

Keysight Technologies Using ADS to Investigate Optimal Performance of a Cree FET

Application Note

Introduction

This application note describes a workspace ¹ that features several load pull and DC I-V simulations of a Cree Field-Effect Transistor (FET). The workspace may be used to see what performance (e.g., output power, gain and power-added efficiency (PAE)) could be obtained, and what source and load impedances should be used to attain a desired level of performance (or make trade-offs). Using the schematics and data displays, you will be able to determine things like:

- How much output power can be attained? At what level of gain or gain compression?
- At a desired output power, what gain, gain compression, power-added efficiency, bias current, adjacent channel power ratio (ACPR), and error vector magnitude (EVM) can be attained? At what source and load impedances?
- How sensitive is the performance to the load impedance?
- How do the optimal load impedances vary with frequency or bias, or some other parameter like parasitic source inductance?
- How does performance depend on the source impedance?
- How does performance depend on the 2nd and 3rd harmonic impedances at the load or source?
- What trade-offs can be made between output power and power-added efficiency?

The device simulated is the CGHV1J025_r7_cree_v440_die, which can be downloaded from Cree's device model and PDK webpage (login required): <https://portal.cree.com/human.aspx>. However, the simulation setups and data displays should be suitable for other devices with a few modifications to the parameter settings.

1. <http://edocs.soco.keysight.com/display/eesofkcds/ADS+Workspace+for+Investigating+the+Performance+of+a+Cree+FET+Using+Load+Pull>

Table of Contents

Simulating Device I-V Curves.....	4
Preliminary Load Pull Simulations.....	5
Load Pull with a Source Power Sweep.....	9
Contours and Data at a Specific Output Power.....	10
Contours and Data at a Specific Available Source Power	12
Contours and Data at a Specific X-dB Gain Compression Point.....	12
Performance Variation Due to 2nd and 3rd Harmonic Loads.....	13
Re-Running Swept-Power Load Pull with Better Harmonic Loads.....	16
Load Pull Data at a Specific Amount of Output Power Back-Off.....	17
Plotting ACPR, EVM and Other Data Using a Modulated Signal	19
Simultaneous Fundamental and Harmonic Source and Load Reflection Coefficient Optimization.....	21

The **0. Device I-V Curve Simulations** folder contains a setup **FET_IV_Gm_PowerCalcs** for simulating a FET's I-V curves and transconductance at a particular input frequency. Figure 1 shows the I-V curves.

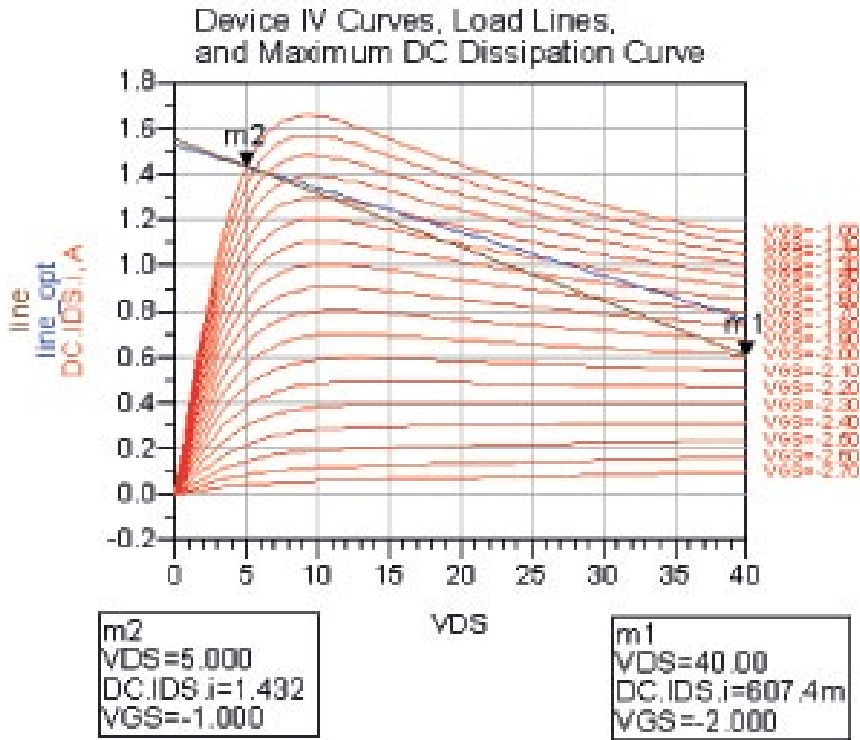


Figure 1. Device I-V curves and two different load lines that assume Class A operation.

Figure 2 shows how the AC transconductance varies with gate bias, with VDS=40 V.

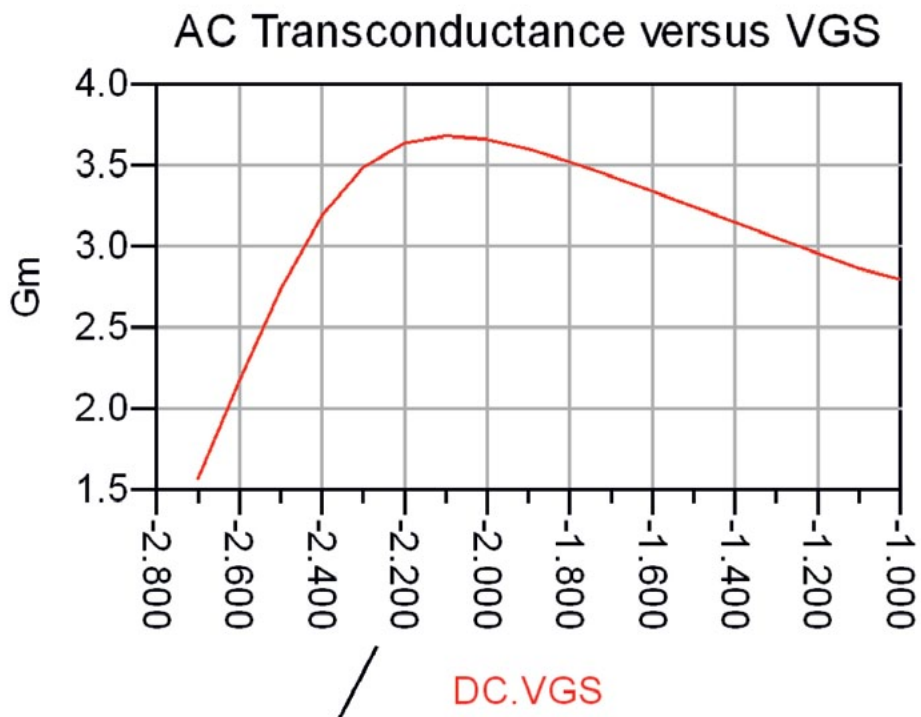


Figure 2. Device AC transconductance versus gate-to-source bias, at one drain-to-source bias voltage.

Preliminary Load Pull Simulations

The **1. Preliminary Load Pull Simulations** folder contains a load pull setup **HB1Tone_LoadPull** for running load pull at a single bias point, input frequency and available source power. This setup is good for initial simulations because it is relatively simple.

With **Sweep_Rectangular_Region=no**, a circular region of reflection coefficients will be sampled. Note that when this is set to **yes**, a rectangular region of reflection coefficients will be sampled. With **Specify_Load_Center_S=yes**, the center of the circle of reflection coefficients is specified as a reflection coefficient. If this is set to **no**, the center of the circle is specified as an impedance. Similarly, this Boolean variable applies to the harmonic loads as well.

