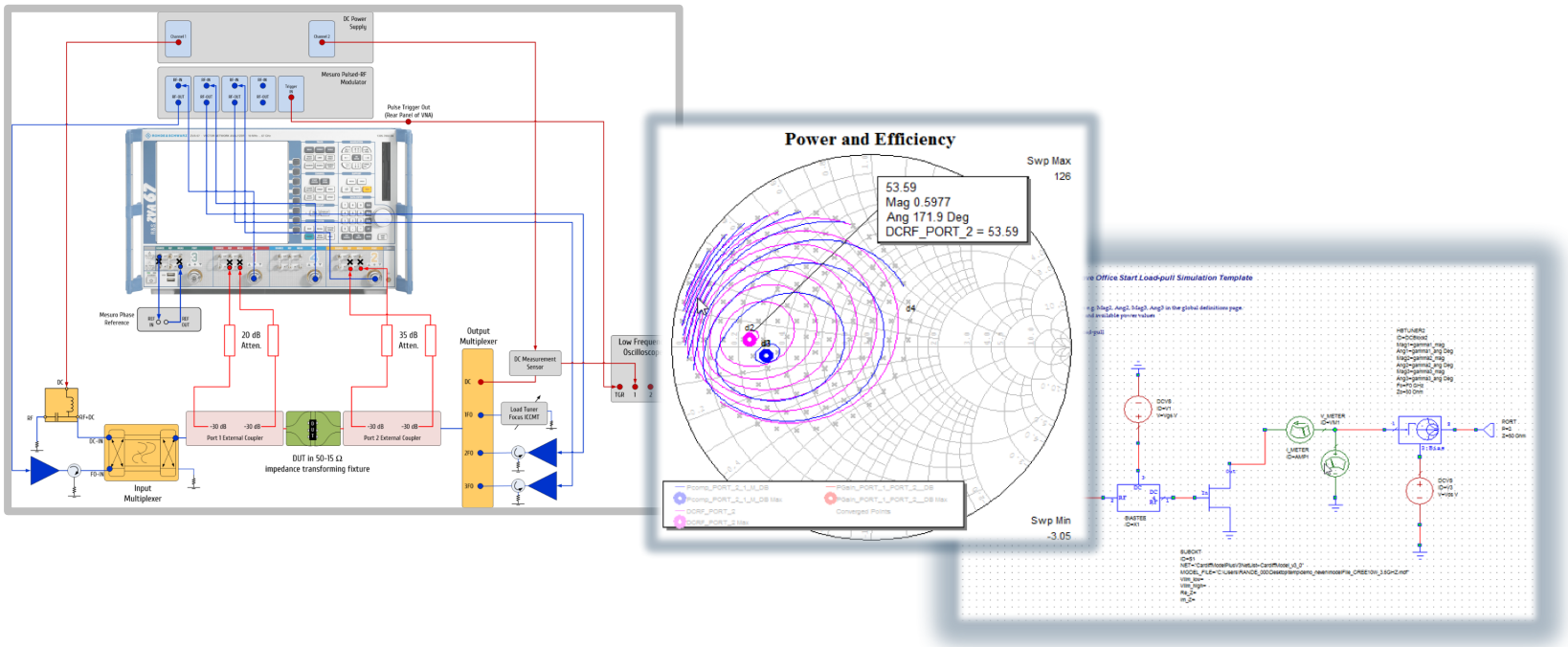
Behavioural Models/ From Wave-based Load-pull to Cardiff Model+



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Outline

- Behavioural model generation
  - Theory of model extraction
  - Measurement strategy
  - Model extraction procedure
- Application – Worked Example Microwave Office

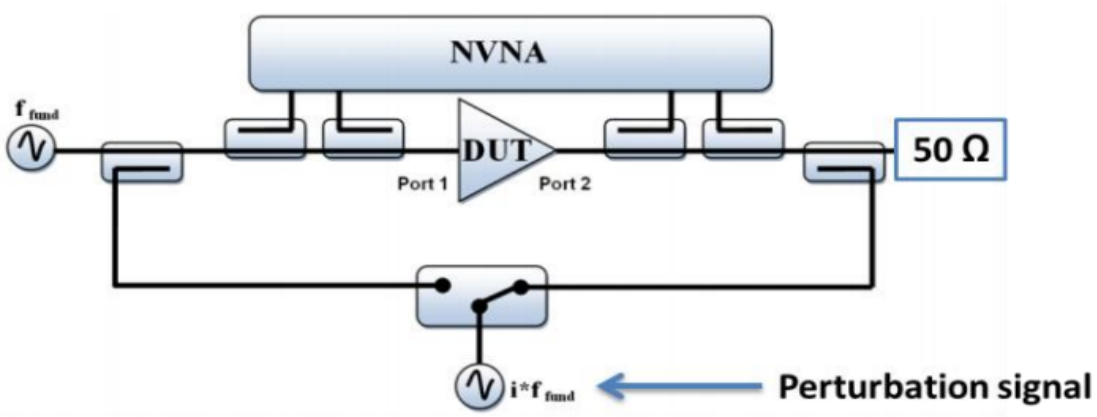
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Behavioural Model Generation

Cardiff Model Lite

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Cardiff Model Lite





- **Extraction process:**
  - Drive the DUT with a fundamental tone (A_{11}).
  - At each fundamental input power (A_{11}), the device will be simultaneously perturbed with a ss tone at each harmonic frequency and for both ports using a second signal generator. The phase of this generator will be randomized. It is recommended to measure at least for 6 different phases.
  - Thus, for each harmonic component, the corresponding $S_{pm,11}$, $S_{pm,qn}$ and $T_{pm,qn}$ parameters will be easily obtained applying a least-squares algorithm to the measured data.

Cardiff Model Lite

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- **Main limitations:**
  - Cardiff model Lite is a **local model** constrained to a specific load impedance space.
    - The linearization applied to get the model just holds when $\mathbf{A_{21} << A_{11}}$
      $Z_L \approx 50\ \Omega$ - Hence good for system level but not transistors
    - To overcome this limitation:
      - **Solution 1:** Make the model parameters a table look-up with A_{21} (Z_L).
      - X-paramter solution.
        - » File size increases dramatically.
        - » Complex to achieve good measurements
      - **Solution 2:** Use of a **n-order polynomial** to fit the A_{21} performance over all the SC (Cardiff model Lite linearization is equivalent to use a 3^{rd} order polynomial approach)
        - » File size remains compact
        - » Simplified Measurement
        - » Captures all harmonic mixing terms

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Behavioural Model Generation

Cardiff Model Plus

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Behavioural Model Generation: Cardiff Model+

- **Cardiff Model+ (CM+)** is a behavioural modelling strategy, based on a polynomial fit of the load-pull measurement data.
- Generalized to an m^{th} odd order in terms of the relative phase component of the incident wave, $a_{p,h}$ at harmonic h and port p.
- For this model, measurement data is indexed as $|a_{p,h}|$ and Q_h/P_1.
- Using least-means squares, we are able to determine the order (complexity of the equation) w which satisfies the *desired accuracy for a global model*.

$$b_{2,1} = P_1 \cdot g\left(v_{1,0}, |a_{1,1}|, v_{2,0}, |a_{2,1}|, Q_1/P_1\right)$$

Where $P_1 = \angle a_{1,1} = \dfrac{a_{1,1}}{|a_{1,1}|}$ and $Q_1 = \angle a_{2,1} = \dfrac{a_{2,1}}{|a_{2,1}|}$

$$K_{p,h,m} = g\left(v_{1,0}, |a_{1,1}|, v_{2,0}, |a_{2,1}|\right)$$

$$b_{p,h} = P_1^h \cdot \left(\sum_{m=-(w-1)/2}^{m=+(w+1)/2} K_{p,h,m} \left(Q_1/P_1\right)^m \right)$$

Cardiff Model+ Differentiators for non 50 Ohm devices (Over CML/X-Parmaters™)

- **Single model encompassing the entire load space**
  - **Reduced model size**
  - **Interpolation uses model coefficients**
  - **F0 extrapolation (Model is not based on load-look-up)**

- **Simplified Extraction Process**
  - **Know what measurements fill the model – (Ensure harmonic Coverage)**
  - **Get a model directly from load-pull data – allows for automatic verification of model accuracy.**

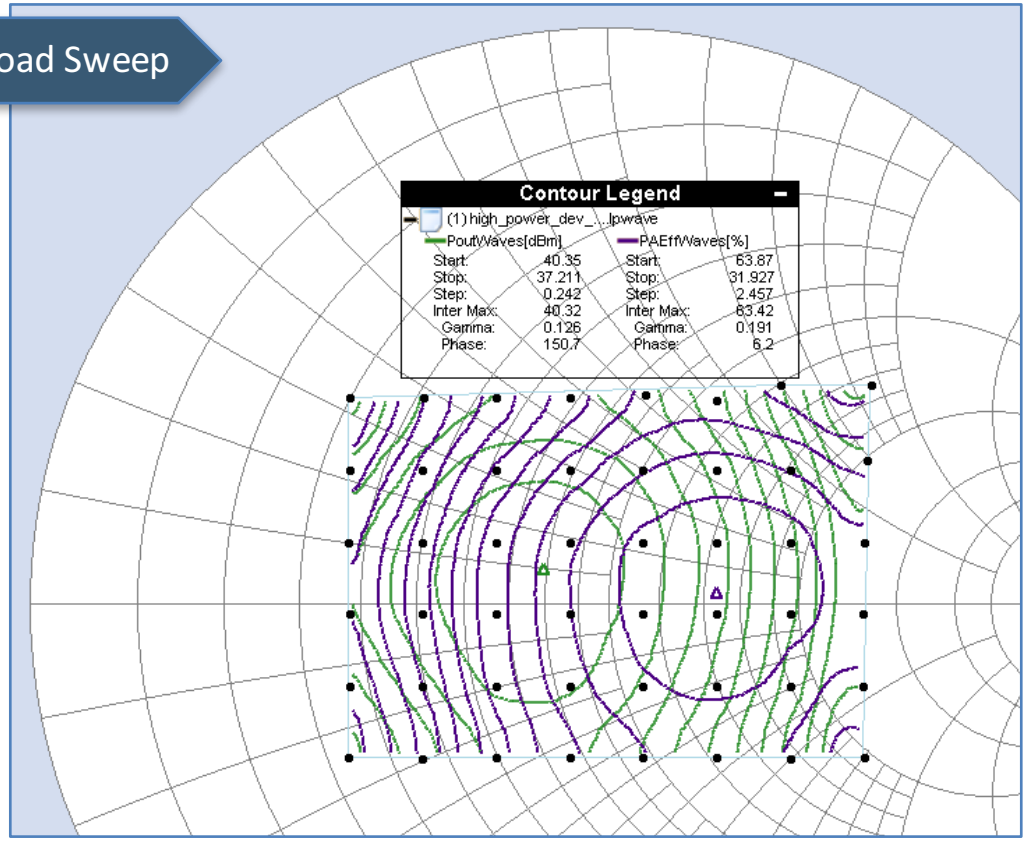
- **Model does not assume superposition**
  - **Full mixing model – deals with harmonic mixing products**
  - **Particularly important for advanced operation modes**

Wave-based Load-pull measurement overview

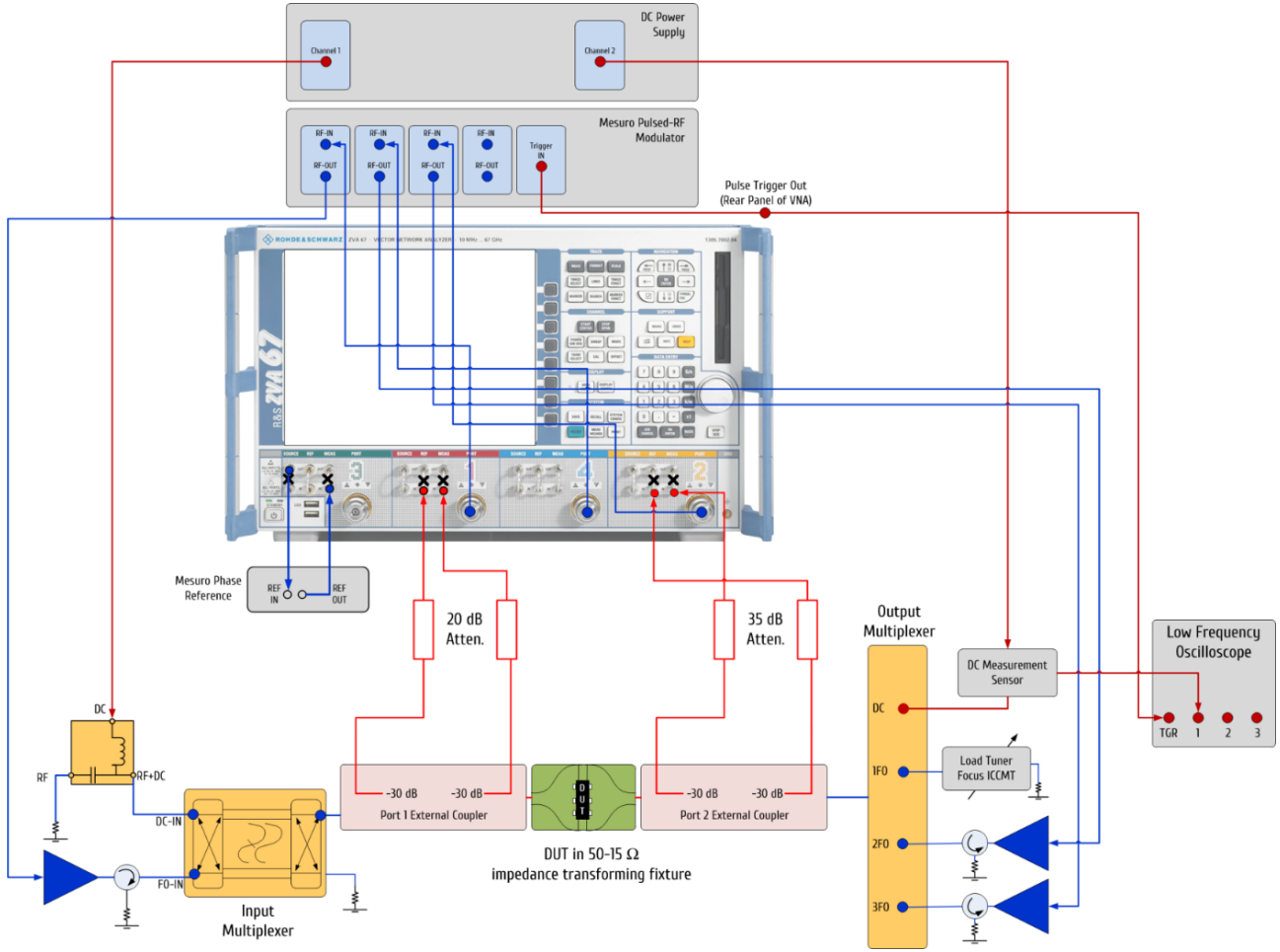
Cardiff Model+ Extraction

Wave-based load-pull measurement: Introduction

- Load-pull is the measurement of key non-linear parameters indexed as a function of load-impedance.
  - Input Power
  - Output power and transducer gain
  - Drain efficiency and Power added efficiency
- Impedance control is provided by a passive tuner or active tuner.
- Traditionally carried out using a scalar bench e.g. using power sensors and calibrated passive tuners.



Wave-based load-pull measurement: Hardware Setup



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From VNA to NVNA

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- To convert a VNA capable of measuring ratios only to a NVNA, capable of large signal measurements we need a phase (time) reference.
- As a VNA steps from one frequency to another, phase coherence is lost which means the time domain waveforms can no longer be displayed.
- Additional measurements are also required to give absolute power and phase measurement capabilities.

- Phase reference can be used to trigger (time align) and to correct the absolute phase.

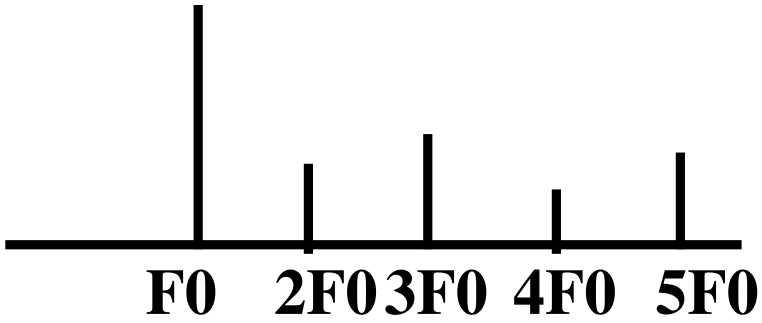
Phase Reference

- A phase reference is a device that has been pre-characterised to uncover the phase relationships between the fundamental and other frequencies.
  - As phase coherence is lost as VNA steps from one frequency to the next, the measured phase on the reference channel can be used to re-align time.
  - You can also do the absolute phase correction at this point by comparing the measured values to those in the look up table of pre-characterised states (contrary to other manufacturers architectures).

