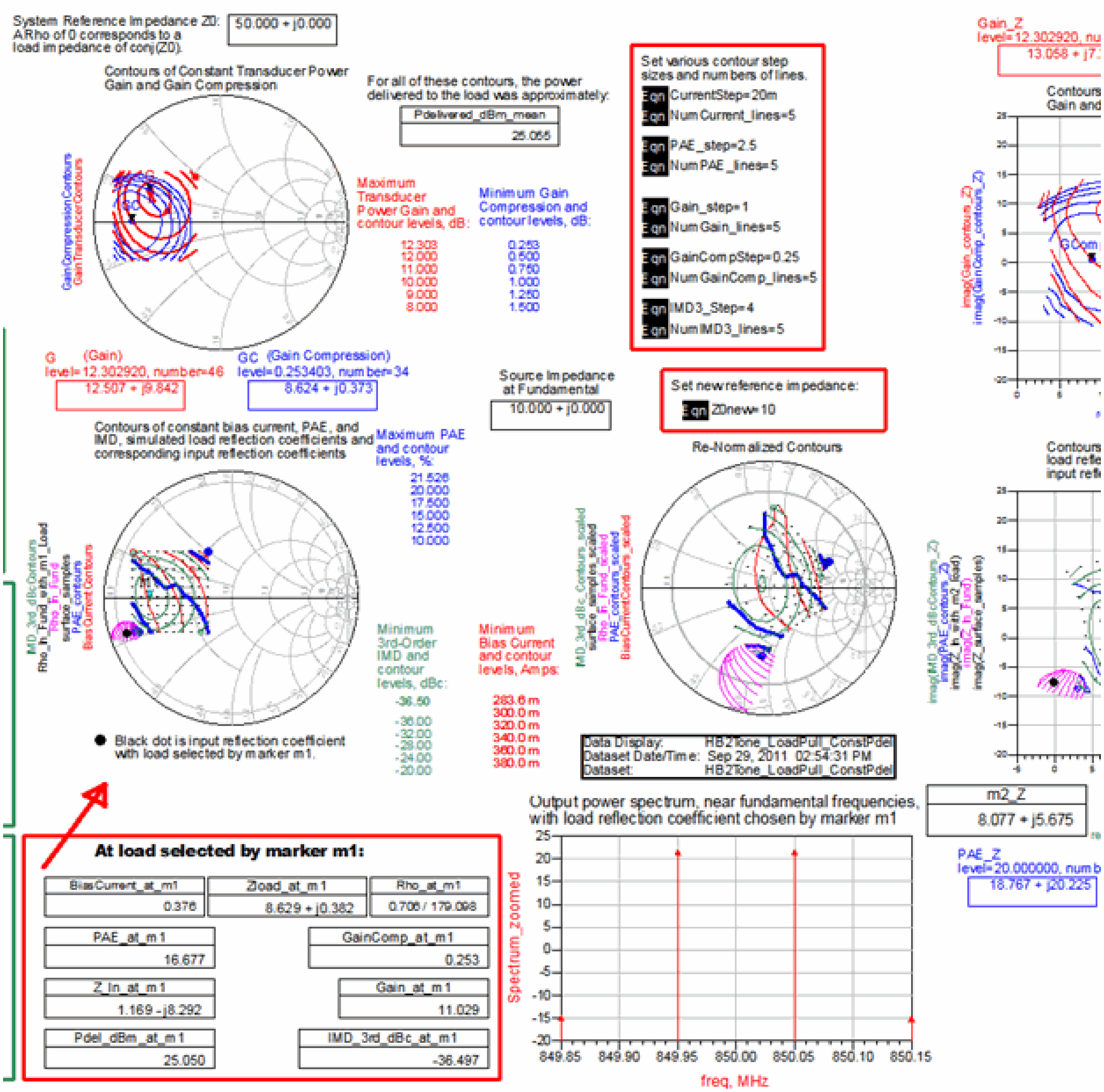
A different device is used here.



Here also you have to replace the sample device with yours and adjust the bias voltages as needed. In addition to all the other variables that you must specify as before, you need to specify the following two variables:

1. Frequency spacing between the two tones `F_Spacing`.
2. Maximum order of intermodulation distortion tones to be included in the simulation `Max_IMD_Order`.

The simulation results include similar information as shown above, with the addition of intermodulation distortion.



There is a clear trade-off between PAE and distortion. For this bias point, if you want maximum PAE, you suffer a lot of gain compression and intermodulation distortion.

At load that gives maximum PAE:

BiasCurrent_at_MaxPAE	Zload_at_MaxPAE	MaxPAE_Rho
0.283	25.000 + j25.000	0.447 / 116.5...

PAEmax	GainComp_at_MaxPAE
21.547	4.440

Z_In_at_MaxPAE	Gain_at_MaxPAE
1.212 - j6.051	8.427

...el_dBm_at_MaxPAE	IMD_3rd_dBc_at_MaxPAE
25.040	-16.490

Tolerating a lower PAE allows much lower gain compression and intermodulation distortion.