With **Swept_Harmonic_Num=1**, a fundamental load pull will run (Figure 3). If you set this to **2** or **3**, you will sweep the load at the 2nd or 3rd harmonic, respectively.

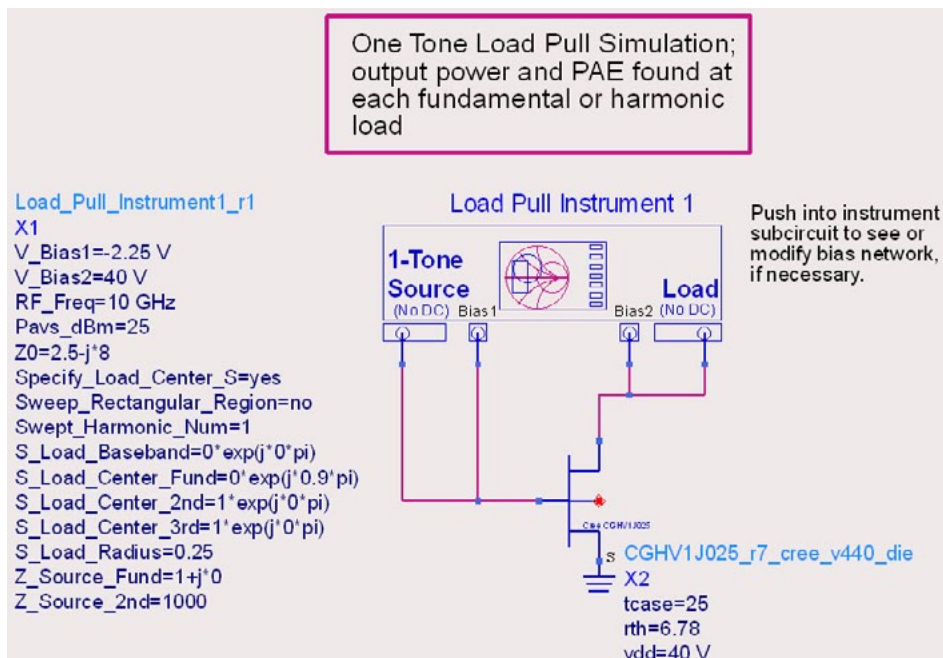


Figure 3.
One-tone load pull simulation setup,
at a single bias point and available
source power.

Initially, with $Z_0=50$, and the radius of the circle of reflection coefficients **S_Load_Radius** set to 0.5, the results in Figure 4 are obtained.

Preliminary Load Pull Simulations (continued)

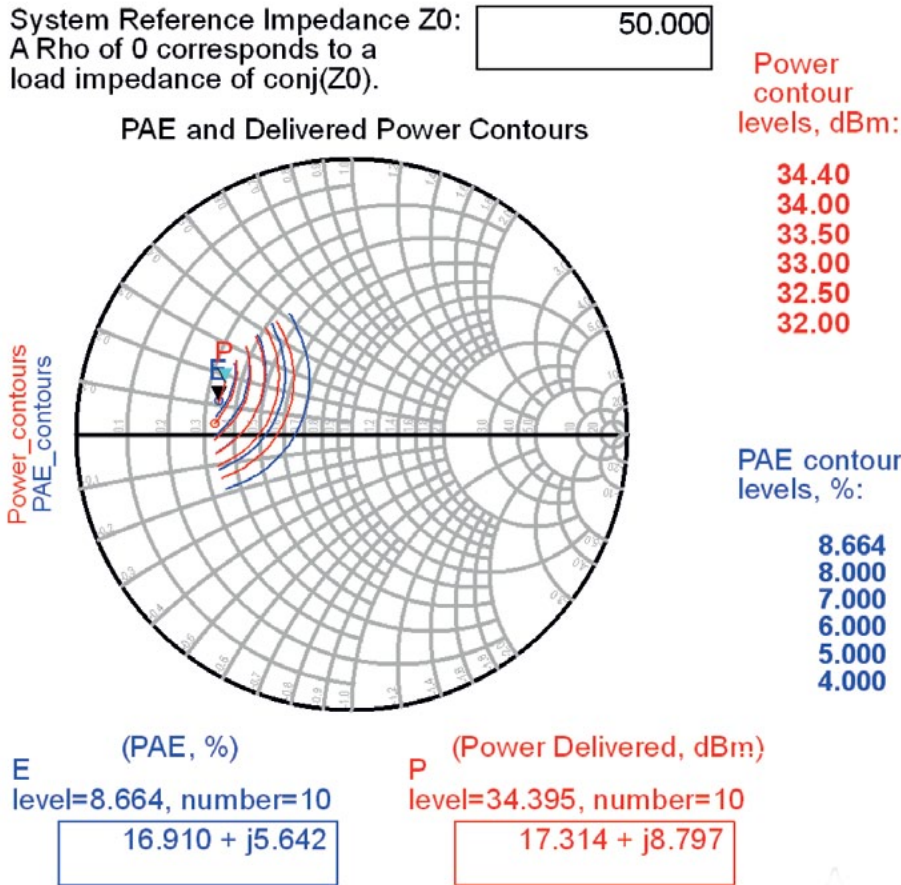


Figure 4. Power delivered and PAE contours from a preliminary simulation.

If we move the center of the circle **S_Load_Center_Fund** over towards a short and make the radius **S_Load_Radius** smaller, as shown in Figure 5, we obtain better results (Figure 6).

```
Swept_Harmonic_Num=1
S_Load_Baseband=0*exp(j*0*pi)
S_Load_Center_Fund=0.6*exp(j*0.9*pi)
S_Load_Center_2nd=1*exp(j*0*pi)
S_Load_Center_3rd=1*exp(j*0*pi)
S_Load_Radius=0.35
```

Figure 5. Parameter settings to sample more optimal load reflection coefficients.

Preliminary Load Pull Simulations (continued)

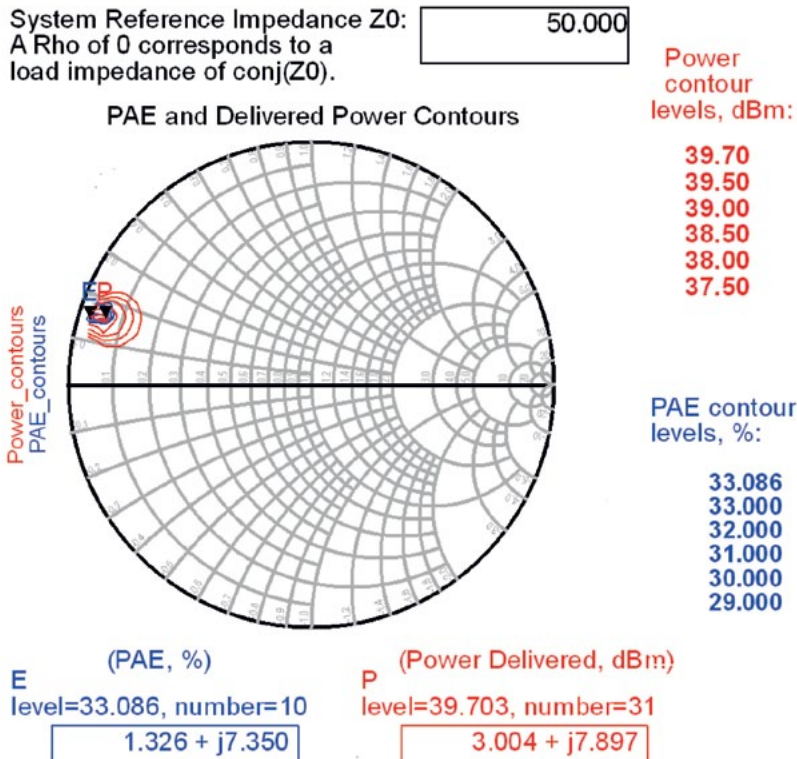


Figure 6.
 Better contours, after adjusting the sampled region of the Smith chart.