Mesuro Phase Reference

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- The Mesuro phase reference is designed for application to harmonic waveform reconstruction.
  - Unlike other approaches where a fine comb is created all the energy is maintained within the harmonics of the drive signal. This improves the quality of the initial characterisation as well as the reconstruction during measurement.

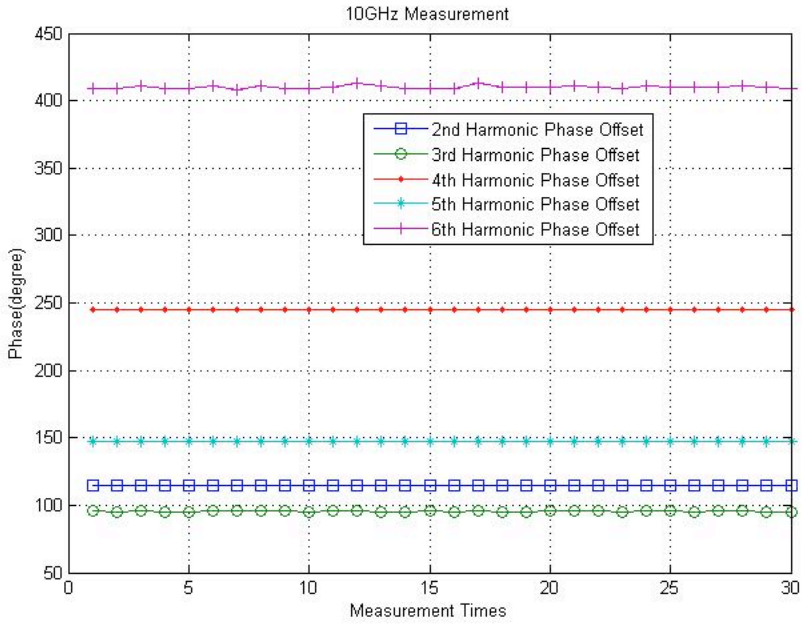


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Mesuro Phase Reference

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Measurements performed every 5 minutes over a period of 2.5 hours, harmonics up to the 6th harmonic 60GHz tracked. Excellent repeatability obtained.



Harmonic	Phase Variations (Degrees)
2nd (20GHz)	±0.13
3rd (30GHz)	±0.14
4th (40GHz)	±0.25
5th (50GHz)	±0.13
6th (60GHz)	±2.36

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ZVA67 for Active/ Hybrid Load-Pull

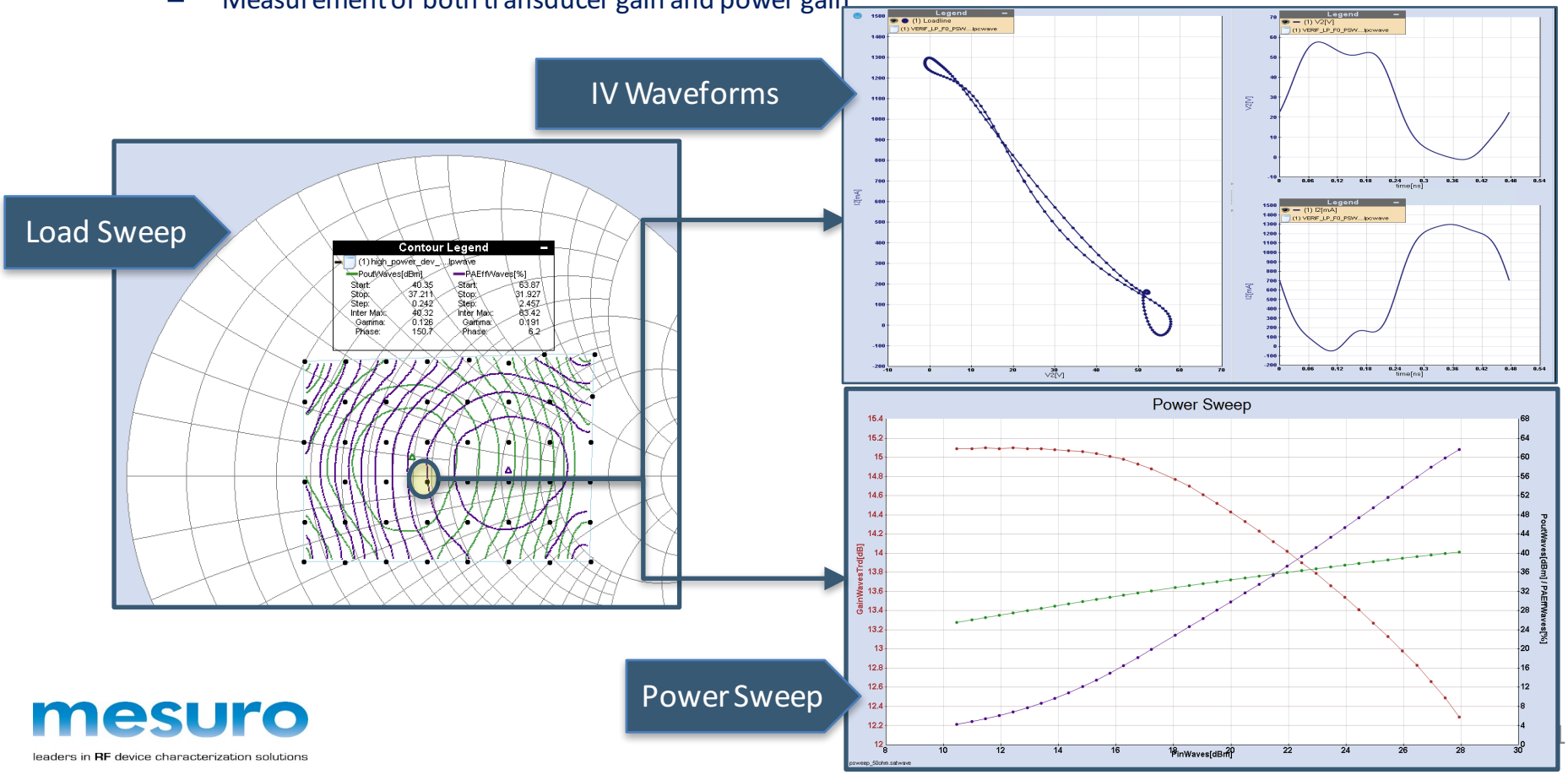
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- **System in a box solution** (receivers plus sources). For low power measurements all that is required is Mesuro Software plus phase reference. High power extension available through reconfigurable Mesuro hardware.
- **DDS based sources** Remove the need for a phase reference during measurement, frees up one of the sources allowing 1-in-3 out operation with no additional sources. Also opens potential for full 4 port measurements with time domain information.
- No phase drift between drive signal and load-pull signals means **convergence is faster**, and makes **very high frequency load-pull** possible. Can also revisit past known impedance states (could be very useful for production testing)

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Wave-based load-pull measurement: Capabilities

- Load-pull data can be captured by measurement of traveling waves with a calibrated network analyser e.g. a_1, b_1, a_2, b_2 as well as dc terms v_1, v_2, i_1, i_2 allow us to compute additional parameters:
  - Input Gamma of the device under test,
  - Accurate measure of load-impedance for the fundamental and harmonic frequencies at the input and output ports
  - Accurate time-domain waveforms (phase reference required).
  - Measurement of both transducer gain and power gain

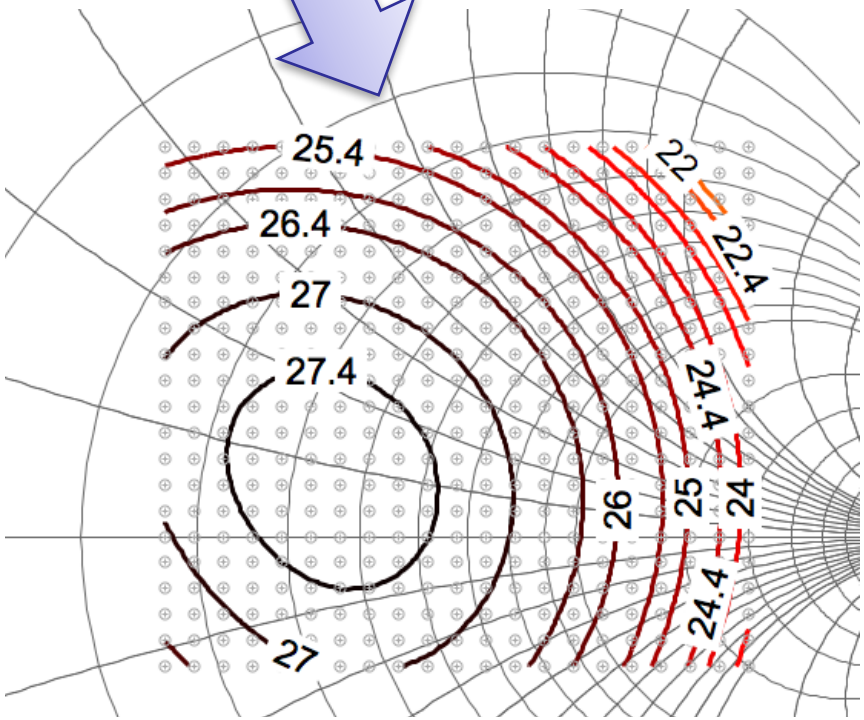


Importance of Polynomial order in PHD for global modelling

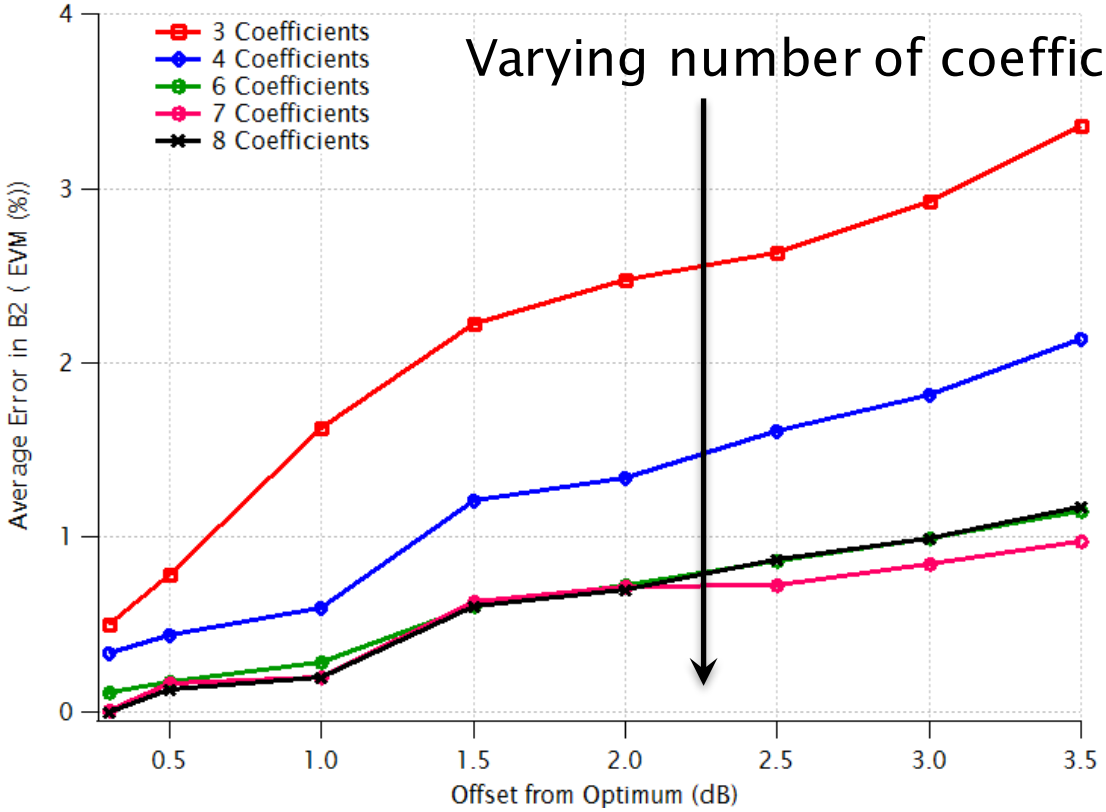
F0 performance Interpolation

- Various sets of impedances were measured for this investigation, all centered around the device's optimum for power.
- All higher harmonics were held constant at 50 ohms and the fundamental frequency, drive and bias were also held constant

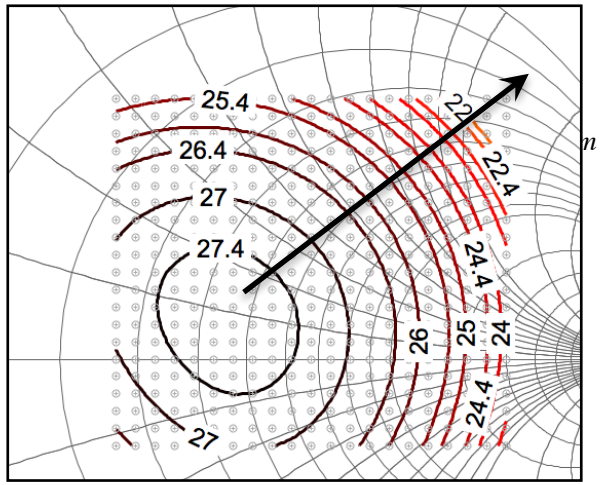
Impedance points were grouped-by and contained within the measured output power contours (0.5 dB steps)



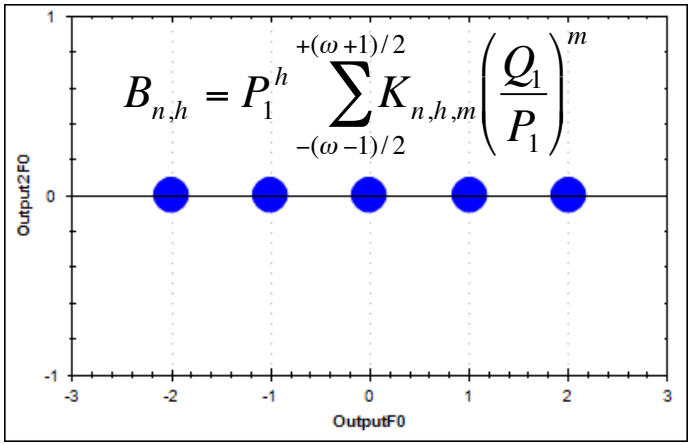
F0 Performance
Vary the Coefficients



Power offsets from optimum



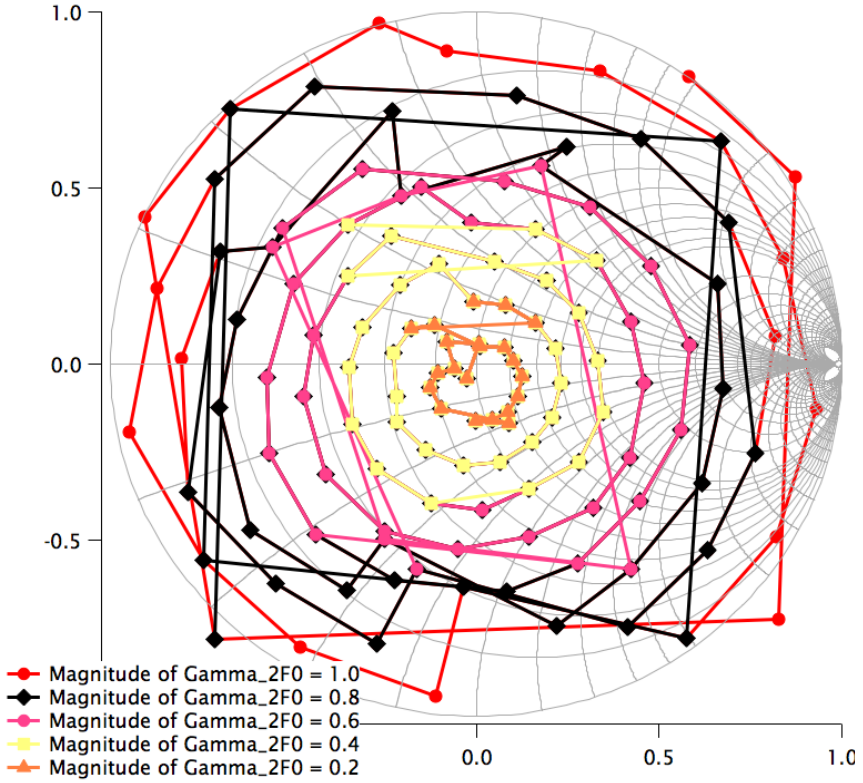
$$B_{n,h} = P_1^h \sum_{-(\omega-1)/2}^{+(\omega+1)/2} K_{n,h,m} \left(\frac{Q_1}{P_1}\right)^m$$