At load that gives minimum 3rd-order IMD:

BiasCurrent_at_MinIMD3	Zload_at_MinIMD3	MinIMD3_Rho
0.376	8.629 + j0.382	0.706 / 179.098

PAE_at_MinIMD3	GainComp_at_MinIMD3
16.677	0.253

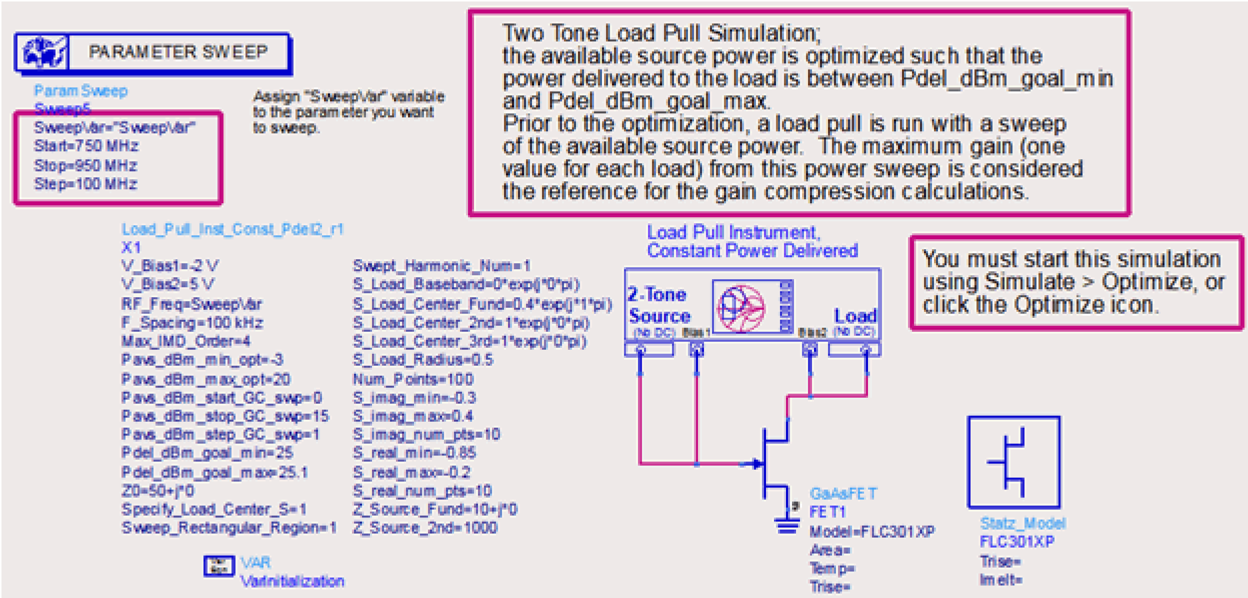
Z_In_at_MinIMD3	Gain_at_MinIMD3
1.169 - j8.292	11.029

Pdel_dBm_at_MinIMD3	IMD_3rd_dBcMin
25.050	-36.497

Two Tone, Constant Power Delivered Load Pull with Swept Parameter

This simulation setup and data display are identical to the "One Tone" version, except that now two tones are supplied instead of one. A two tone test signal stresses the device more because of its much higher peak-to-average ratio. The data display from this simulation shows the same information as shown in the one-tone version and also includes intermodulation distortion.