Finer resolution of the contours can be achieved by setting $Z_0=3-j*8$ (the complex conjugate of the load indicated by the **P** marker) and setting **S_Load_Center_Fund=0**. Re-running the simulation produces the results in Figure 7.

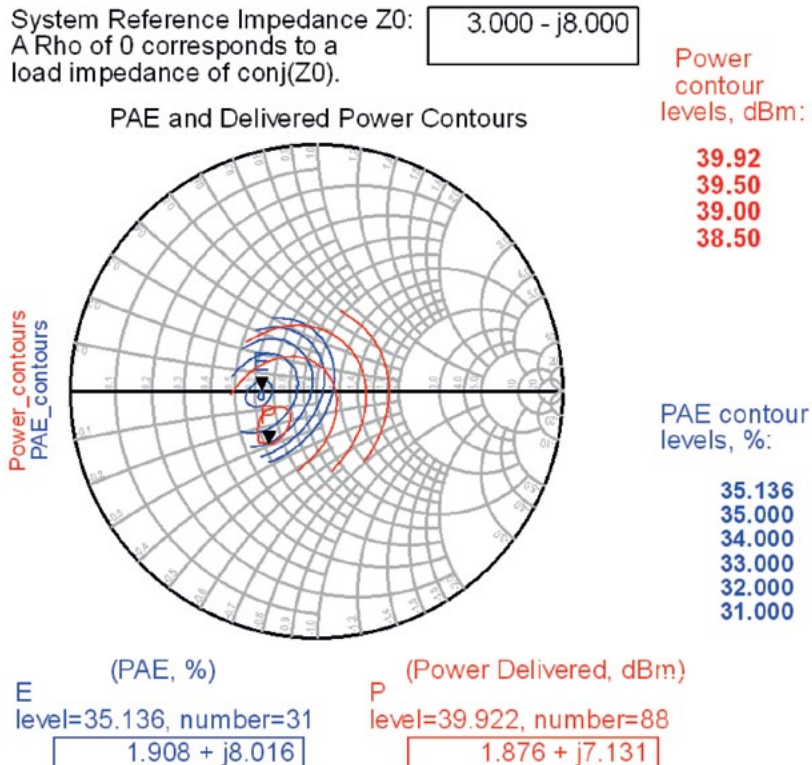


Figure 7.
 Finer resolution contours obtained by specifying a non-50-Ω reference impedance, which allows the center of the Smith chart to be nearer the optimal reflection coefficient.

Preliminary Load Pull Simulations (continued)

The same contours may be plotted on an impedance plot, as shown in Figure 8.

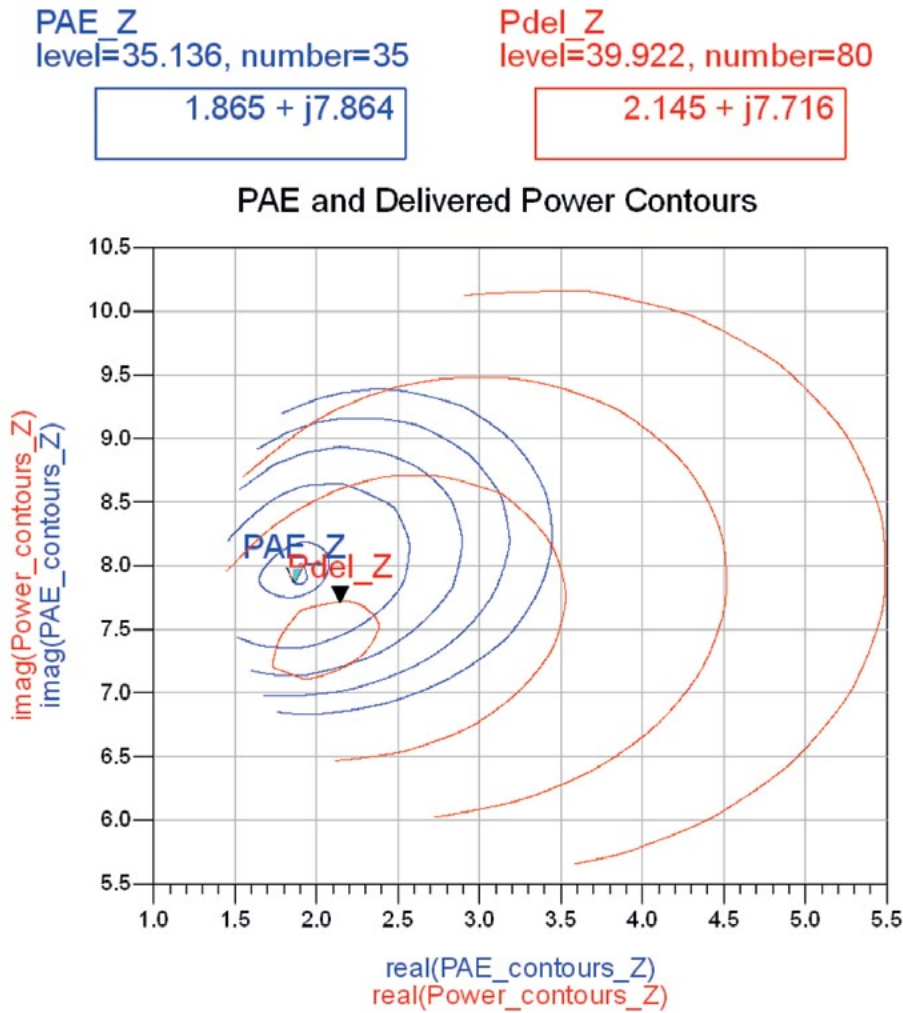


Figure 8.
The same contours from Figure 7,
but plotted on an impedance chart.

These simulations can be repeated after changing the gate bias. As expected, a more negative gate bias produces higher efficiency, but lower gain.

Load Pull with a Source Power Sweep

The simulations in the previous section were performed with a single source power. Consequently, we don't know how far into compression the device is operating. Next, let's sweep the available source power. The **2. Load Pull with a Power Sweep** has a load pull **HB1Tone_LoadPull_P Sweep_Z Sweep** that includes a sweep of the available source power. In this case, instead of sweeping a circular region of reflection coefficients (as previously shown), the real and imaginary parts of the load impedance are swept, which some designers may prefer (Figure 9).