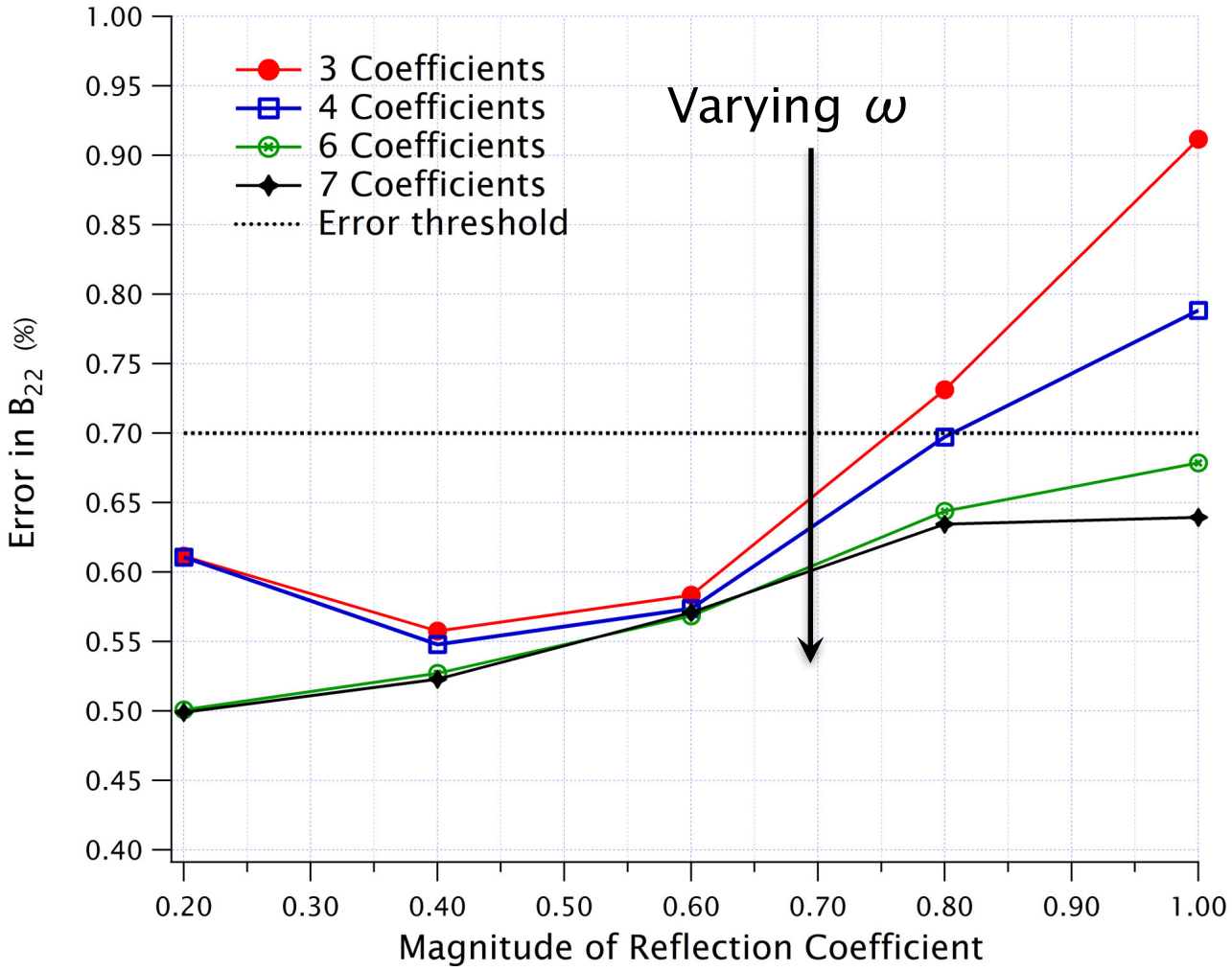
5 behavioural models, defined by varying *number of coefficients* in the above equation are compared in this graph

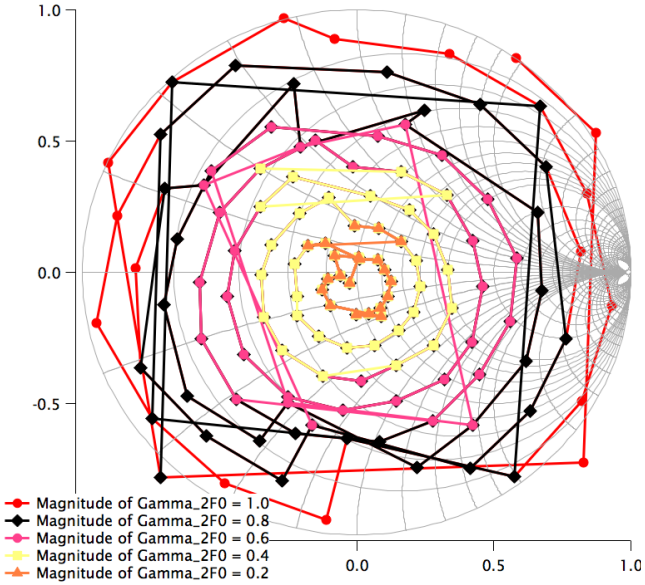
2F0 performance Interpolation

- 144 Measured 2F0 impedances were filtered and grouped by magnitude of the 2F0 reflection coefficient.
- Models of increasing order were used to capture the behaviour of each of these subsets
- Fundamental gamma was held at a constant corresponding to the device optimum for power.



F0 performance
Interpolation





A low model complexity is required to capture an accurate 2F0 model.

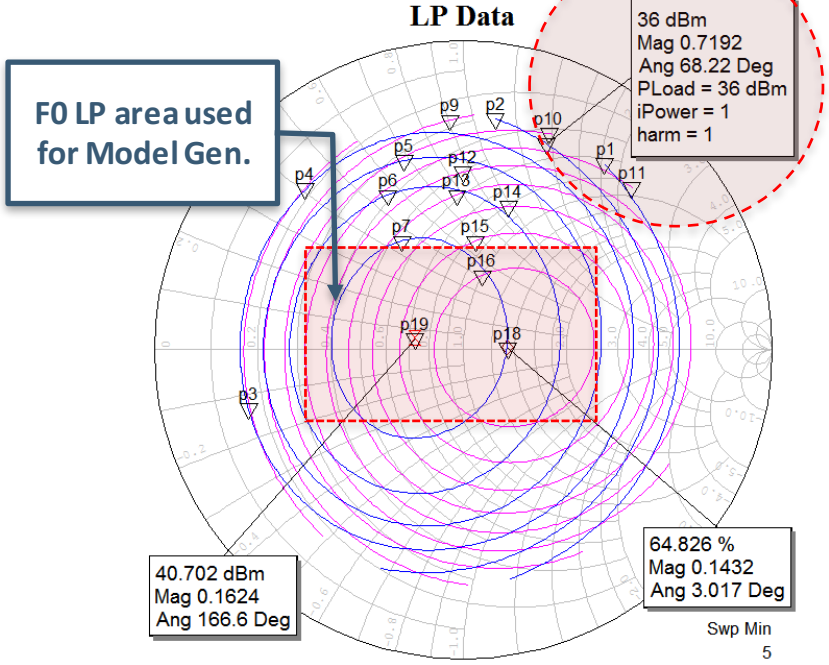
Increasing the order ω improves accuracy, especially for high impedance terminations (Γ_{22}> 0.7)

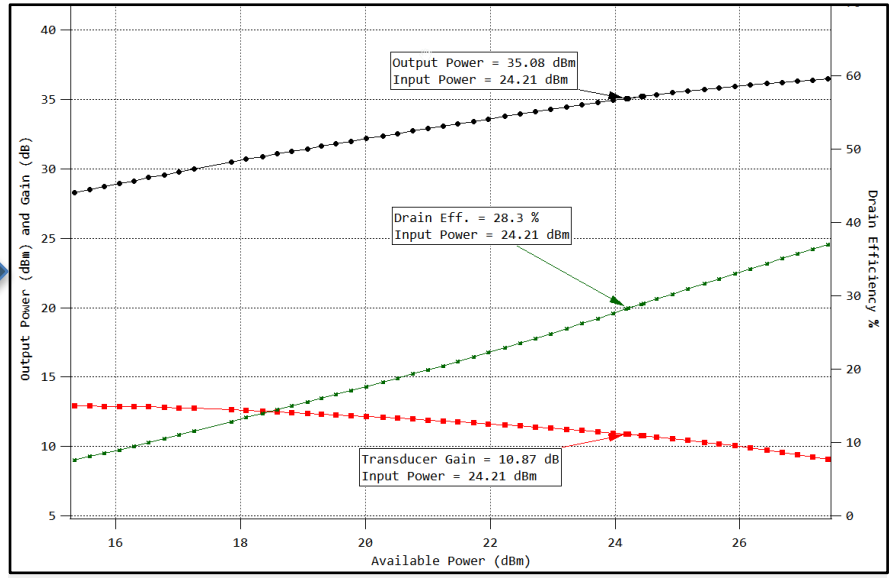
F0 performance Extrapolation

- Model uses 6 coefficients
- Measured power sweep in an impedance where the model was not captured.

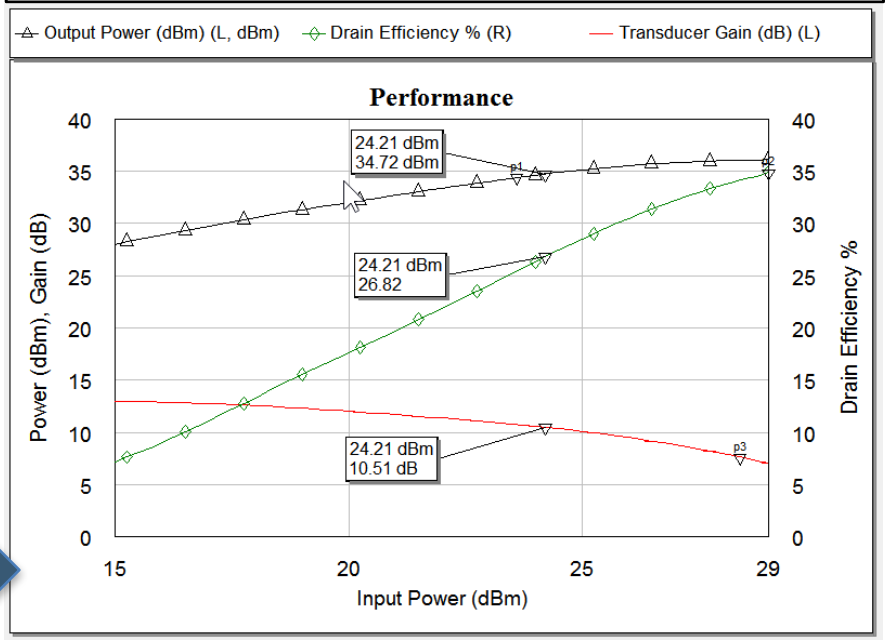
Test for Load F0 extrapolation

Measurement



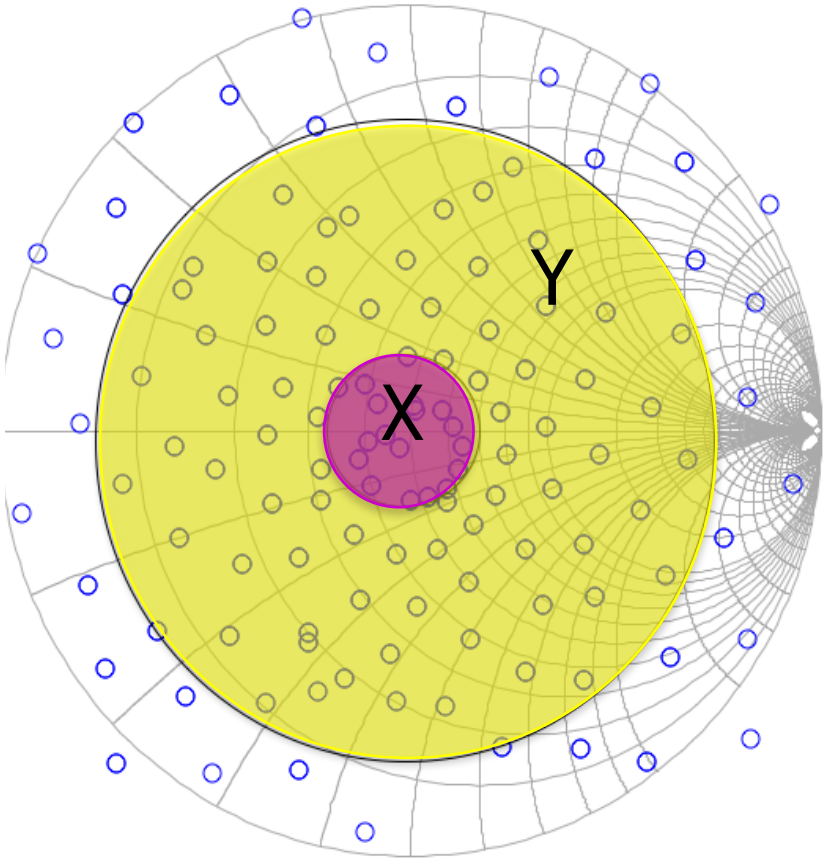


Simulation



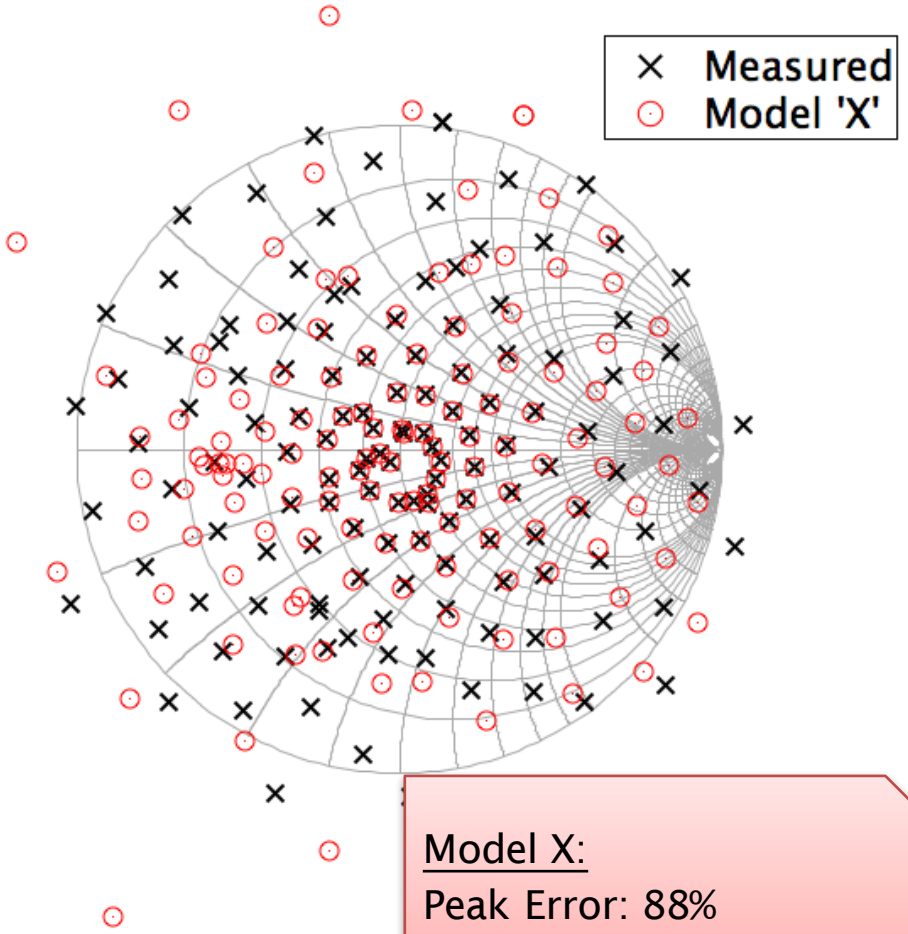
Harmonic performance Extrapolation

- The 2F0 gamma was varied to cover concentric circles of the smith chart while the F0 gamma was held constant
- A 6-element model was extracted under two conditions
  - For 2F0 $|\Gamma_{22}|$=0.2 (model 'X')
  - For 2F0 $|\Gamma_{22}|$=0.7 (model 'Y')
- Each model was then required to predict the measured behaviour of the device on impedances spread all over the smith chart.