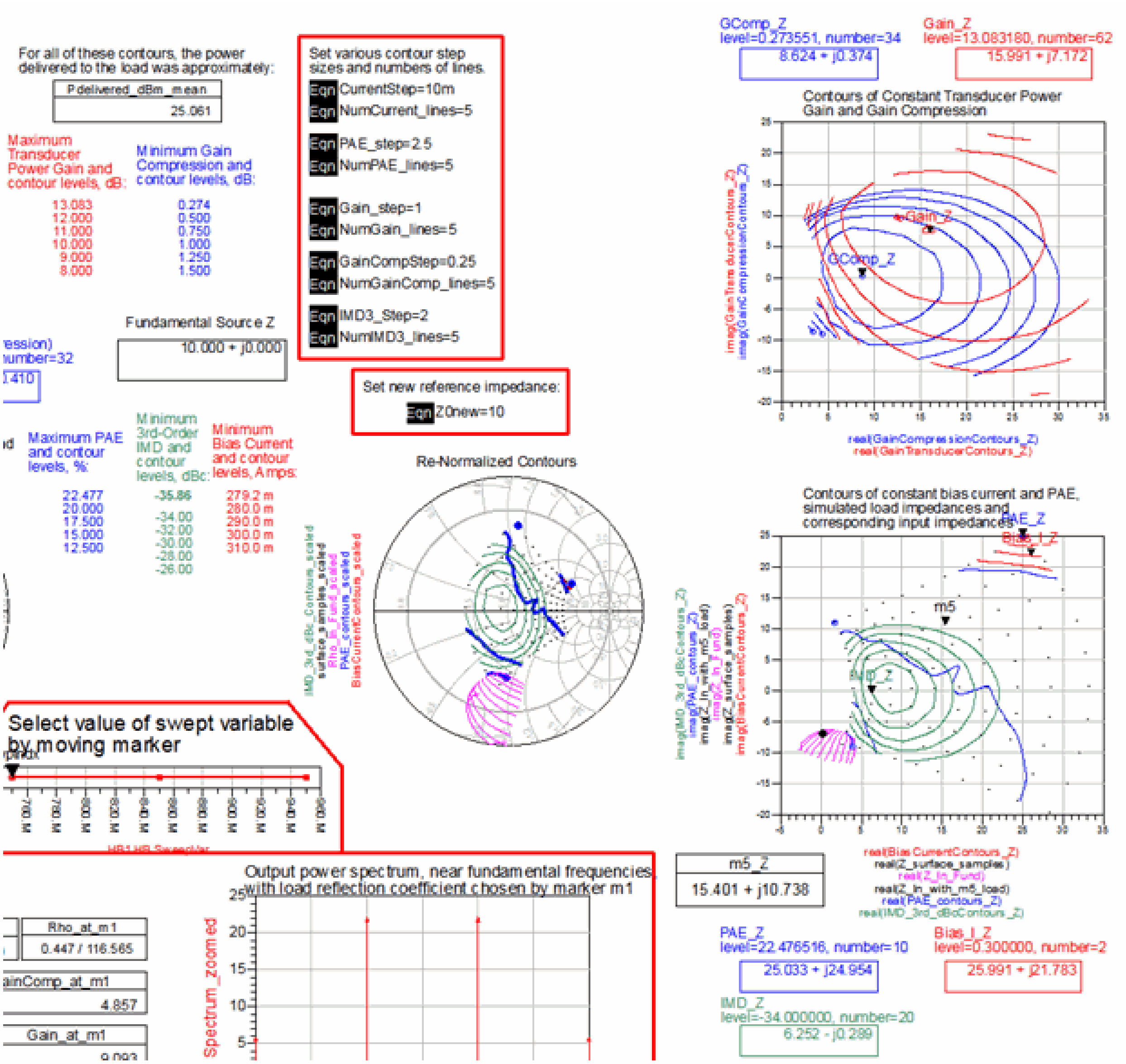
A different device is used here.



Here also you have to replace the sample device with yours and adjust the bias voltages as needed. You have to assign the swept variable SweepVar to some parameter on the schematic. In addition to all the other variables that you must specify as before, you need to specify the following two variables:

1. Frequency spacing between the two tones `F_Spacing`.
2. Maximum order of intermodulation distortion tones to be included in the simulation `Max_IMD_Order`.

The simulation results include similar information as shown above, with the addition of intermodulation distortion.



There is a clear trade-off between PAE and distortion. For this bias point, if you want maximum PAE, you suffer a lot of gain compression and intermodulation distortion.

WCDMA Signal Simulation

WCDMA uses a source with WCDMA modulation instead of one or two sinusoids. The adjacent channel power ratios are computed in addition to other performances such as gain, gain compression, and PAE. These simulations take longer to run, so you might want to run at least one of the one- or two-tone simulations above first.