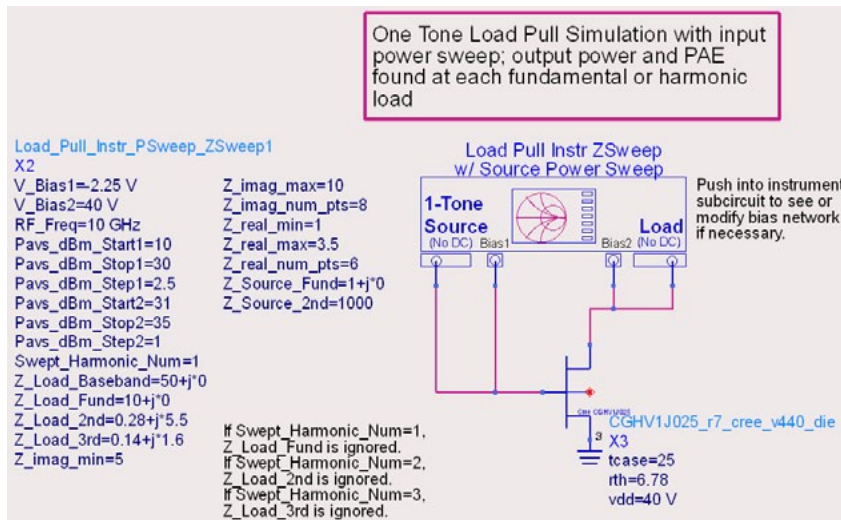


Figure 9. Load pull simulation setup in which the sampled region is specified by minimum and maximum values of the real and imaginary parts of the load impedance.

Contours and Data at a Specific Output Power

Because we have swept the available source power, we can interpolate the data in post-processing and plot contours at a specific output power, which you select with a marker (Figures 10 and 11).

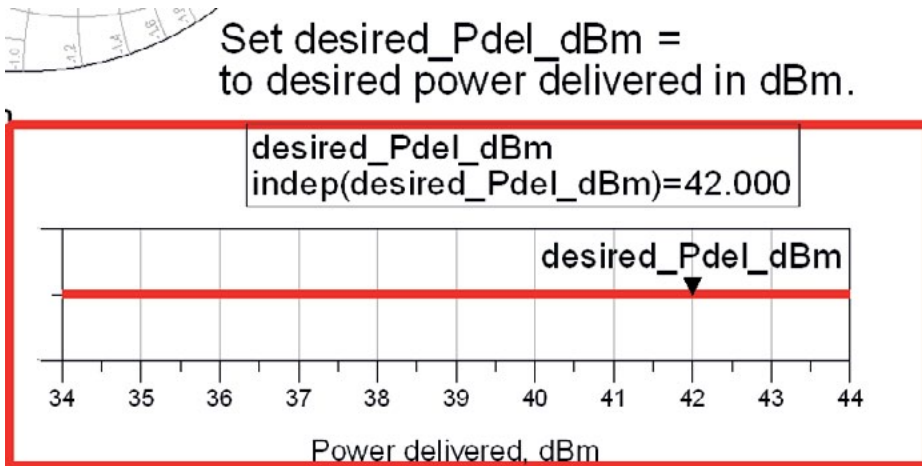


Figure 10.
Marker to select the desired power delivered (Note that contours are immediately updated when a different power level is selected).

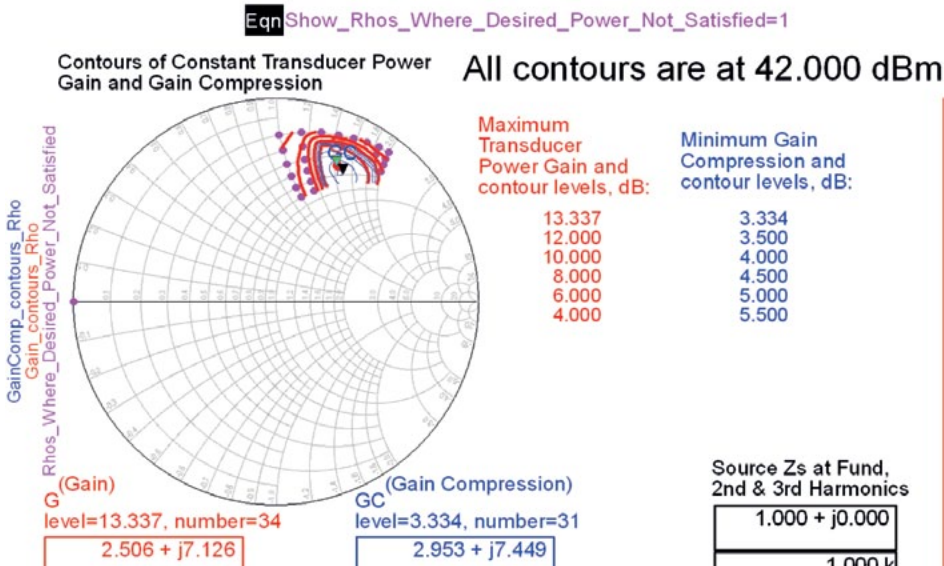


Figure 11.
Contours of gain and gain compression at 42 dBm power delivered.

Contours and Data at a Specific Output Power (continued)

Contours of constant PAE, simulated load reflection coefficients and corresponding input reflection coefficients



Figure 12. Contours of PAE at 42 dBm power delivered, with thick dots indicating loads at which the desired power was not achieved, given the maximum available source power in the sweep.

The thick dots in Figure 12 indicate reflection coefficients where the power delivered does not reach the value you have requested.

You can choose the load based on a trade-off between gain and power-added efficiency, as shown in Figure 13.

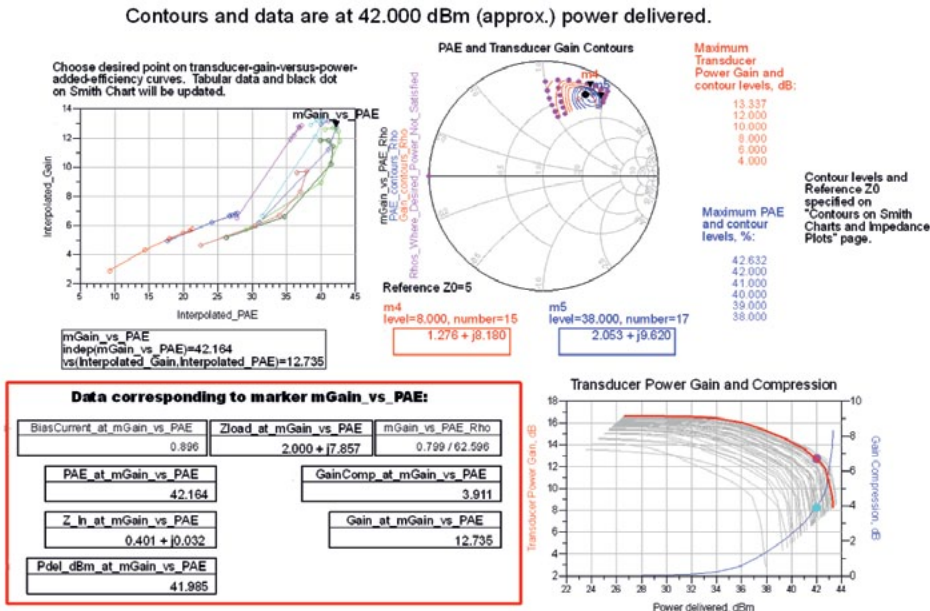


Figure 13. A different page in the data display that helps you make trade-offs between gain and PAE while delivering 42 dBm.

Contours and Data at a Specific Available Source Power

You may also plot contours at a specific available source power, and choose a load that is a trade-off between the power delivered and power-added efficiency (Figure 14).