Harmonic performance Extrapolation

- The 2F0 gamma was varied to cover concentric circles of the smith chart while the F0 gamma was held constant
- A 6-element model was extracted under two conditions
  - For 2F0 $|\Gamma_{22}|$=0.2 (model 'X')



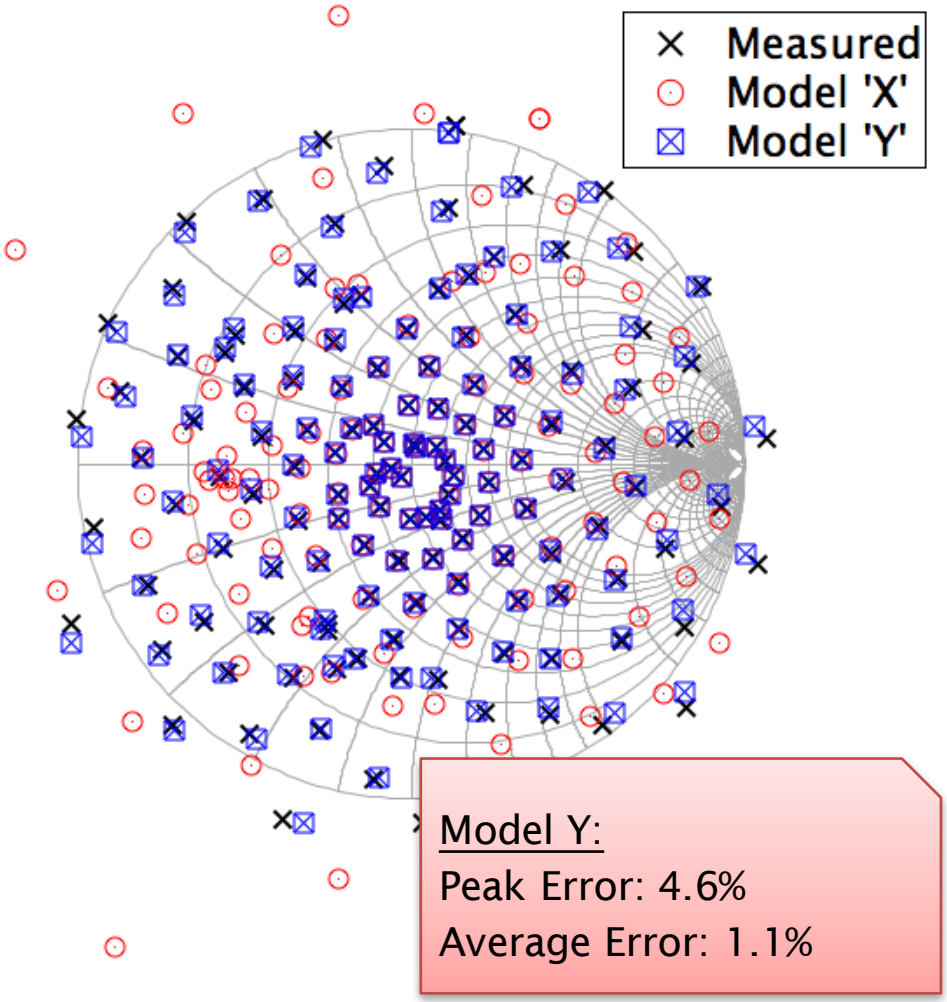
Model X:
Peak Error: 88%
Average Error: 4%

Harmonic performance Extrapolation

- The 2F0 gamma was varied to cover concentric circles of the smith chart while the F0 gamma was held constant

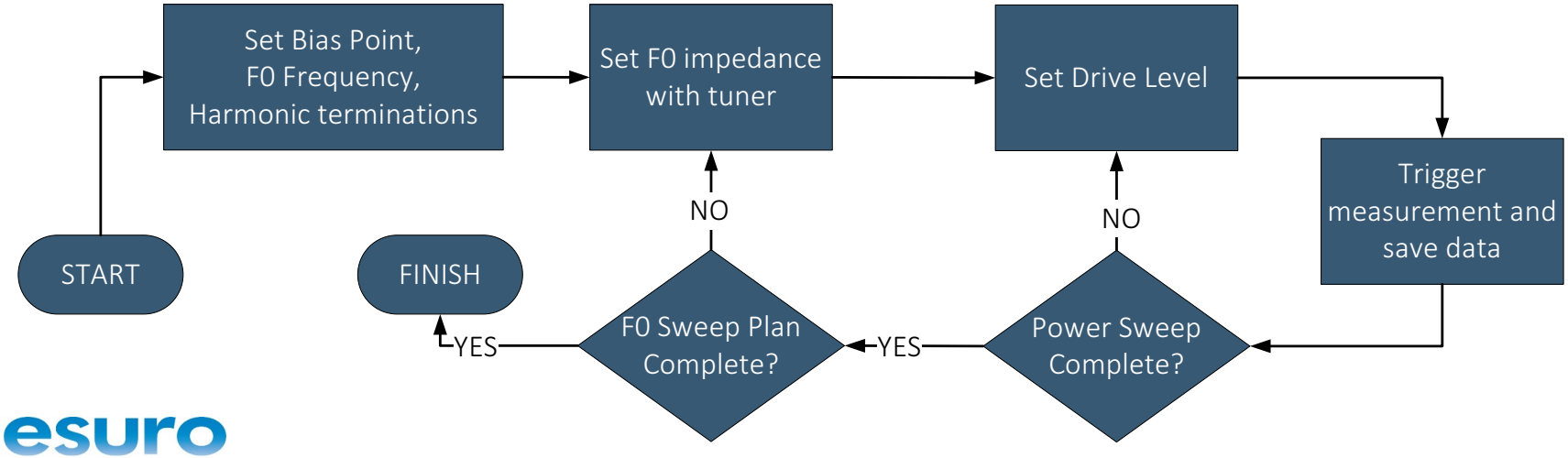
- A 6-element model was extracted under two conditions
  - For 2F0 $|\Gamma_{22}|$=0.2 (model 'X')
  - For 2F0 $|\Gamma_{22}|$=0.7 (model 'Y')

This means it is vital to have good harmonic extraction during model extraction –
Difficult to achieve and verify with tickle tones.



Behavioural Model Generation: Measurement Strategy (F0 Only)

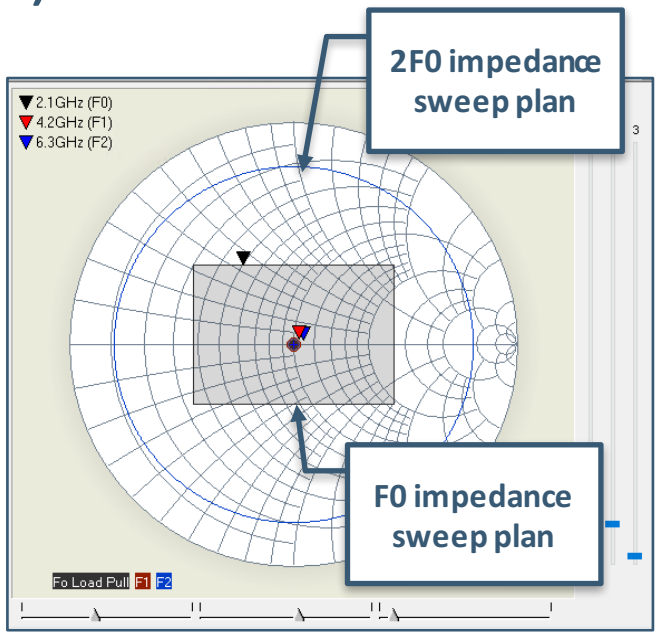
- For fundamental-only (F0) model generation, the load-F0 impedance is swept through a pre-defined sweep plan; centred around the optimum for power and efficiency performance.
- The harmonic frequencies e.g. 2F0 and 3F0 are kept at a constant impedance.
- Measurements of a_1, b_1, a_2, b_2 at all calibrated frequencies and dc values v_{1dc}, v_{2dc}, i_{1dc}, i_{2dc} are captured and stored in a file indexed by fundamental load impedance and input drive.
- We usually recommend carrying out an input drive power sweep with a ~20dB dynamic range which covers compressed as well as linear operation points.
- Fundamental source-pull is not necessary however it can aid in minimising the input return loss and thus provide a facility for driving the DUT into compression.

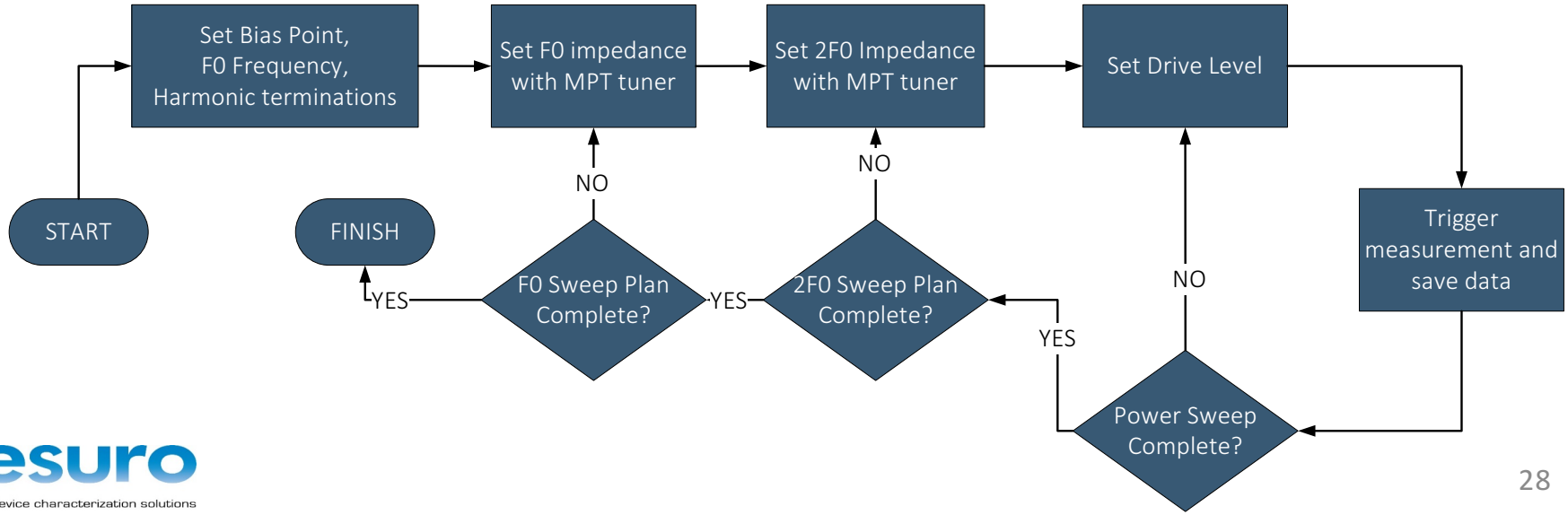


Behavioural Model Generation: Measurement Strategy (harmonics)

- For harmonic model generation, the load-F0 impedance is swept through a pre-defined sweep plan. This is "nested" with another sweep plan at each harmonic required within the model.

- An MPT Tuner can be used to simultaneously change the fundamental and harmonic impedance for the above plan.
- Such a sweep can also be realised with active Load-pull.





Behavioural Model Generation: Importing data

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Import Wave-based LP Data

Measurement Data processing…

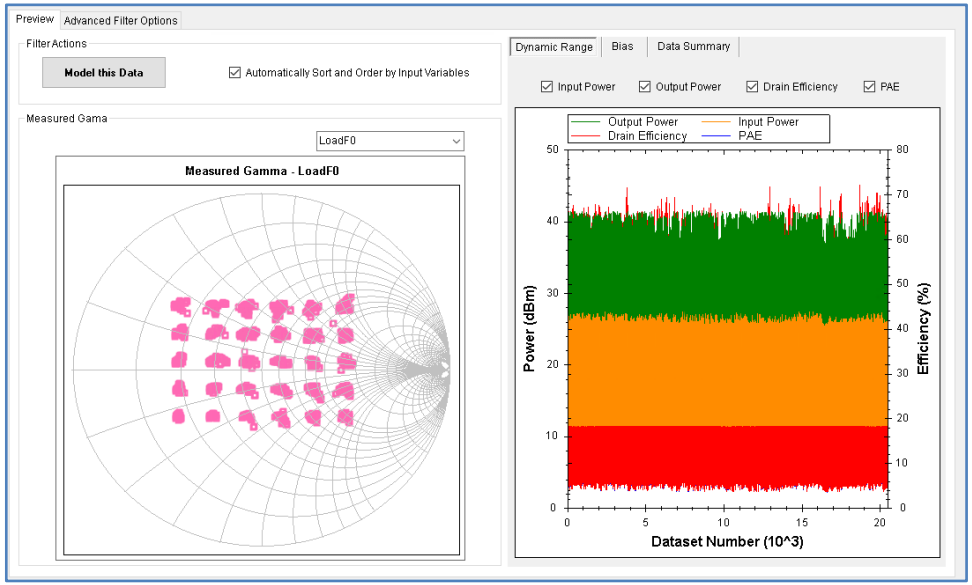
Determine the complexity (w) required to fit a global model for the given load-pull space.

Generate the Model

Model Verification:
Immediate feedback of model vs. measurement performance

Export model coefficients as MDF file or XNP File

- The generator requires measured *a* and *b* waveforms for all the harmonics and ports.
- It also requires the measured DC parameters v_{dc} *and* i_{dc}.
- Generator sorts the datasets in sub-sets of input power, frequency and bias.
- Indexing of the data-sets in |ap,h| and Q/P is carried out for each load-pull point.
- User can remove *erroneous data points* before attempting to create a model using the advanced filtering options.



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Behavioural Model Generation: Selecting the order

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Import Wave-based LP Data

Measurement Data processing…

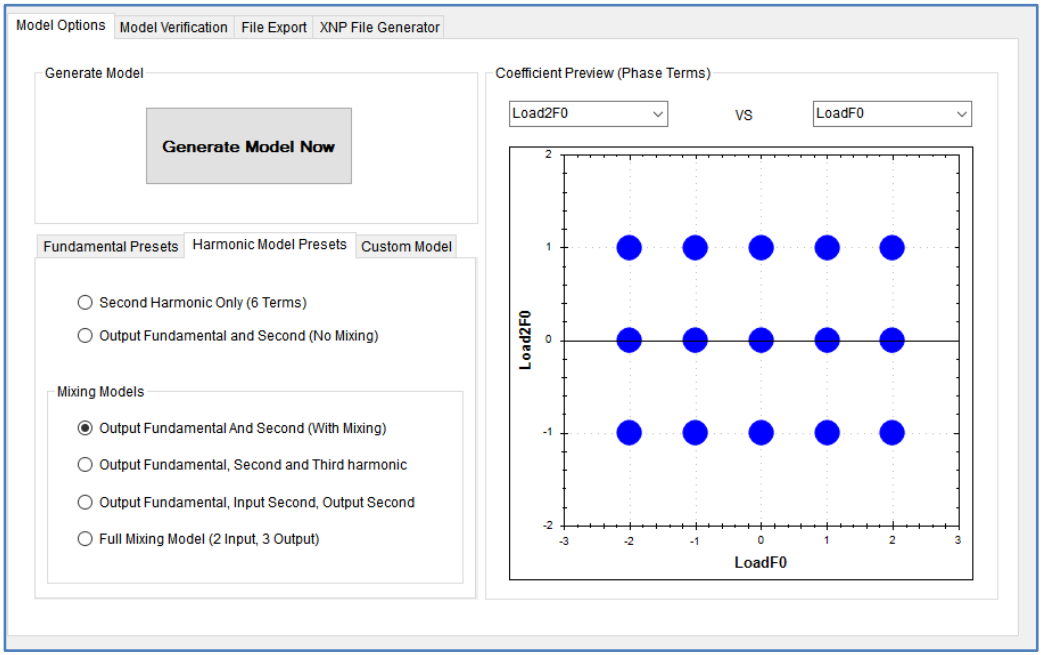
Determine the complexity (w) required to fit a global model for the given load-pull space.

Generate the Model

Model Verification:
Immediate feedback of model vs. measurement performance

Export model coefficients as MDF file or XNP File

- Based on user requirements, the generated model can be conditioned to a coefficient pattern e.g.
  - Fundamental Only,
  - Fundamental and Second Harmonic Mixing model, etc.
- Users can also define custom patterns for the behavioural model



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Behavioural Model Generation: Built-in Verification

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Import Wave-based LP Data

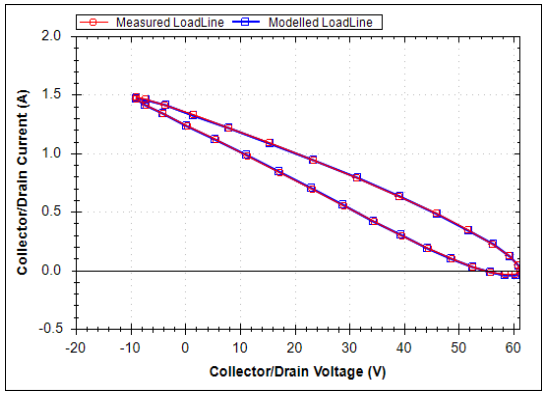
Measurement Data processing…

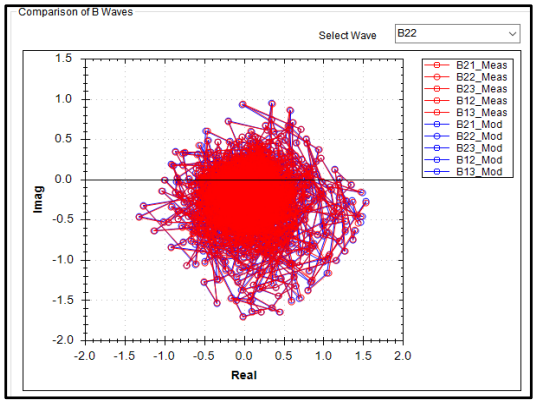
Determine the complexity (w) required to fit a global model for the given load-pull space.