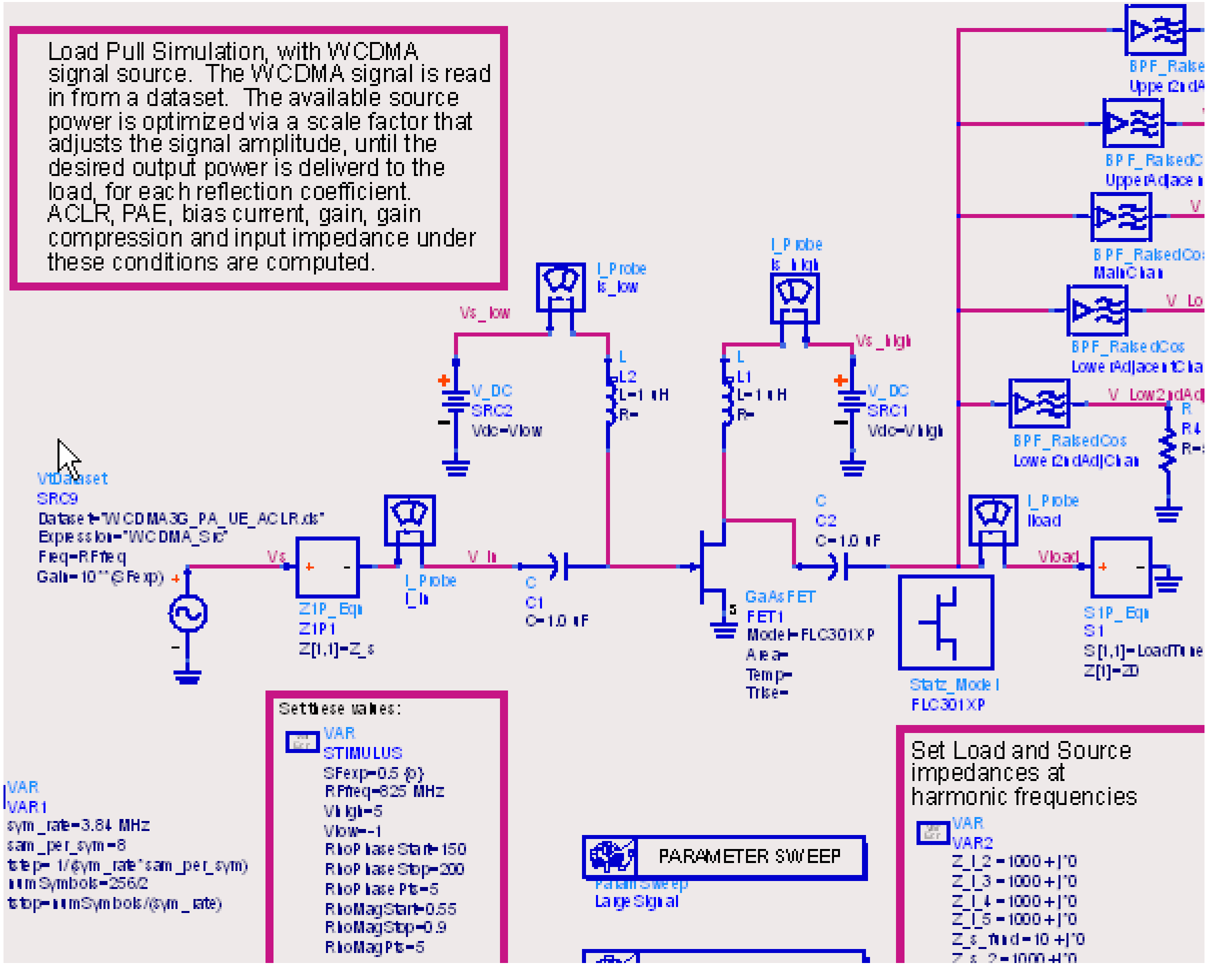
Select **WCDMA Load Pull > Constant Power Delivered, Mag/Phase Load Pull** to copy WCDMA_LoadPullMagPh_ConstPdel schematic and corresponding data display into your workspace.

This setup sweeps the load reflection coefficient in a fan-shaped region of the Smith Chart and optimizes the source power level for each load reflection coefficient until the desired power is delivered to the load. The source is a WCDMA signal read in from a dataset, and its amplitude (and thus the available source power) is set by a variable, *SFexp*, and the gain applied to this signal is 10**(*SFexp*). The WCDMA signal was generated by connecting a Timed Sink to the output of the signal source in the ADS example `examples/WCDMA3G/WCDMA3G_PA_Test_wrk/WCDMA3G_PA_UE_ACLR` schematic.

The load pull is performed twice.

1. In first case, *SFexp* is set to 0.01. This is assumed to make the input signal small enough that the amplifier is operating linearly. The gain under this condition for each load reflection coefficient is the reference used to compute the gain compression.
2. In second case, *SFexp* is optimized until the desired power is delivered to the load.

The data display shows contours of constant PAE, ACLR, bias current, gain, and gain compression. The input reflection coefficient is also shown for a particular load that you specify. This allows you to pick the optimal load that produces the best PAE, ACLR, gain compression, or bias current, or make trade-offs among these specifications.



When using this schematic, there are a number of different things you need to specify, and these are listed in a paragraph on the schematic. First, you would replace the device with your device or amplifier. You have to set the bias voltages or modify the bias network, as needed. However, the data display calculates the DC power consumption assuming current probe *Is_low* is connected to supply voltage node *Vs_low* and current probe *Is_high* is connected to supply voltage node *Vs_high*. If you delete any of these or re-name them, you will have to modify the equations like **Is_highDC=mean(Is_high.i[0])** and the *Pdc* equation on the schematic.