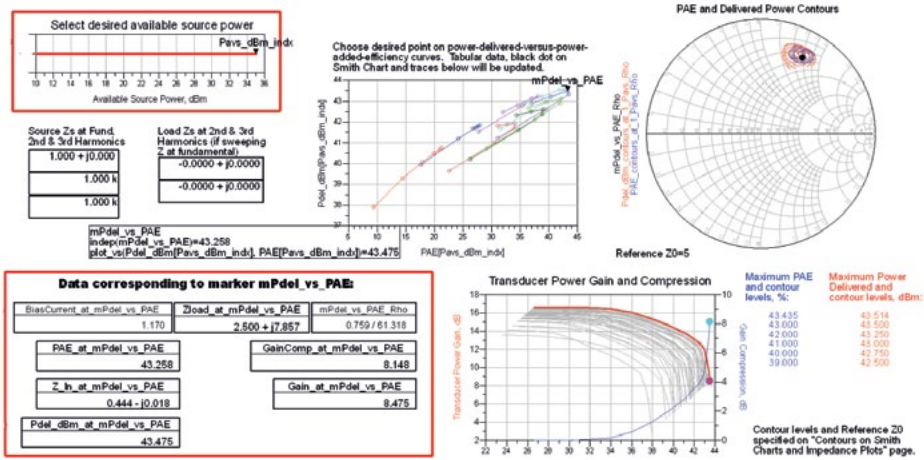


Figure 14. Page showing contours of power delivered and PAE, at a specific available source power, which helps you make trade-offs between power delivered and PAE.

Contours and Data at a Specific X-dB Gain Compression Point

The **HB1Tone_LoadPull_PSweep_ZSweep_wXdB** data display allows you to see contours and data at a specific level of gain compression, based on interpolation.

Performance Variation Due to 2nd and 3rd Harmonic Loads

With high-power devices driven well into compression, the load impedances at the harmonic frequencies will have an effect on the performance.

The 3. **Sweeping the Phase of the 2nd and 3rd Harmonic Loads** folder contains a setup **HB1Tone_Load_Harmonic_Phase_Sweep** that allows you to see the performance variation due to the load at the 2nd and 3rd harmonics (Figure 15).

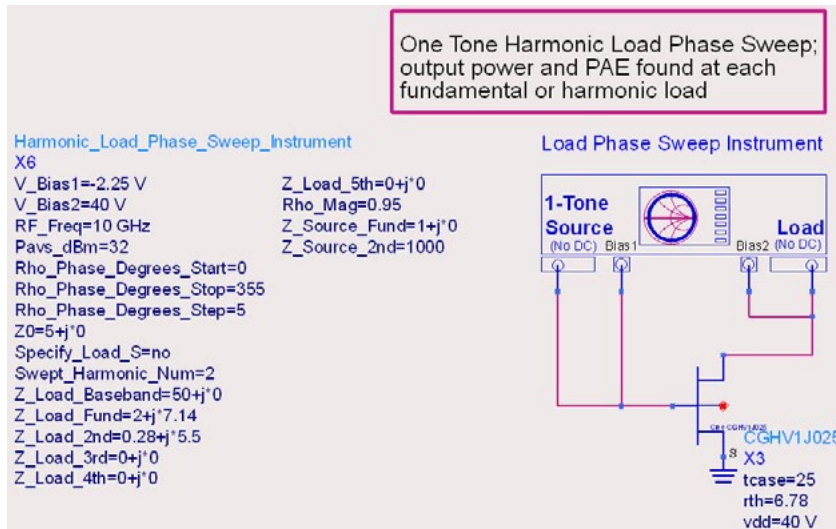


Figure 15.
Setup for sweeping the phase of the load reflection coefficient at the 2nd (or 3rd) harmonic (Note that the magnitude of the reflection coefficient may be set arbitrarily and is held constant during the sweep).

Here, the load impedances at the fundamental and all harmonics are fixed, except for the 2nd harmonic because **Swept_Harmonic_Num=2**, and the phase of the 2nd harmonic reflection coefficient is swept (its magnitude **Rho_Mag=0.95** is held constant). The simulation results in Figure 16 show significant variation in PAE and power delivered as the phase of the 2nd harmonic load is varied.

Performance Variation Due to 2nd and 3rd Harmonic Loads (continued)

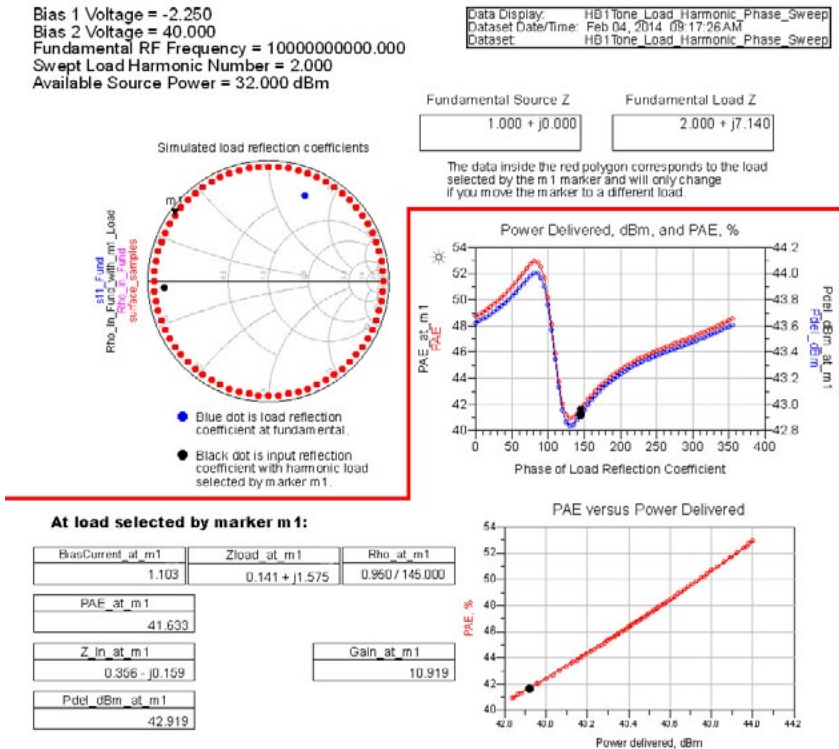


Figure 16. Variation in the PAE and power delivered as the phase of the reflection coefficient at the 2nd harmonic is swept.

We can repeat the simulation, this time setting the second harmonic load impedance to $0.28 + j5.5$ (found previously), and sweeping the phase of the 3rd harmonic load (Figure 17).

Swept_Harmonic_Num=3
 Z_Load_Baseband= $50 + j*0$
 Z_Load_Fund= $2 + j*7.14$
 Z_Load_2nd= $0.28 + j*5.5$
 Z_Load_3rd= $0 + j*0$

Figure 17. Specifying load impedances in preparation for sweeping the phase of the 3rd harmonic reflection coefficient; in this case, Z_Load_3rd is not used in the simulation.

Performance Variation Due to 2nd and 3rd Harmonic Loads (continued)

In this case, the variation due to the 3rd harmonic is smaller (Figure 18).