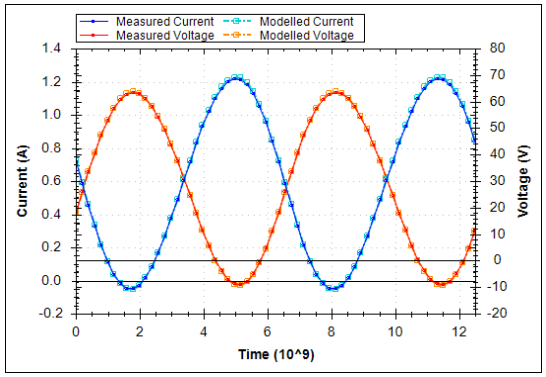
Generate the Model

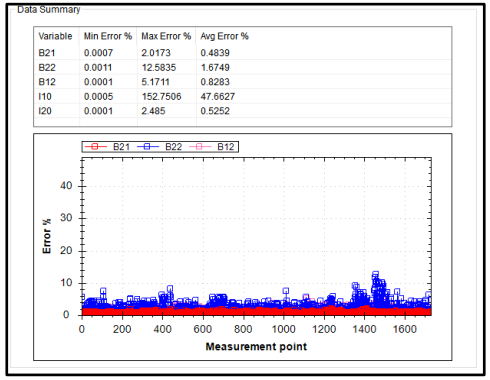
Model Verification:
Immediate feedback of model vs. measurement performance

Export model coefficients as MDF file or XNP File









- Once the model is generated, the coefficients are used to simulate measurement conditions.
- Error bars, time-domain waveforms and other plots are displayed to check the accuracy of the model.

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Behavioural Model Generation: Model files

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Import Wave-based LP Data

Measurement Data processing…

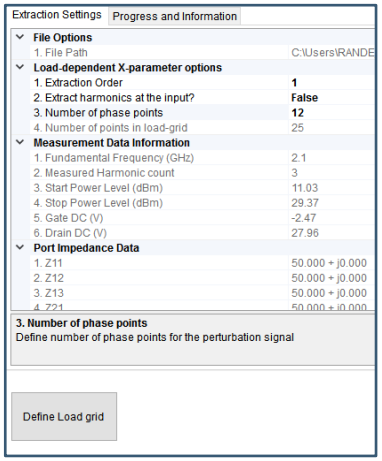
Determine the complexity (w) required to fit a global model for the given load-pull space.

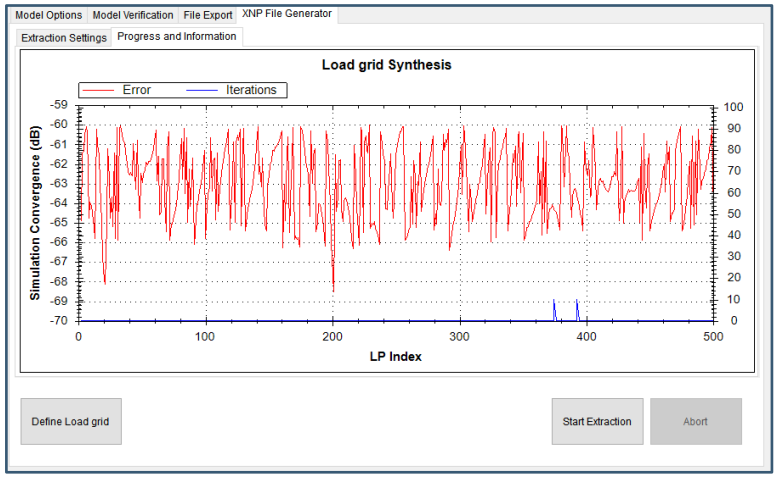
Generate the Model

Model Verification:
Immediate feedback of model vs. measurement performance

Export model coefficients as MDF file or XNP File

- CM+ Model files are in MDF format with a very small file size (<100kB) compatible with
  - Keysight ADS v2009-2015
  - AWR Microwave office v9.0-12.0
- CM+ Models can also be saved as *.xnp files with the built-in XNP Model file generator





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Performance of Model in CAD

A Worked Example

Using AWR Microwave Office

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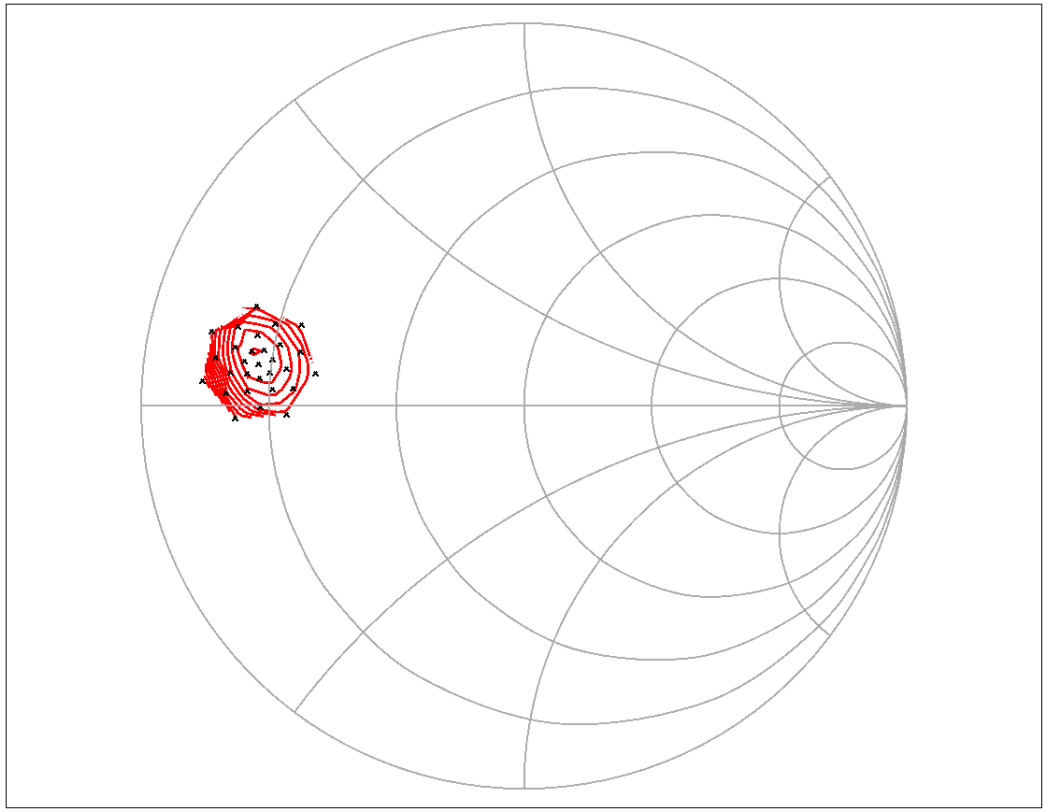
High Power transistor modeling example

- Measurements were conducted on a 21mm GaN device with 75V drain voltage. Device was biased at 2mA/mm.
- Hybrid Load-Pull approach employed with F0 controlled through a passive tuner and harmonics controlled using active load-pull (ZVA with DDS Sources).
- Impedance transformer (15 Ohms) is used to reduce the requirements on the tuner along with the system amplifiers.

- First a model is extracted. I then follow up with a rough device optimisation using measurements (not the ones used to generate the model) then track the performance of the measurements to simulation.

F0 Load-Pull Contours Power

- Load-pull contours for power. Available power is 38.3dBm. Harmonics terminated into system impedance (Nominally 15Ohms). Reference plane is device tabs.



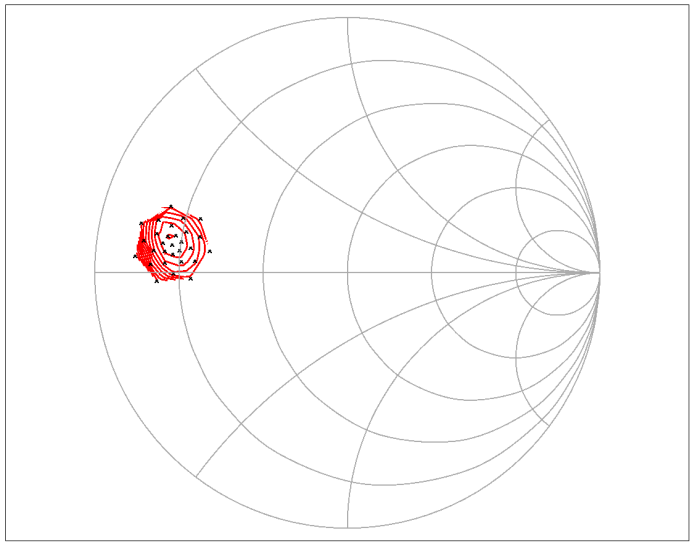
Min Pout_dBm = 51.72
Mag = 0.84
Phase = 175.52 degs

Max Pout_dBm = 53.2
Mag = 0.72
Phase = 168.67degs

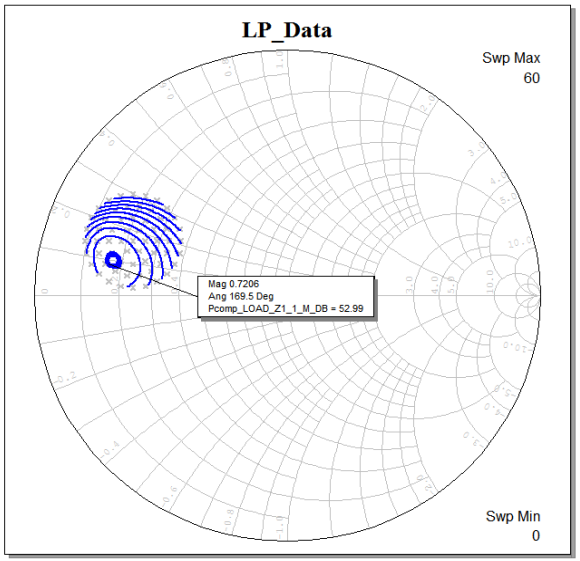
F0 Load-Pull Contours
Power **Model Verification**

- Measurement Comparison to simulation using the same 38.3dBm available power forom the source.

Measurement



Simulation



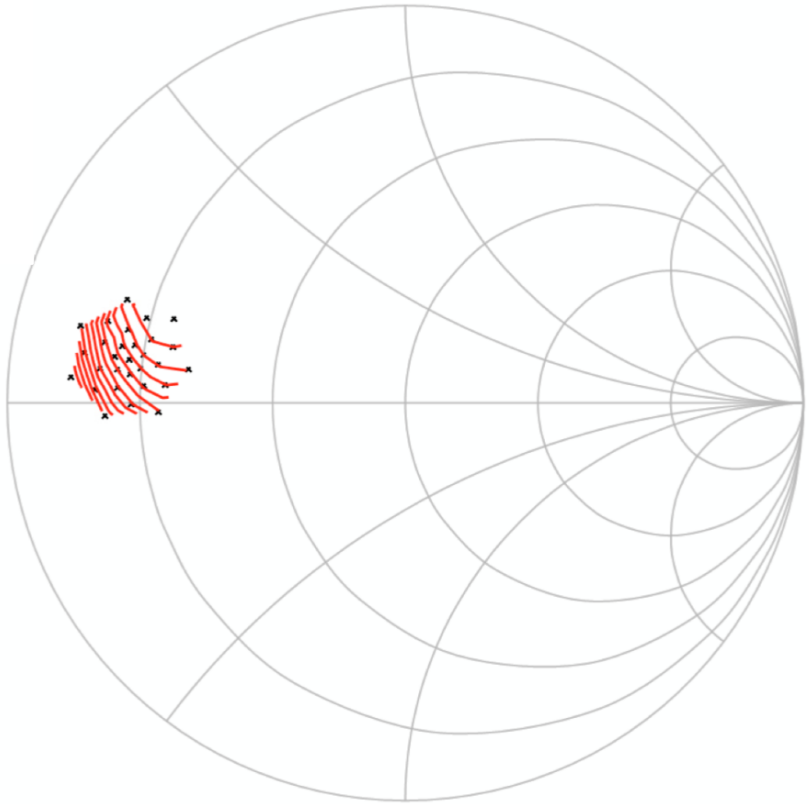
Measured Pout Max = 53.2 dBm
At point – 0.72<169

Simulated Pout Max = 53 dBm
At point – 0.72<169.5

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F0 Load-Pull Contours
Drain Efficiency

- Load-pull contours for Drain Efficiency. Available power is 38.3dBm. Harmonics terminated into system impedance (Nominally 15Ohms). Reference plane is device tabs.



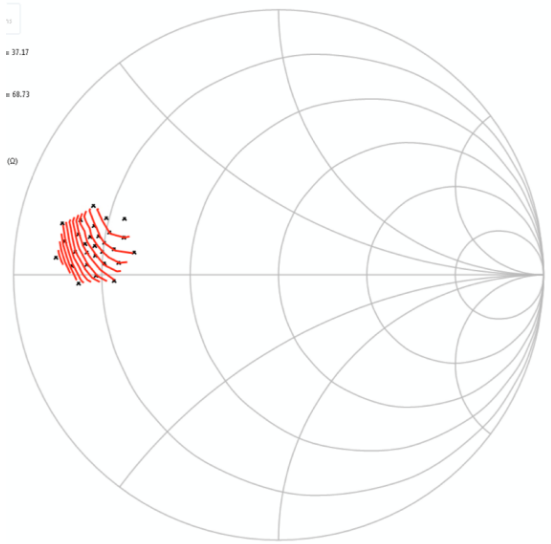
Min Drain Efficiency = 37.17
Mag = 0.84
Phase = 175.52 degs

Max Drain Efficiency = 68.73
Mag = 0.62
Phase = 160.02degs

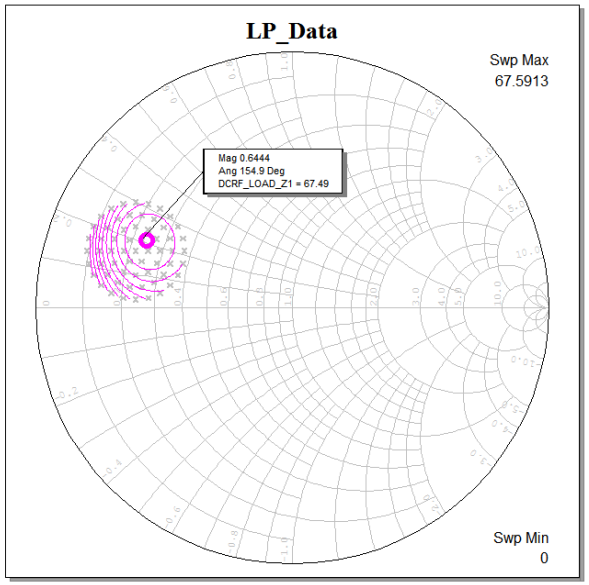
F0 Load-Pull Contours
Efficiency **Model Verification**

- Measurement Comparison to simulation using the same 38.3dBm available power from the source.