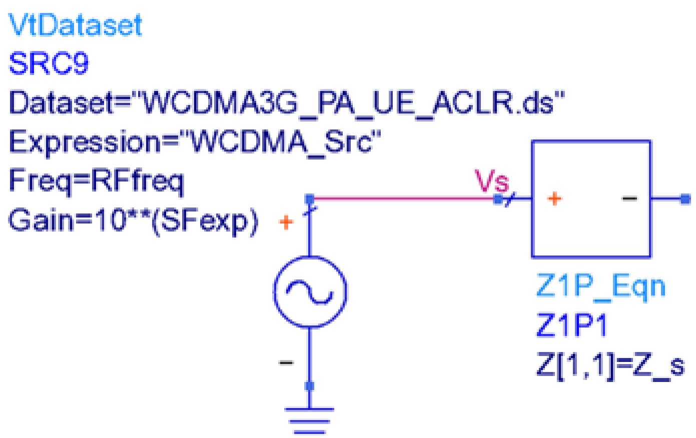
You have to specify the range of phases and magnitudes of the reflection coefficients. The total simulation time will increase linearly with the product of the numbers of phases and magnitudes simulated. The tradeoff is that you should get better contour lines with more points simulated.

```
RhoPhaseStart=150
RhoPhaseStop=200
RhoPhasePts=6
RhoMagStart=0.55
RhoMagStop=0.9
RhoMagPts=5
```

If the device or amplifier is potentially unstable and the region of reflection coefficients that you specify includes the unstable region, the simulation may run into convergence problems. This would be due to the device wanting to oscillate. A solution to this problem is to add stabilizing components at the input, output, or in parallel with the device. You may want to use a simulation setup for this purpose, **DesignGuide > Amplifier > S-Parameter Simulations > Feedback Network Optimization to Attain Stability**. Another solution is to specify the range of reflection coefficients such that the unstable region is avoided.

You also have to specify the reference impedance, *Z0*, and the source center frequency, *RFfreq*.

You have to specify the nominal and allowed range of the signal source gain scale factor exponent, *SFexp*. It is necessary to adjust this gain to set the available source power, because we are using a voltage source to generate the signal.



It is not obvious what the relationship is between this exponent and the available source power. However, the *WCDMA_SrcTest* schematic in the same workspace allows you to sweep this scale factor and calculate the corresponding available source power. In this case, stepping *SFexp* from -1 to 1 increases the available source power from about -20 dBm to +20 dBm. This does vary with the source impedance you specify.

When setting the range of *SFexp* values, you want the highest *SFexp* value to correspond to the maximum available source power you will accept. For example, if you want to deliver 27 dBm to the load and you want the device to provide at least 7 dB of transducer power gain, you would set the maximum value of *SFexp* to correspond to an available source power of approximately 20 dBm. The optimization will run fastest if *SFexp* is allowed to vary over a relatively large range, but with the nominal value close to the value needed to give you the desired output power. You may get extremely high gain compression values for some reflection coefficients near the edge of the Smith Chart.

Figure: Prior to starting on-screen editing

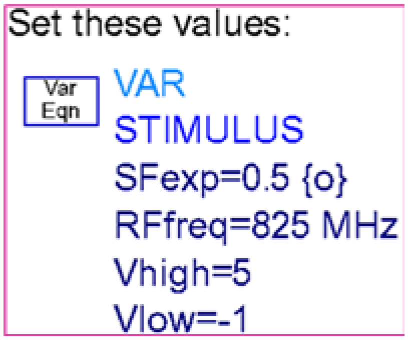
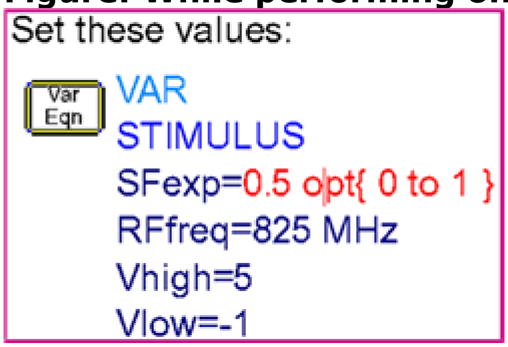


Figure: While performing on-screen editing



During the optimization, this variable is adjusted within the limits until the power that you want is delivered to the load.

You specify the desired power to be delivered to the load in *OptimGoal1*.

In this case, we want the power delivered to be within 0.25 dB of 27 dBm. You may also specify different load and source impedances at the harmonic frequencies and (for the source) at the fundamental frequency.

Set Load and Source impedances at harmonic frequencies

```
Var Eqn  VAR
         VAR2
         Z_l_2 =1000 + j*0
         Z_l_3 =1000 + j*0
         Z_l_4 =1000 + j*0
         Z_l_5 =1000 + j*0
         Z_s_fund =10 + j*0
         Z_s_2 =1000 +j*0
         Z_s_3 =1000 + j*0
         Z_s_4 =1000 + j*0
         Z_s_5 =1000 + j*0
```

There is a bank of raised cosine filters connected to the output node. These are used to compute the upper and lower adjacent and second adjacent channel leakage ratios. If you modify this setup to simulate a signal corresponding to a different standard (non-WCDMA, for example) then you most likely will need to modify the filter parameters and the channel frequency limits, which are specified as an offset from the carrier center frequency, *RFfreq*.

```
Meas Eqn  MeasEqn
          meas1
          Up2ndAdjLimits=mainlimits+(10 MHz)
          UpAdjLimits=mainlimits+(5 MHz)
          mainlimits={(-3.84 MHz)/2,(3.84 MHz)/2}
          LowAdjLimits=mainlimits-(5 MHz)
          Low2ndAdjLimits=mainlimits-(10 MHz)
```

As mentioned above the simulation time is directly proportional to the total number of different load reflection coefficients. It also depends directly on the number of symbols simulated at each load. When initially exploring the Smith Chart to find an approximate optimal load, it might be useful to run the simulation with a relatively small number of symbols. Later, after determining a smaller, optimal region of the Smith Chart, you might want to increase the number of symbols to get more accurate results.