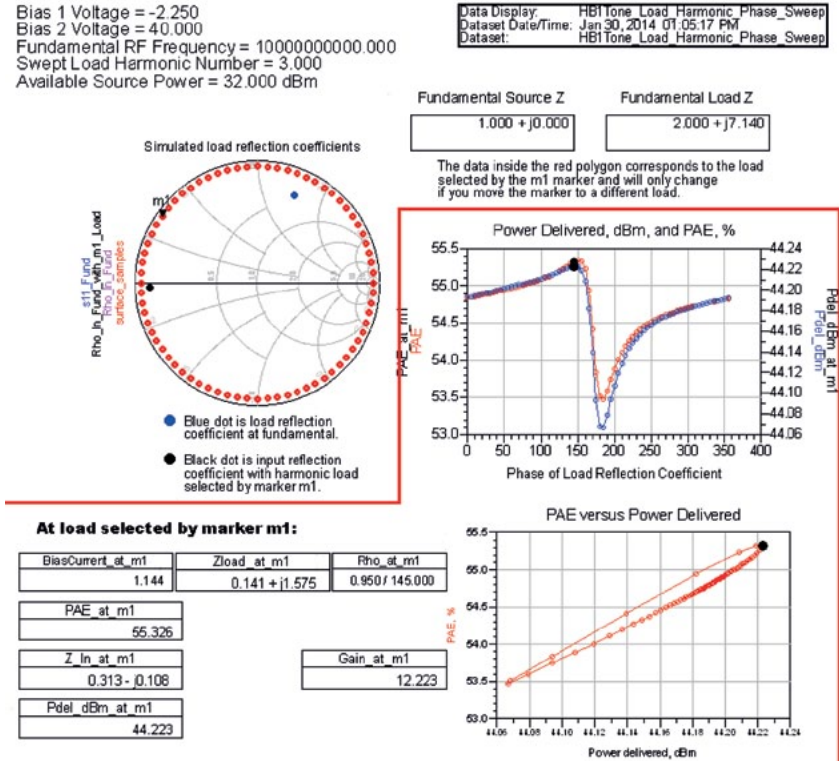


Figure 18. Variation in PAE and power delivered due to the phase of the 3rd harmonic reflection coefficient.

Re-Running Swept-Power Load Pull with Better Harmonic Loads

We can now return to the swept-power load pull simulation schematic **HB1Tone_LoadPull_Psweep_ZSweep** and re-run the load pull simulations. This time, however, we use the better 2nd and 3rd harmonic loads. By doing so, we obtain a somewhat higher efficiency and output power (Figure 19).

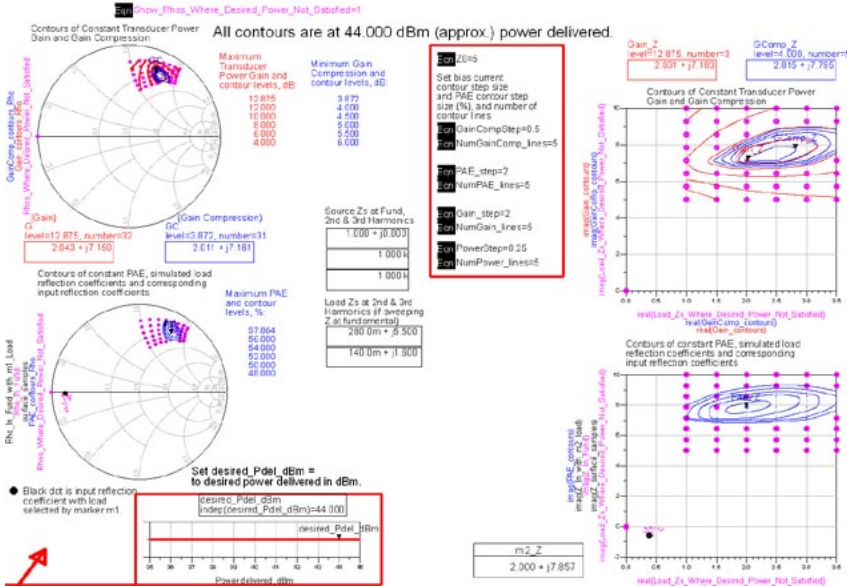


Figure 19. Plots showing somewhat better performance from a fundamental load pull, while using more optimal 2nd - and 3rd -harmonic loads.

Figure 20 shows data from the same simulation, with the available source power set to 35 dBm.

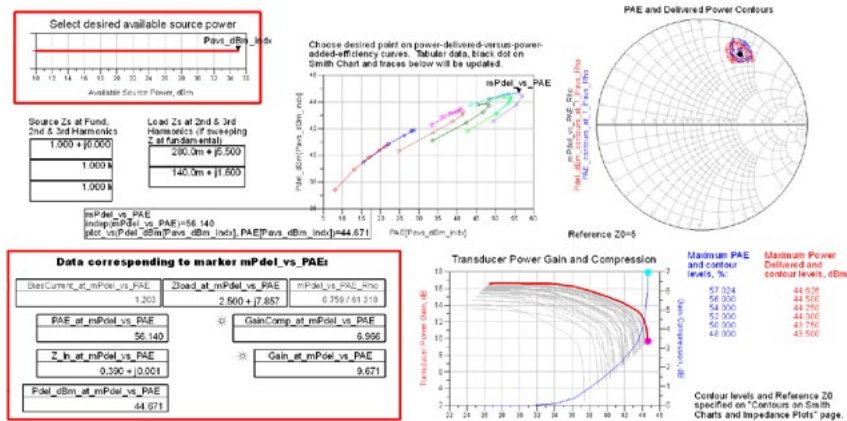


Figure 20. Plots that show the trade-off between power delivered and PAE for a specific available source power.

Load Pull Data at a Specific Amount of Output Power Back-Off

The **HB1Tone_LP_Psweep_Zsweep_wXdB_wOBO** data display in Figures 21 to 23 shows contours and data at a specific amount of gain compression and at a specific output power, as well as at a specific amount of back-off relative to the gain compression point that you specify.

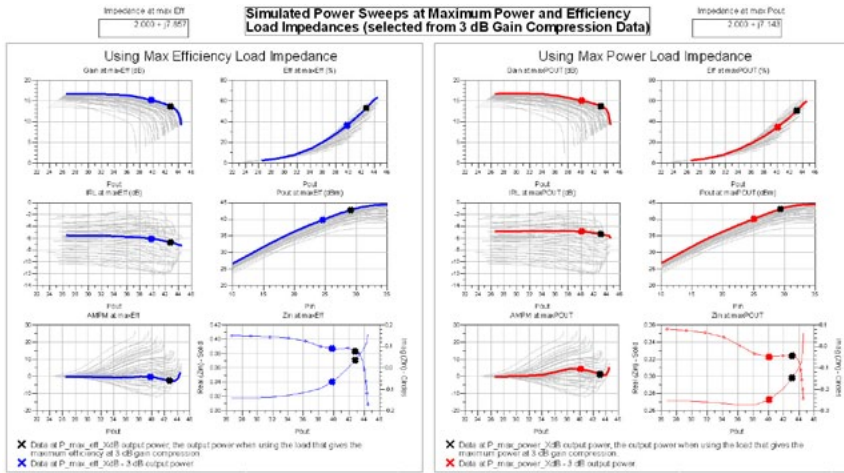


Figure 21. Plots showing the responses if (at X-dB gain compression) the maximum efficiency load is chosen (on the left) or if the maximum power delivered load is chosen (on the right); black X's show data corresponding to the X-dB gain compression point, while blue and red X's show data at a specified amount of back off.