Measurement



Simulation

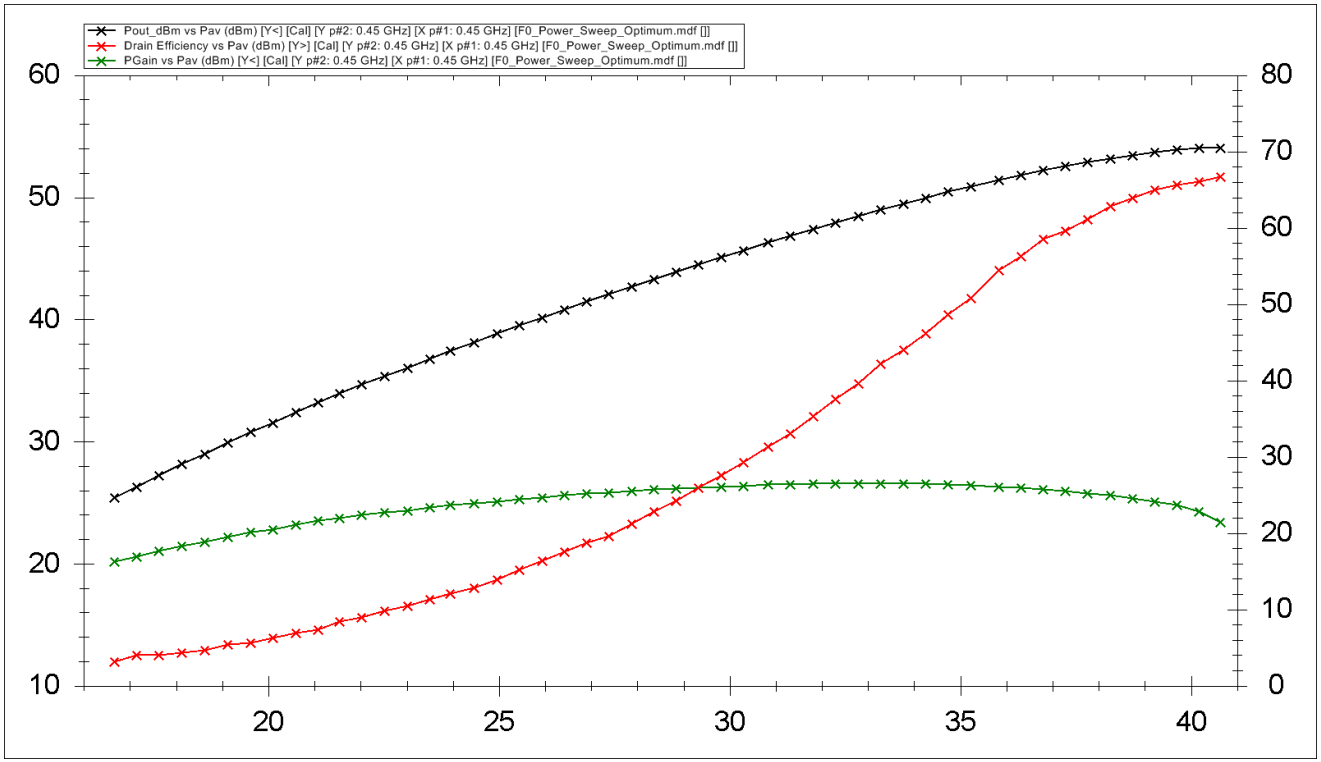


Measured Drain Efficiency Max = 68.73%
At point – 0.62<160

Simulated Drain Efficiency Max = 67.49%
At point – 0.64<155

F0 Power Sweep
Power Optimum

- Power Sweep into impedance for optimum power.



Pout Max – 54.03dBm - 253W

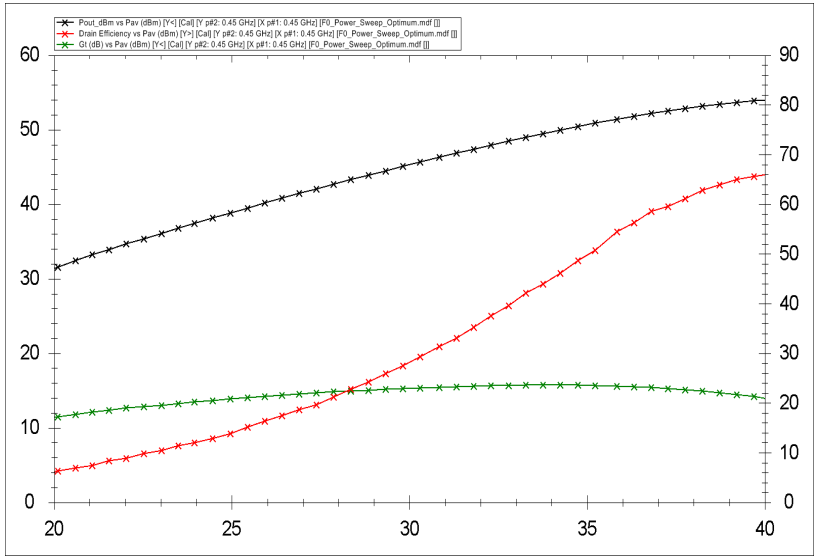
Drain Eff Max – 66.67%

F0 – 0.69<169

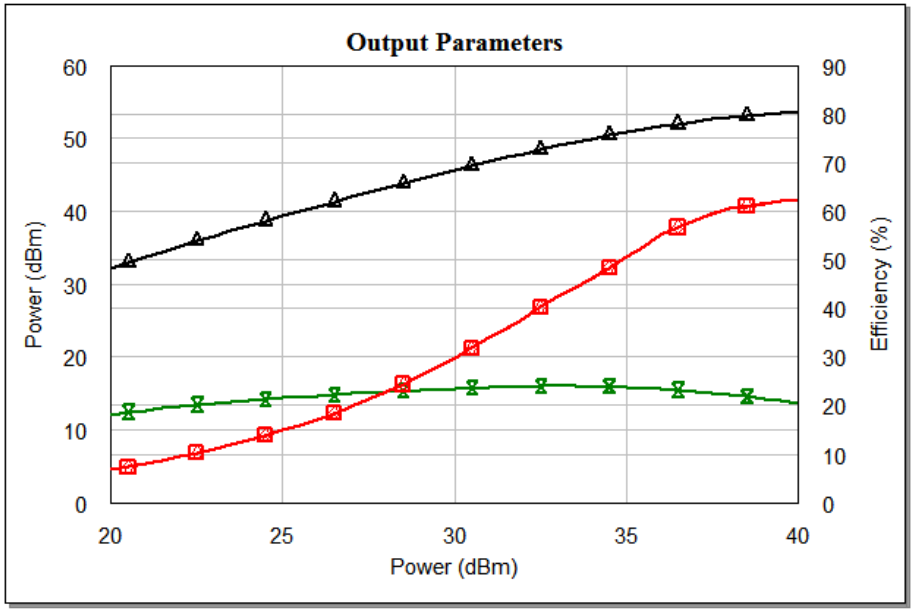
F0 Power Sweep
Power Optimum
Model Verification

- Power Sweep into impedance for optimum power.
- F0 = 0.69<169

Measurement



Simulation



Pout – 53.87dBm
Drain Eff – 65.57%

Compare Data With Pav=40dBm

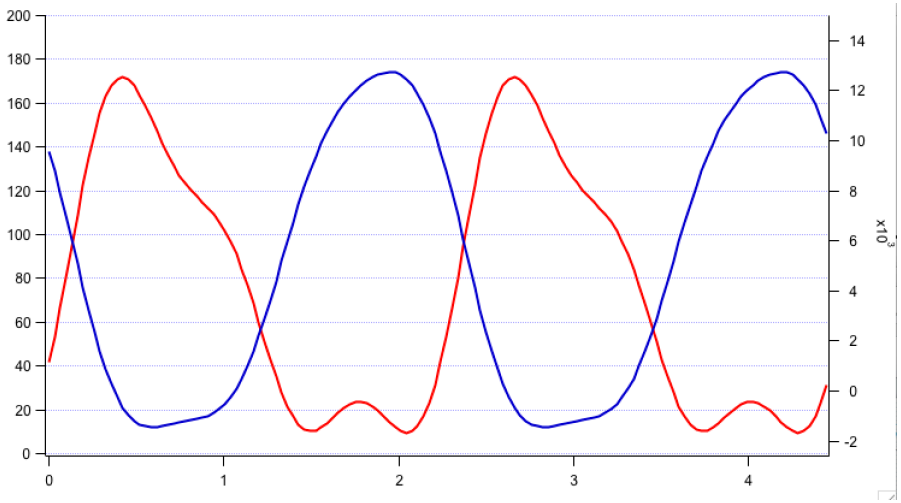
Pout – 53.55dBm
Drain Eff – 62.48%

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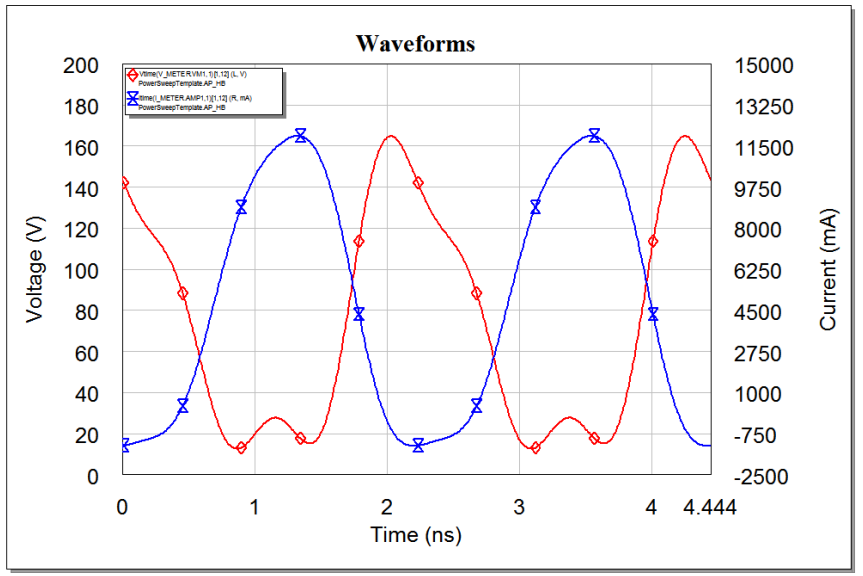
Power Sweep
Power Optimum F0
Model Verification

- Waveforms

Measurement



Simulation

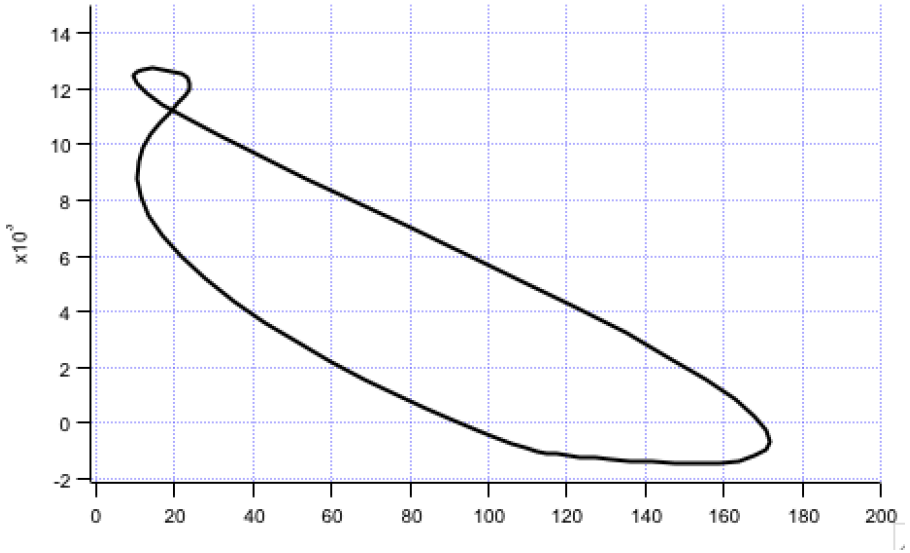


Compare Data
With Pav=40dBm

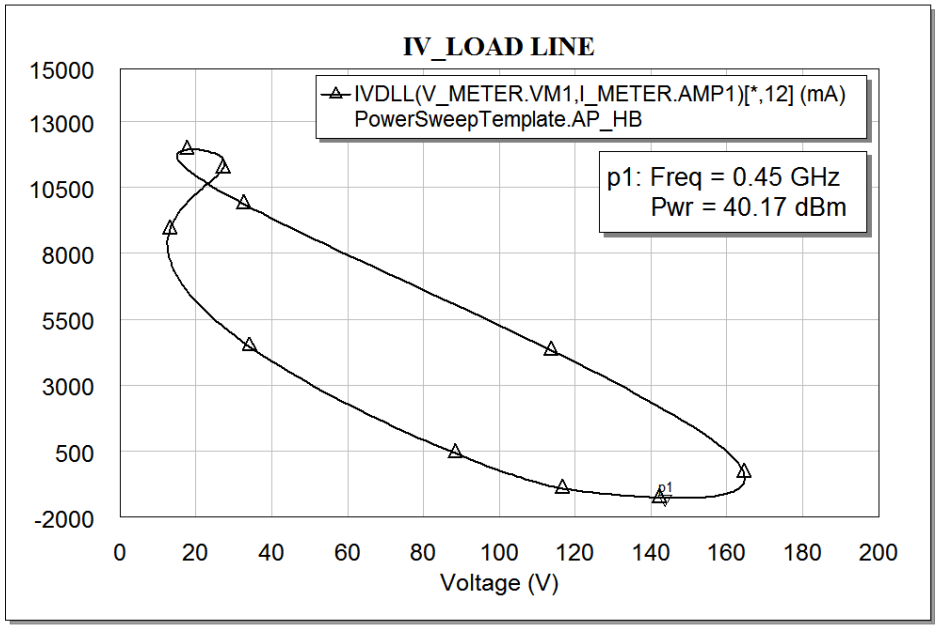
Power Sweep
Power Optimum F0
Model Verification

- Dynamic Load-line

Measurement



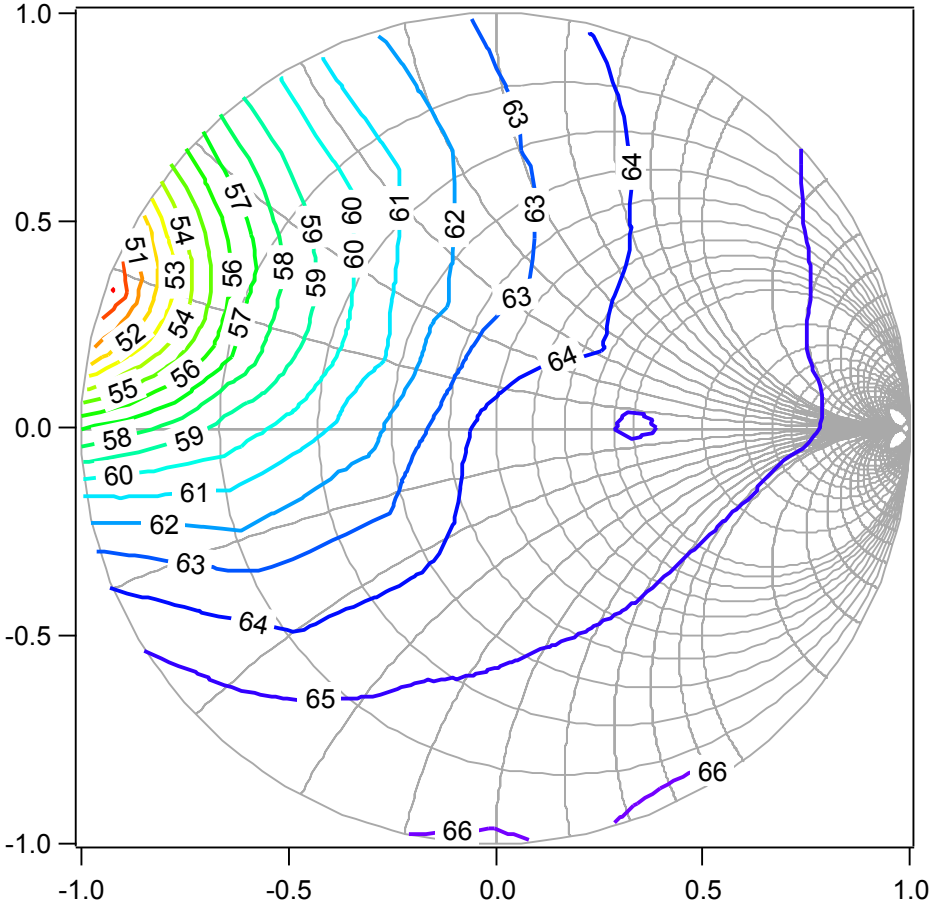
Simulation



Compare Data
With Pav=40dBm

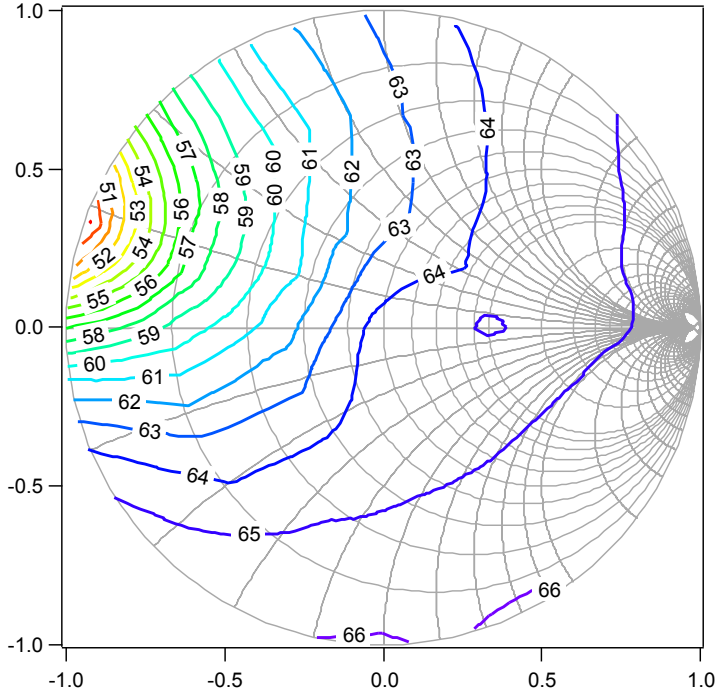
2F0 Sweep
F0 held at Power Optimum

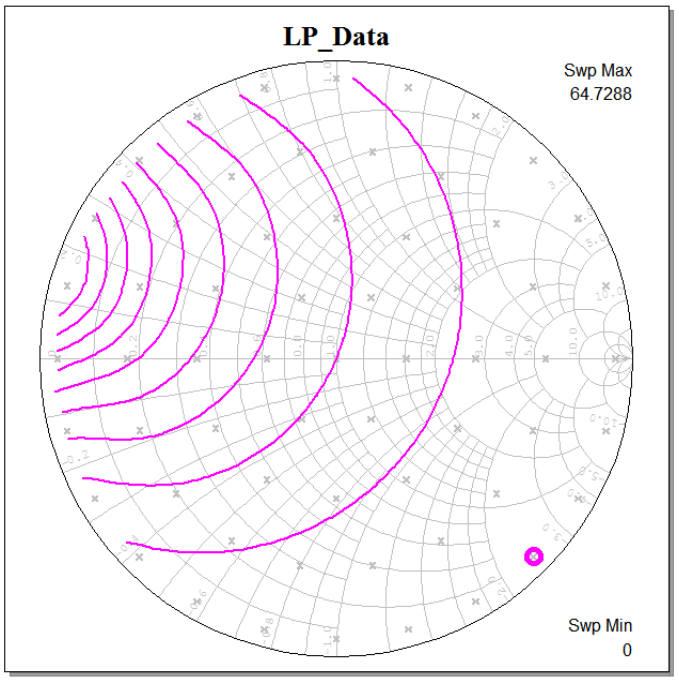
- 2F0 Drain Efficiency contour.