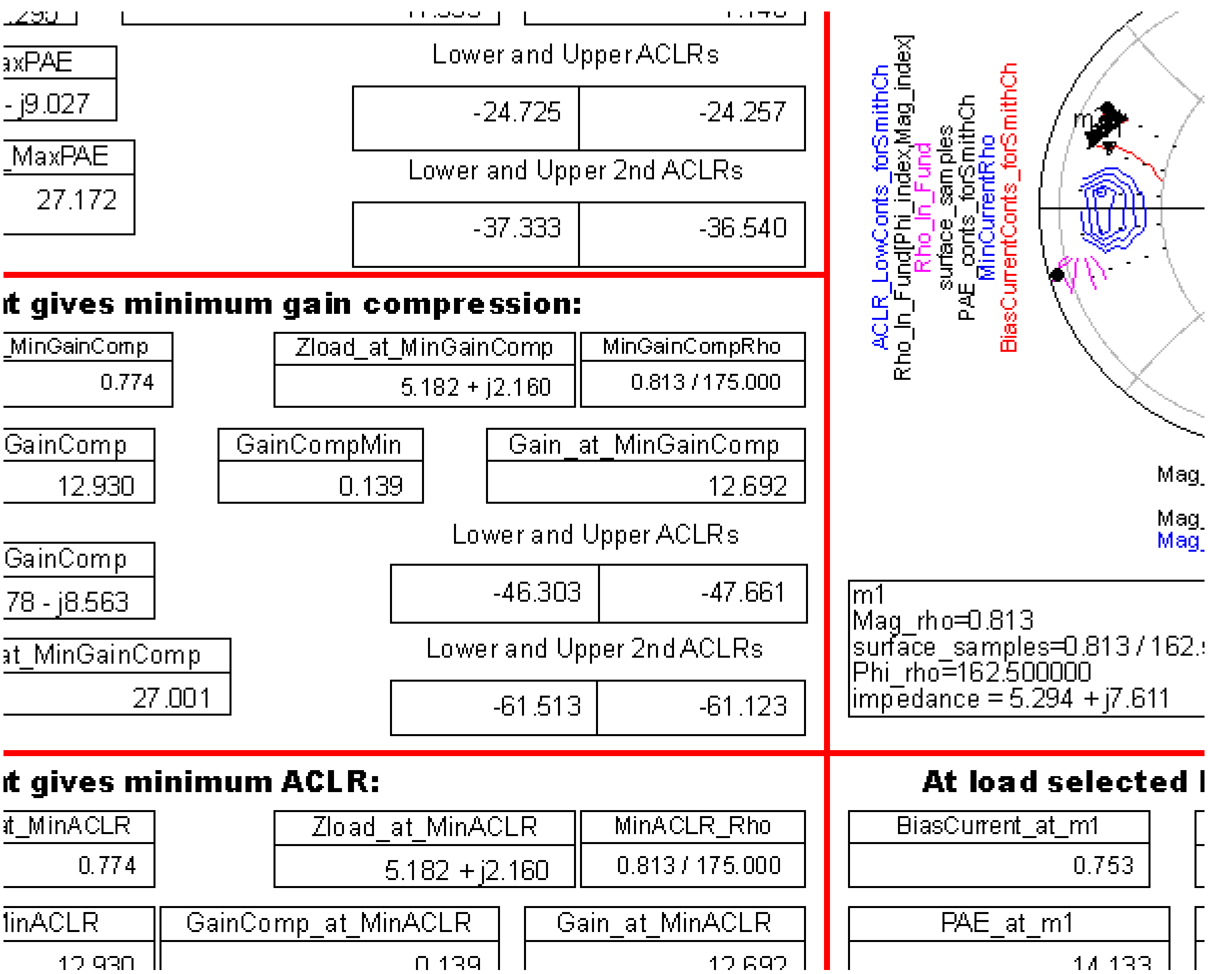
```
Var Eqn  VAR
         VAR1
         sym_rate=3.84 MHz
         sam_per_sym=8
         tstep= 1/(sym_rate*sam_per_sym)
         numSymbols=256/2
         tstop=numSymbols/(sym_rate)
```

If using a data file as the source, setting the simulation time step *tstep* equal to the time step in the data file is good, to minimize effects that may arise due to interpolation.