Simulated Performance at Backoff

RF performance at XdB OBO (output backoff) is determined by backing off from max power load at 3 dB gain compression (amount of compression is specified on "Constant Compression Load Pull Contours" page.) All other parameters are evaluated at this backed off power.

$$\text{Eqn maxPout_OBO_dB}=3$$

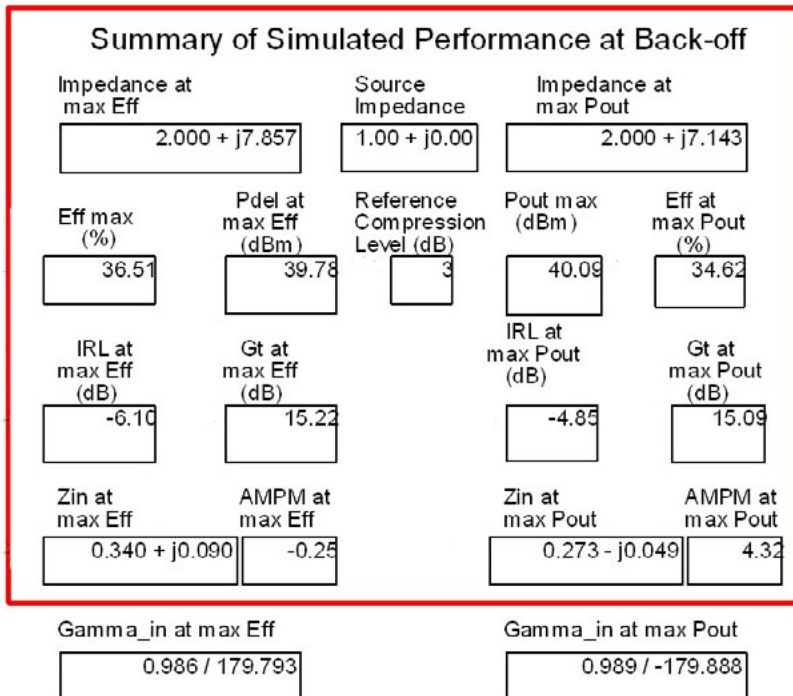


Figure 22. A different page in the data display: numeric data corresponding to the blue and red X's in Figure 21.

Load Pull Data at a Specific Amount of Output Power Back-Off (continued)

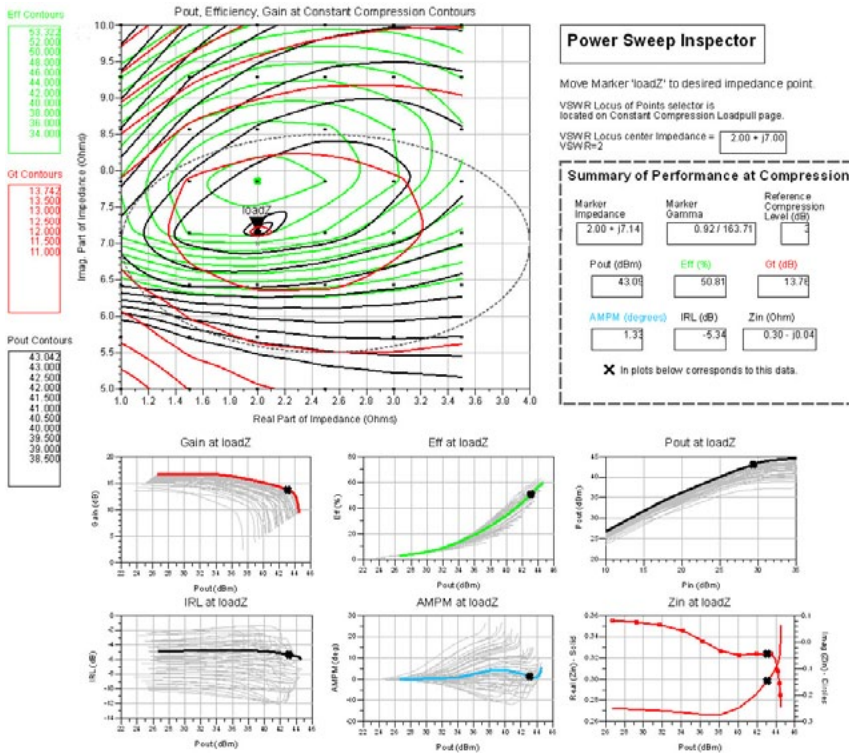


Figure 23. A different page in the data display; data corresponds to the load selected by the "loadZ" marker and the desired X-dB gain compression specified (on a different page).

Plotting ACPR, EVM and Other Data Using a Modulated Signal

You may also plot ACPR and EVM data, computed from the 1-tone, swept-power load pull simulation data. The **HB1Tone_LP_ZSweep_ACPR_EVM_Pavs_Swp** data display plots contours of modulated output power, ACPR, EVM, bias current, and efficiency (Figure 24). You must specify the modulated signal dataset. In this case, an LTE dataset from a Ptolemy Wireless Library example is used.

Specify modulated signal to be used in the calculations. Adding syntax like [0::1000] forces only the first 1001 time points to be used, which speeds up the calculations.

```
Eqn Vin_fund=LTE_UL_TxSpectrum..Waveform[0::500]
```

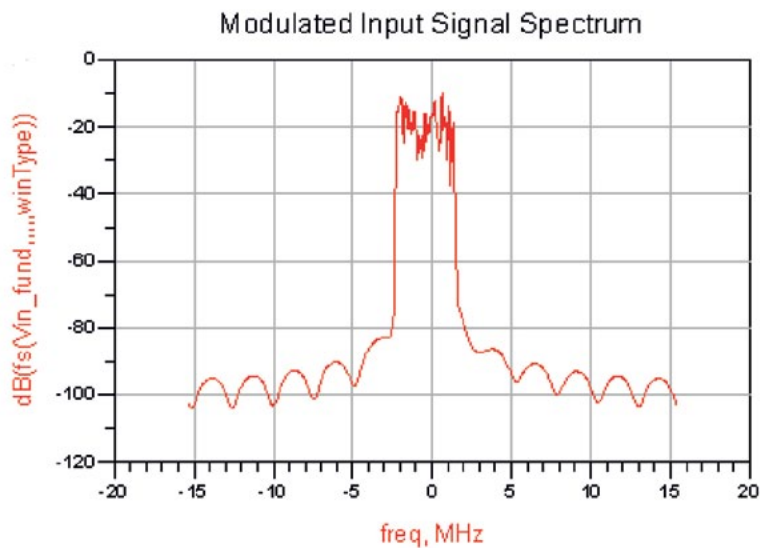


Figure 24.
Specifying the modulated input signal data to be used in ACPR and EVM calculations.

You also must specify the available source powers of the modulated input signal (Figure 25).

Specify the ranges of modulated input signal powers (dBm):

```
Eqn inputSigPowers1=[20::2.5::30]
Eqn inputSigPowers2=[31::1::33]
Eqn inputSigPowers=[inputSigPowers1,inputSigPowers2]
```

Figure 25.
Specifying the ranges of modulated input signal powers; the amplitude of the modulated input signal is scaled according to these values.

Plotting ACPR, EVM and Other Data Using a Modulated Signal (continued)

Figure 26 shows the data, which is keyed (via a marker) to one of the specified input signal powers.