2F0 Sweep
F0 held at Power Optimum
Model Verification

- 2F0 Drain Efficiency contour.



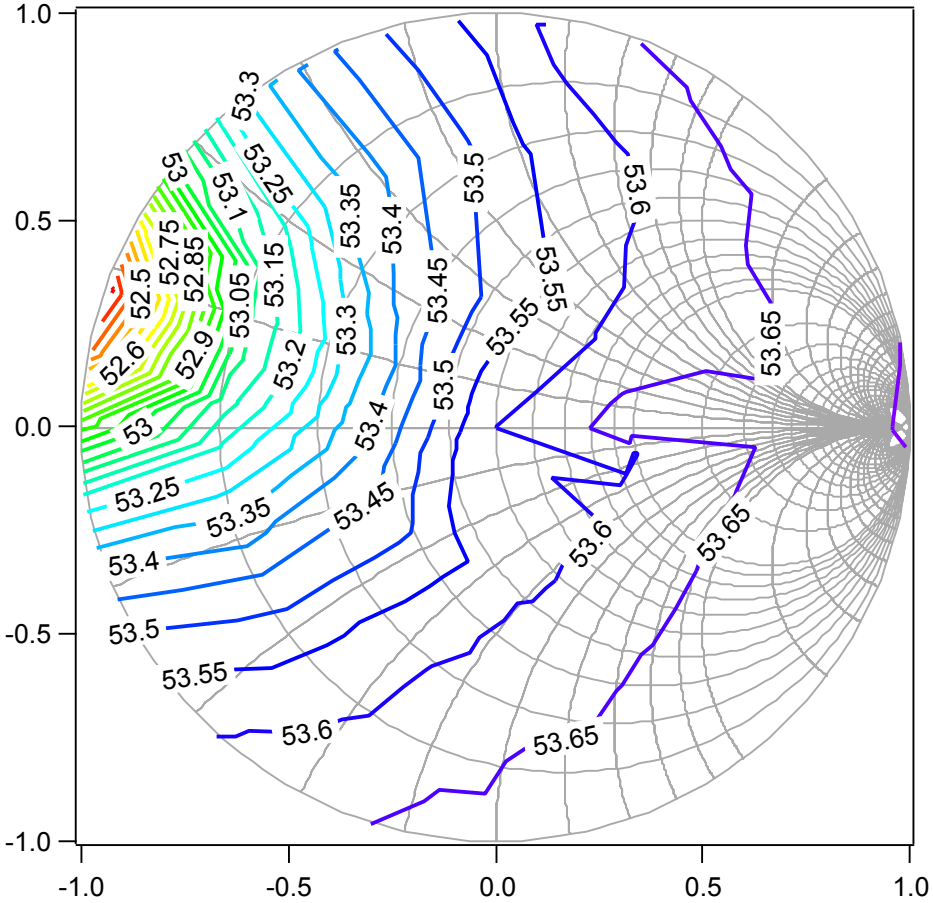


Measured Max – 65.97%
Measured Min – 48.94%

Simulation Max – 64.73
Simulation Min – 50.02%

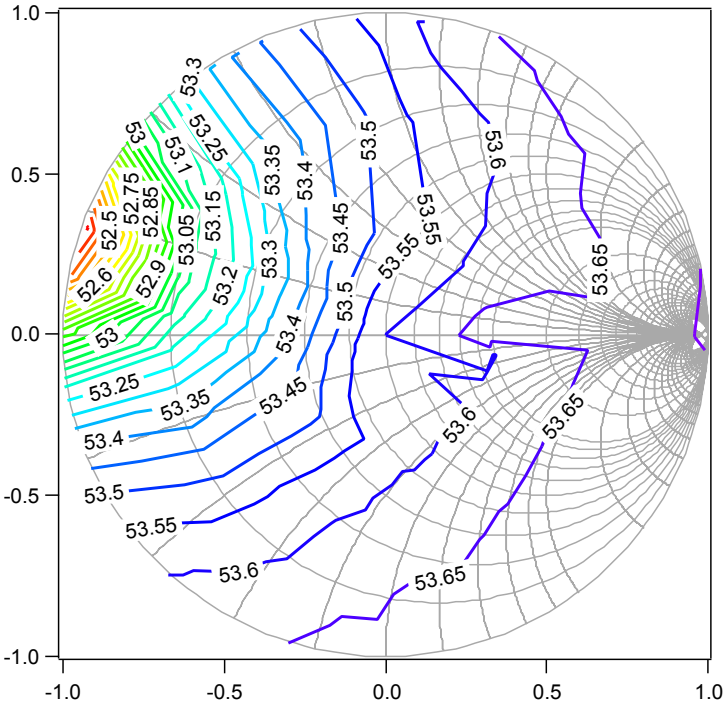
2F0 Sweep
F0 held at Power Optimum

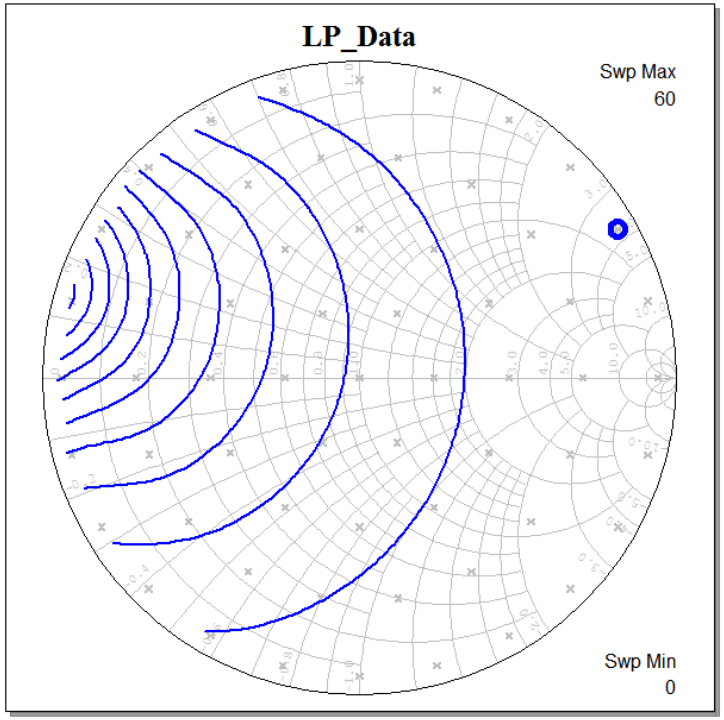
- 2F0 Power contour



2F0 Sweep
F0 held at Power Optimum
Model Verification

- 2F0 Power contour



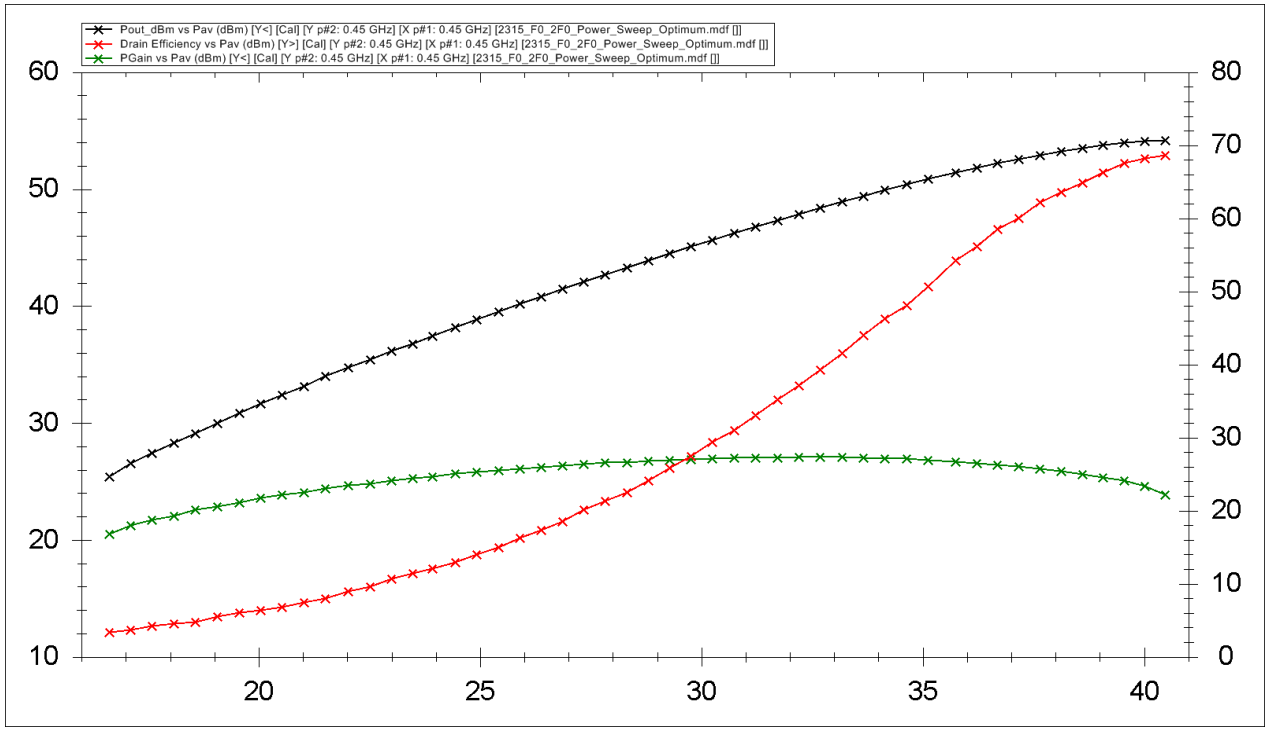


Measured Max – 53.71dBm
Measured Min – 52.34dBm

Simulation Max – 53.49dBm
Simulation Min - 52.58dBm

Power Sweep
Power Optimum F0+2F0

- Power Sweep with optimums at F0 and 2F0.



Pout Max – 54.15dBm
- 260W

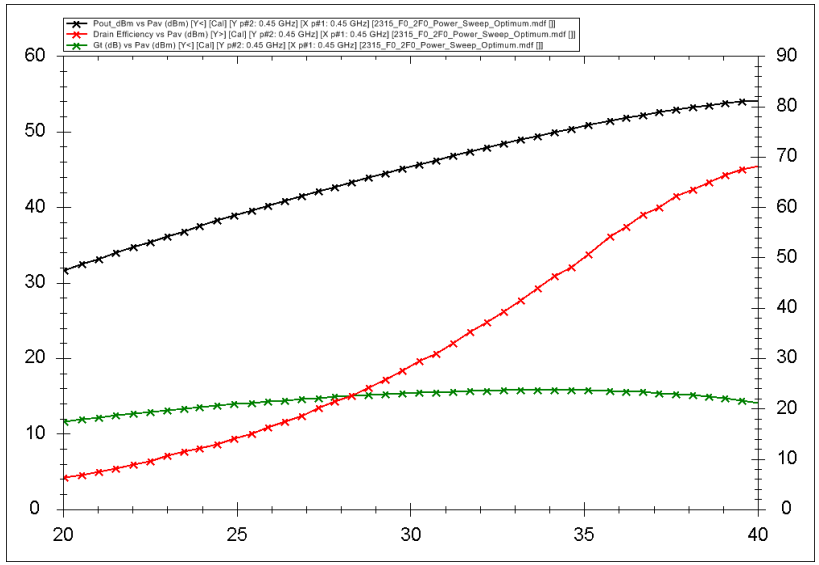
Drain Eff Max – 68.671

F0 – 0.69<169
2F0 – 1<-60

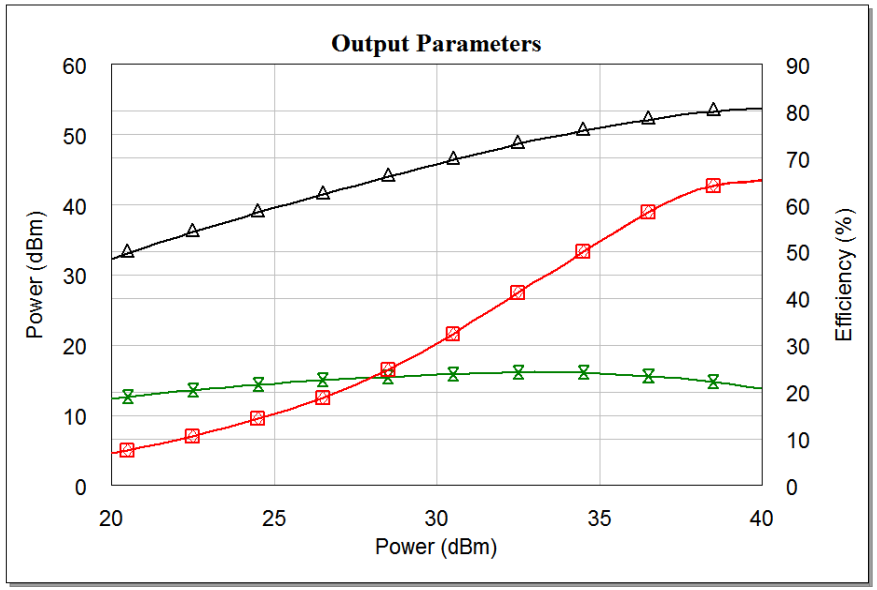
Power Sweep
Power Optimum F0+2F0
Model Verification

- Power Sweep, F0, 2F0 optimums

Measurement



Simulation



Pout – 53.95dBm
Drain Eff – 68.00%

Compare Data With Pav=40dBm

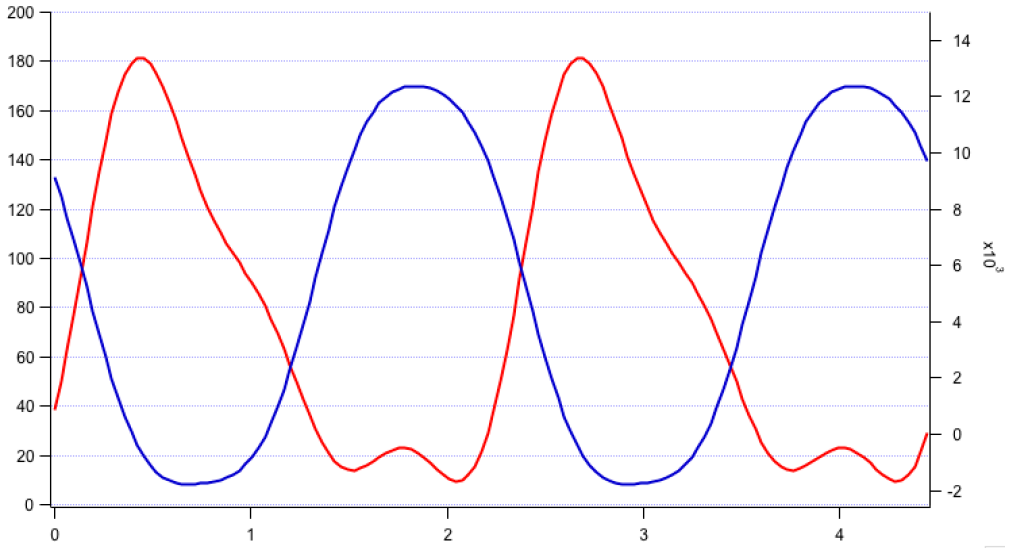
Pout – 53.76dBm
Drain Eff – 65.19%

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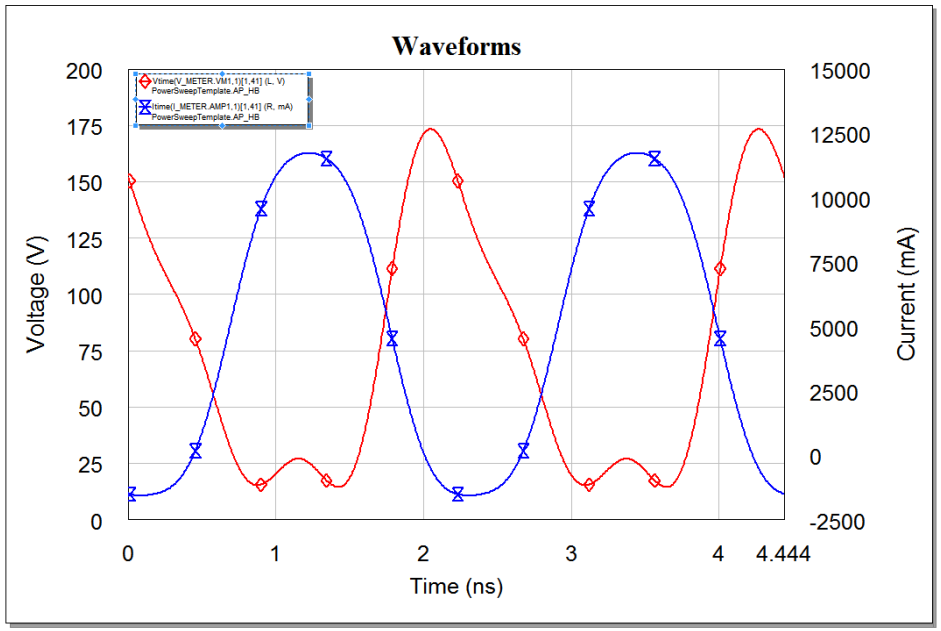
Power Sweep
Power Optimum F0+2F0
Model Verification