The Envelope analysis includes a *SweepOffset*. This simulates but does not keep the first 12 symbols in the simulation during which the input signal amplitude is ramping on. If you want to include this turn-on ramp data in the post-processing computations, just set **SweepOffset=0**.

Because the simulation includes an optimization, click *Optimize* icon to launch the simulation. If instead you just launch the simulation by hitting the F7 key or selecting **Simulate > Simulate**, an optimization will not be run and the data display will not display the simulation results.

After running the optimization, this *WCDMA_LoadPullMagPh_ConstPdel* data display shows the results.

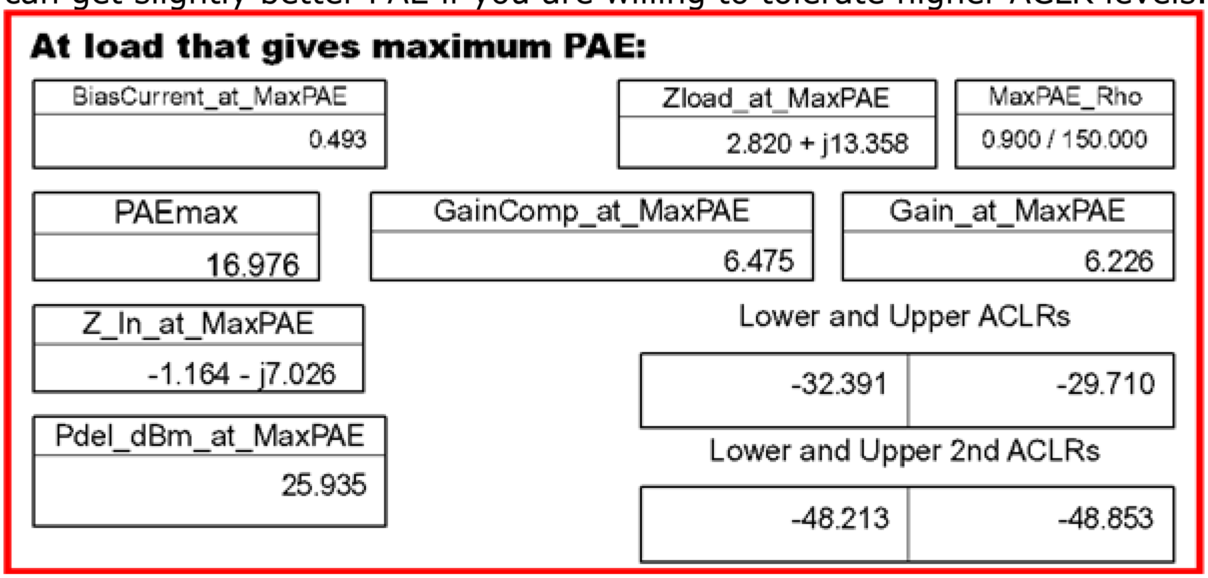


To see the contours effectively, you may need to change the *CurrentStep*, *PAE_step*, *Gain_step*, *GainCompStep*, and *ACLR_step* variables. These set the step sizes between the contours. The bias supply current calculations only include the current in the probe *Is_high*. If you change the name of the current probe, you will need to edit the BiasCurrent equation on the Equations page.

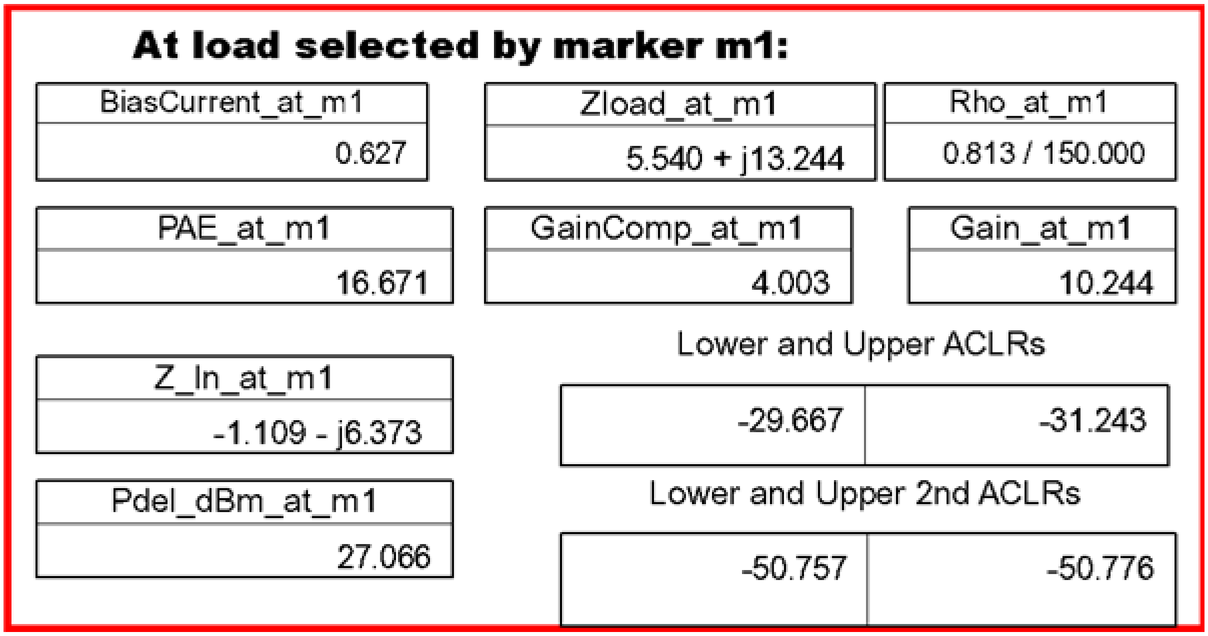
The upper Smith Chart shows contours of constant gain and gain compression. The lower left Smith Chart shows contours of constant bias current, power-added efficiency (PAE), and lower adjacent channel ACLR, as well as the simulated load reflection coefficients and the corresponding input reflection coefficients. The lower right Smith Chart shows the same data on a Smith Chart with a different reference impedance.