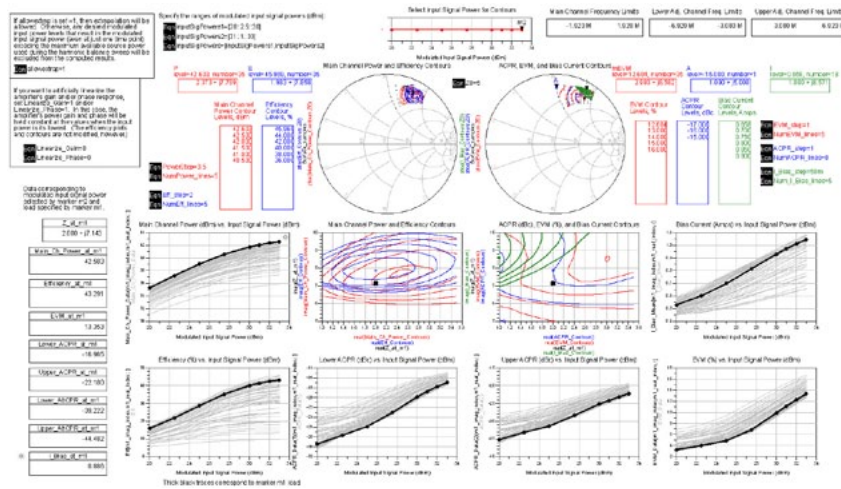


Figure 26. Contours of main channel power, efficiency, EVM, ACPR, and bias current at one of the available source powers with black traces corresponding to data of one particular load that you select with a marker.

It is also possible to plot data at the X-dB gain compression point. This is shown in the **HB1Tone_LP_ZSweep_ACPR_EVM_wXdB** data display, which depicts the main channel power and gain data at the 2-dB gain compression point (Figure 27).

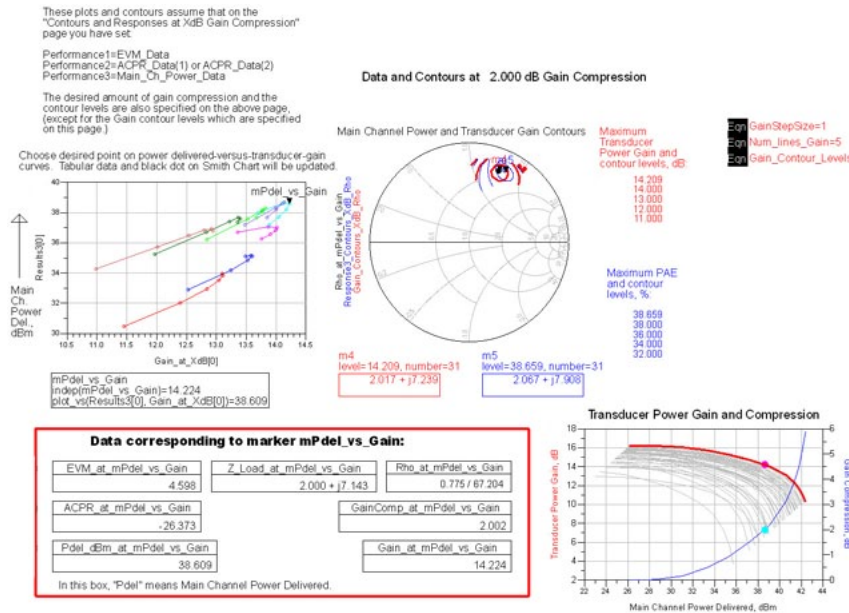


Figure 27. Plots that allow you to make a trade-off between main channel power delivered and gain at the X-dB gain compression point.

Plotting ACPR, EVM and Other Data Using a Modulated Signal (continued)

Figure 28 shows main channel power and EVM data at the 2-dB gain compression point.

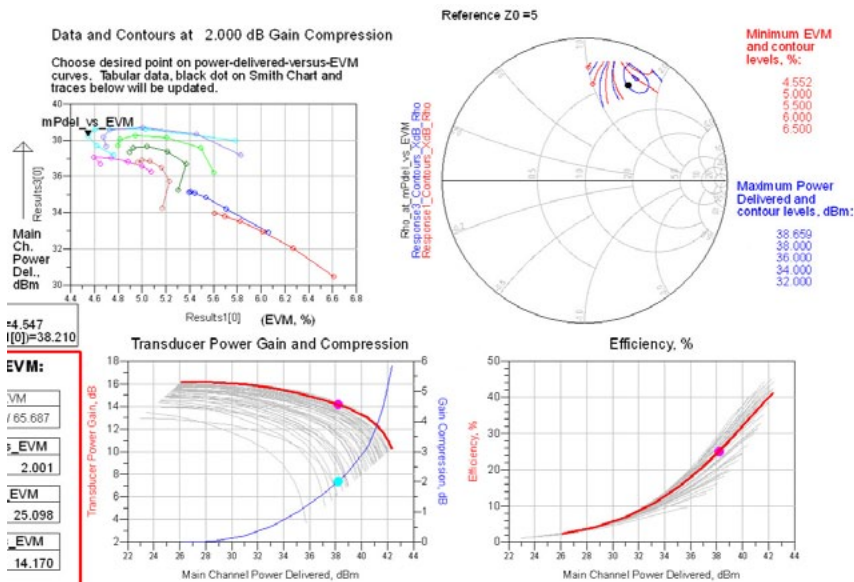


Figure 28. Plots that allow you to make a trade-off between main channel power delivered and EVM at the X-dB gain compression point.

The load pull simulation setups previously shown are from the ADS 2014 Load Pull DesignGuide.

Supported ADS customers using ADS 2012 or 2013 may download and install this version of the Load Pull DesignGuide from the Keysight EEsof Knowledge Center: <http://edocs.soco.keysight.com/display/eesofkcds/Content+from+ADS+Power+Amplifier+Hands-on+Workshop>

Note that there are many more load pull simulation capabilities than what have been shown. Also, while the simulations shown here use just one tone, you can plot contours of intermodulation distortion from two-tone load pull simulations.

Simultaneous Fundamental and Harmonic Source and Load Reflection Coefficient Optimization

It is also possible to simultaneously optimize the source and load impedances at the fundamental and harmonic frequencies, which is an alternative to load pull. This is shown in the **HarmGammaOpt1tone** schematic and data display in the **6. Simultaneous Source and Load Gamma Optimization** folder. You can specify goal power delivered, power-added efficiency and bias current values, or add different goals. The results you obtain will depend on what variables you allow to be optimized and the ranges of values you allow.

myKeysight

www.keysight.com/find/mykeysight

A personalized view into the information most relevant to you.

For more information on Keysight Technologies' products, applications or services, please contact your local Keysight office. The complete list is available at: www.keysight.com/find/contactus

Americas

Canada	(877) 894 4414
Brazil	55 11 33 51 7010
Mexico	001 800 254 2440
United States	(800) 829 4444

Asia Pacific

Australia	1 800 629 485
China	800 810 0189
Hong Kong	800 938 693
India	1 800 112 929
Japan	0120 (421) 345
Korea	080 769 0800
Malaysia	1 800 888 848
Singapore	1 800 375 8100
Taiwan	0800 047 866
Other AP Countries	(65) 375 8100

Europe & Middle East

Belgium	32 (0) 2 404 93 40
Denmark	45 45 80 12 15
Finland	358 (0) 10 855 2100
France	0825 010 700* *0.125 €/minute
Germany	49 (0) 7031 464 6333
Ireland	1890 924 204
Israel	972-3-9288-504/544
Italy	39 02 92 60 8484
Netherlands	31 (0) 20 547 2111
Spain	34 (91) 631 3300
Sweden	0200-88 22 55
United Kingdom	44 (0) 118 927 6201

For other unlisted countries:

www.keysight.com/find/contactus

(BP-04-11-14)