In the red boxes on the left side are data that correspond to a particular optimal condition such as minimum bias current, maximum PAE, minimum gain compression, or minimum ACLR. However, you have to make sure that the desired power delivered was actually achieved. In some cases with load reflection coefficients very close to the edge of the Smith Chart, the desired power will not be achieved.

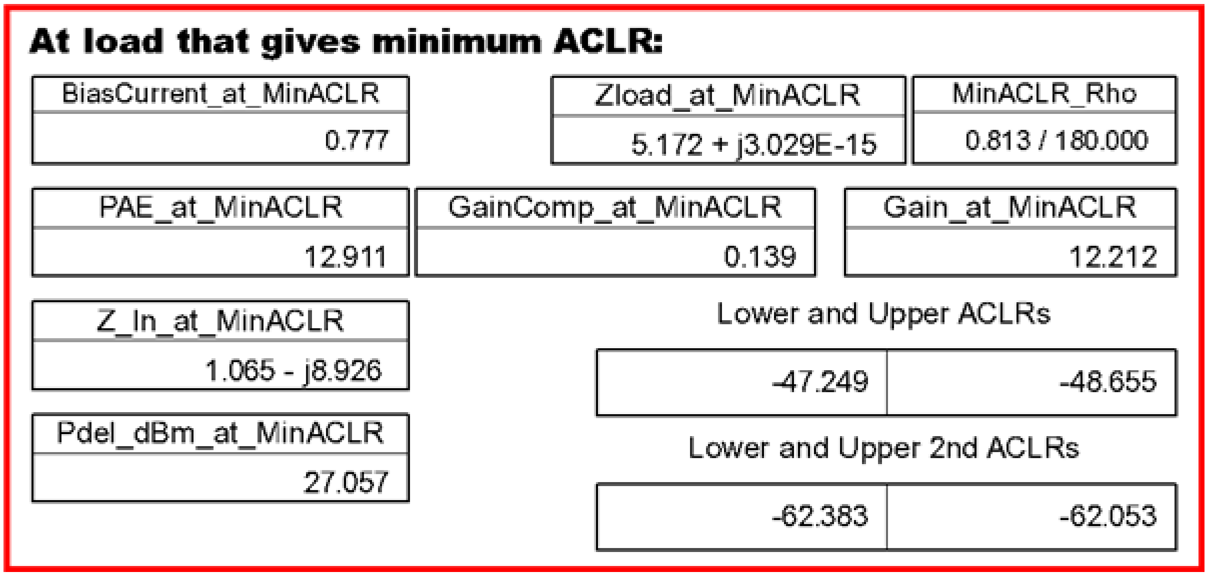
The results show there is a trade-off between power-added efficiency and distortion. You can get slightly better PAE if you are willing to tolerate higher ACLR levels.



Note that the power delivered specification is not satisfied. You could re-run the simulation, allowing SFexp to vary over a larger range, or you could move marker m1 to a load near this one and see if the power delivered specification is satisfied. Moving marker m1 allows you to select any of the simulated load reflection coefficients. The corresponding data appears in a separate box, which allows you to see potential tradeoffs as you move around the Smith Chart.



The gain compression is still excessive, however.



The ACLR is somewhat sensitive to the load impedance.

The **WCDMA Load Pull > Constant Power Delivered, Circular Region Load Pull** menu pick copies into your workspace a schematic and data display nearly identical to the **WCDMA_LoadPullMagPh_ConstPdel** ones above, except that it sweeps a circular region of the Smith Chart instead of a fan-shaped region.

Time Taken by Simulation

For 25 different load reflection coefficients, *numSymbols*=128, and the optimization type set to Gradient with *MaxIters*=5, this simulation required about 4 minutes. For 49 different load reflection coefficients, about 6.75 minutes were required.