- Waveforms

Measurement



Simulation

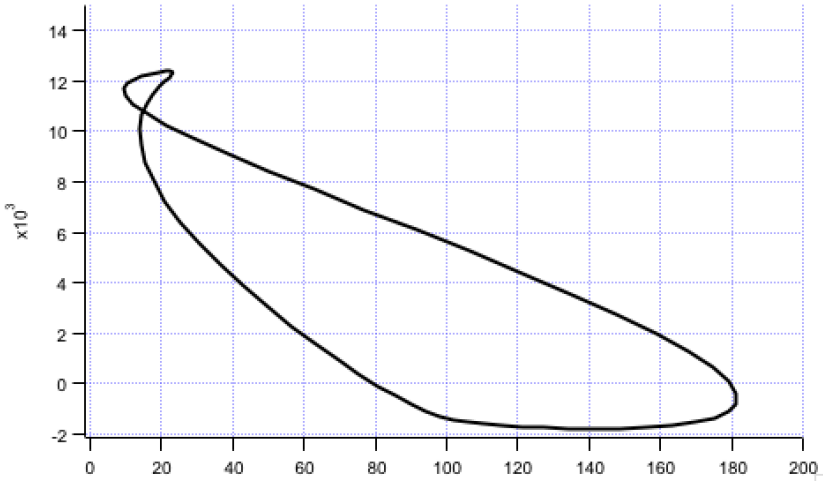


Compare Data
With Pav=40dBm

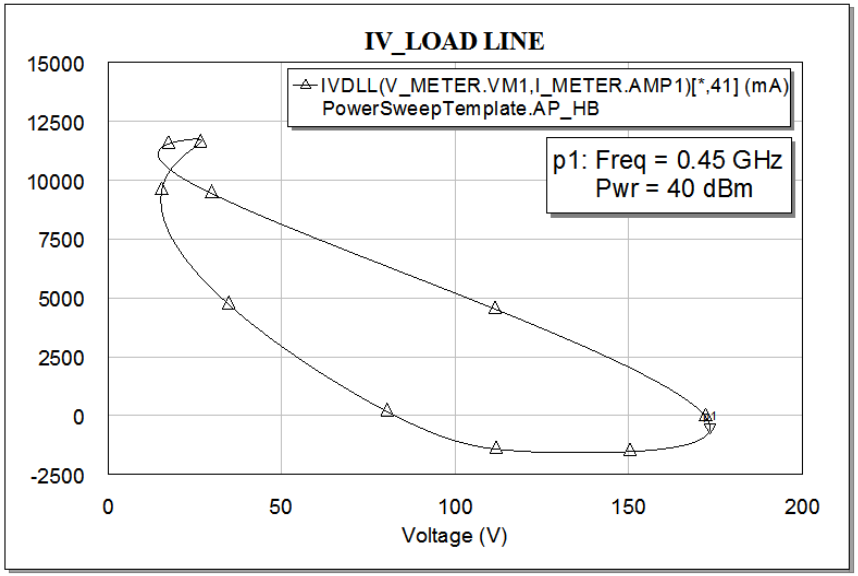
Power Sweep
Power Optimum F0+2F0
Model Verification

- Dynamic Load-line

Measurement



Simulation



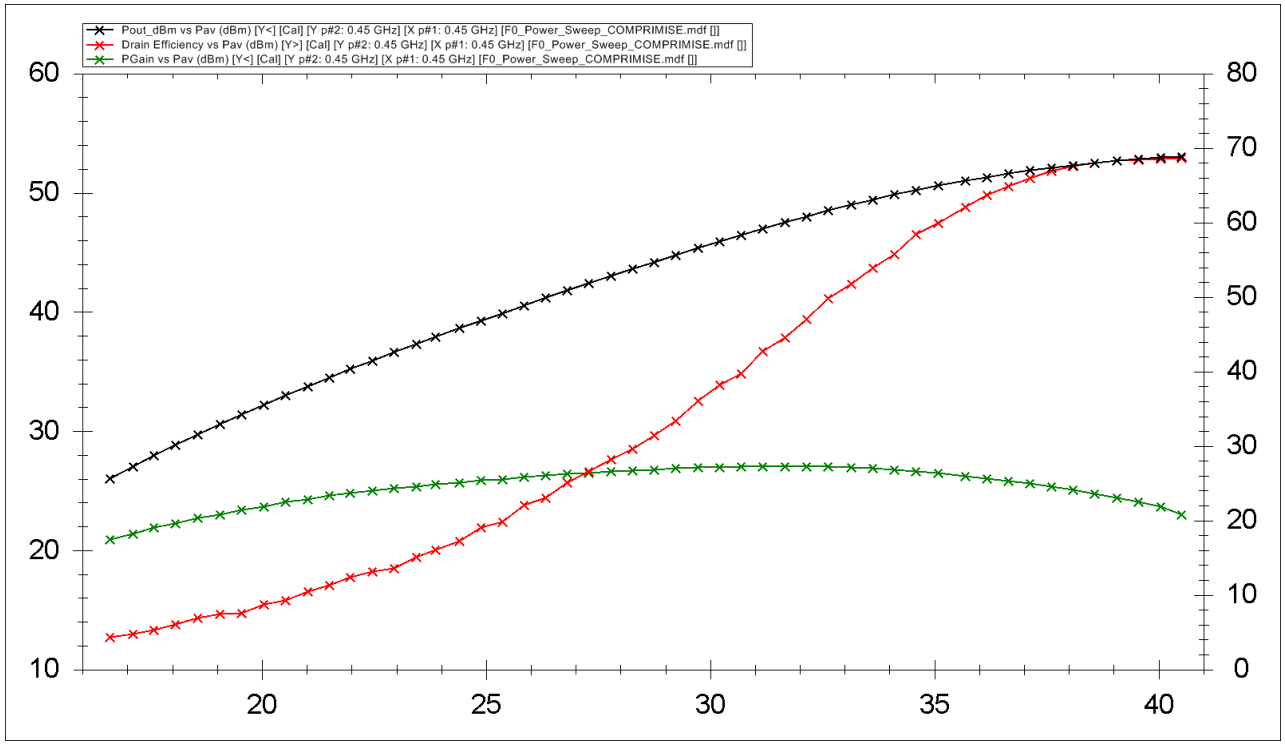
Compare Data With Pav=40dBm

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Pick Compromise point for Power/Efficiency

Power Sweep
F0 Compromise Point

- Power Sweep with compromise point chosen at F0, harmonics terminated into system impedance nominally 15 ohms.



Pout Max – 53.02dBm - 200.44W

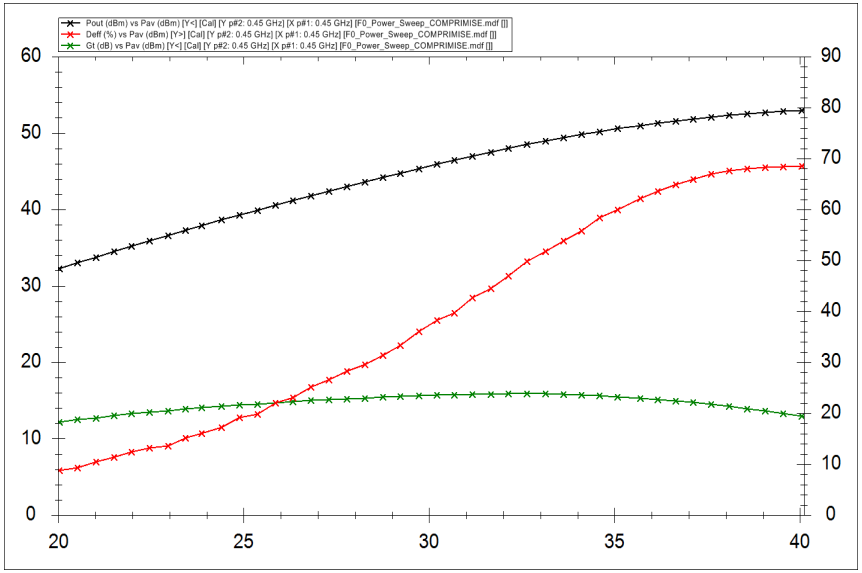
Drain Eff Max – 68.6%

F0 – 0.618<159

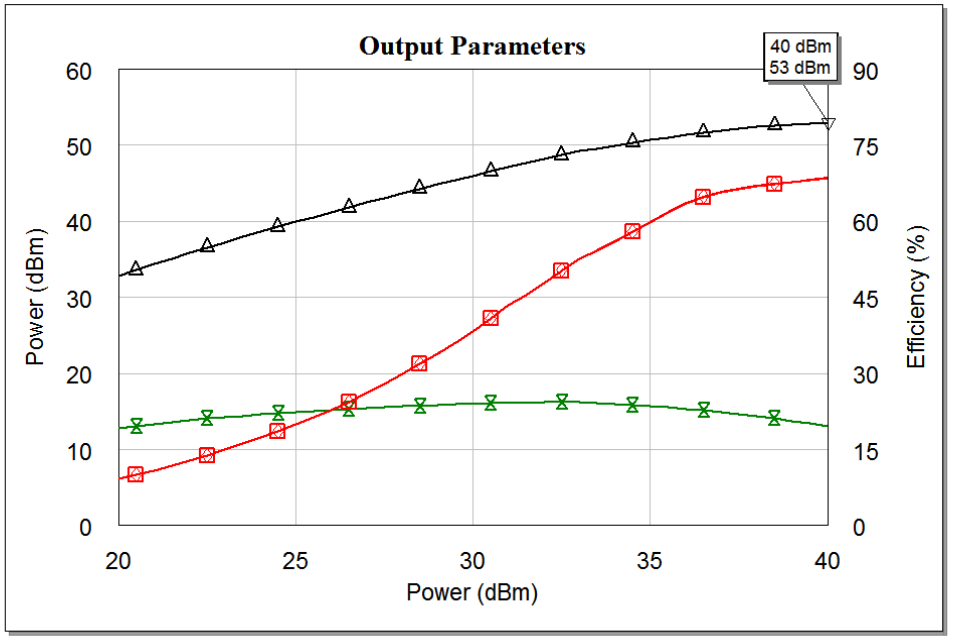
Power Sweep
Compromise Point F0
Model Verification

- Power Sweep, F0 held at compromise point, harmonics into system impedance.

Measurement



Simulation



Pout – 52.95dBm
Drain Eff – 68.51%

Compare Data With Pav=40dBm

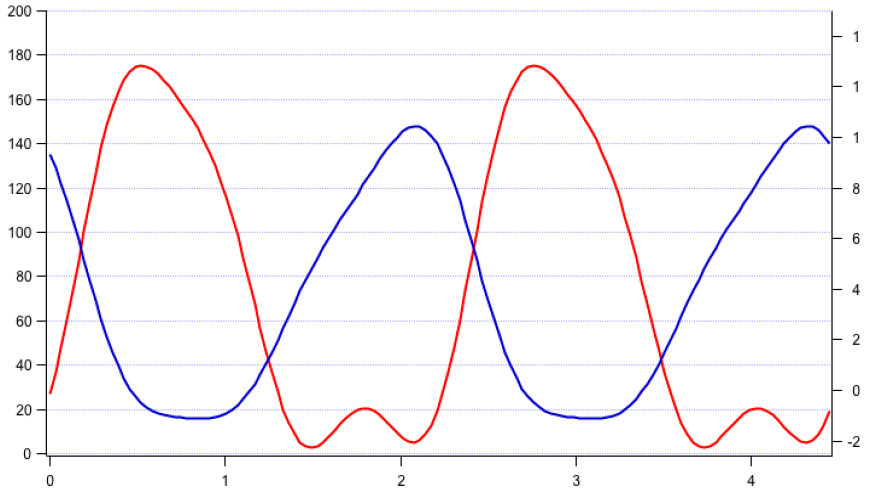
Pout – 52.99dBm
Drain Eff – 68.65%

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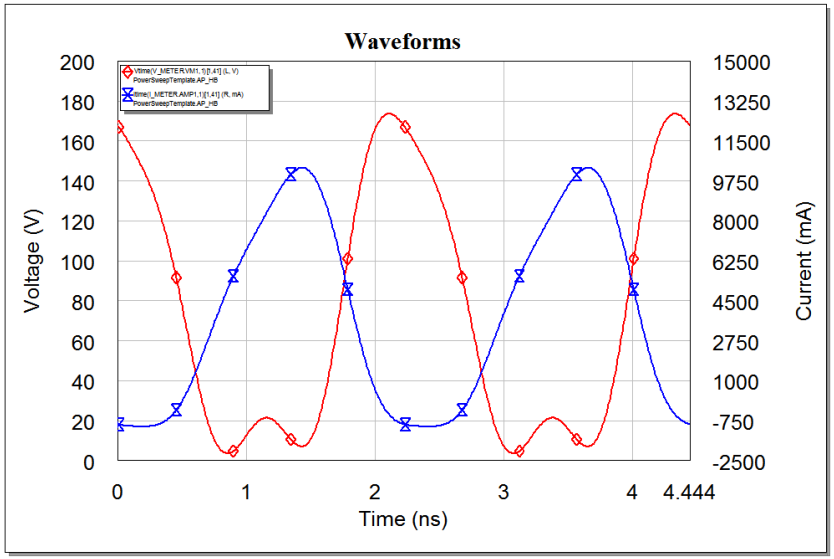
Power Sweep
Power Optimum F0
Model Verification

- Waveforms

Measurement



Simulation

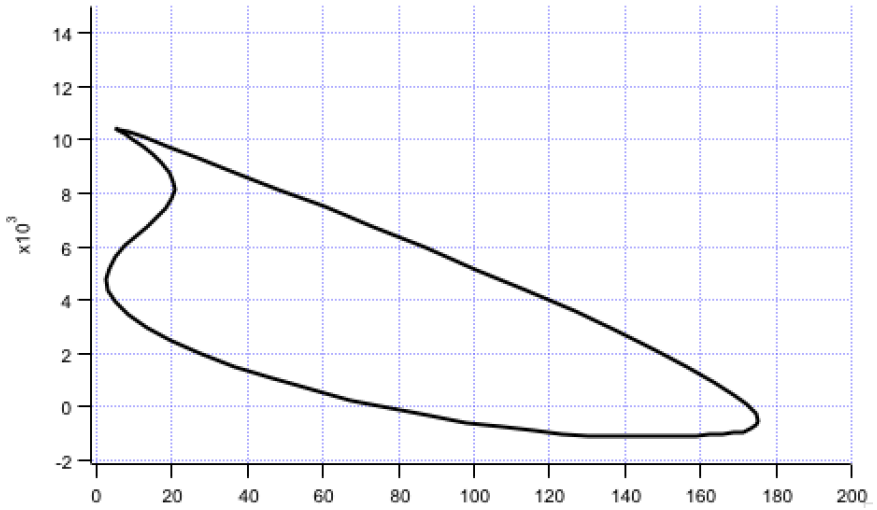


Compare Data
With Pav=40dBm

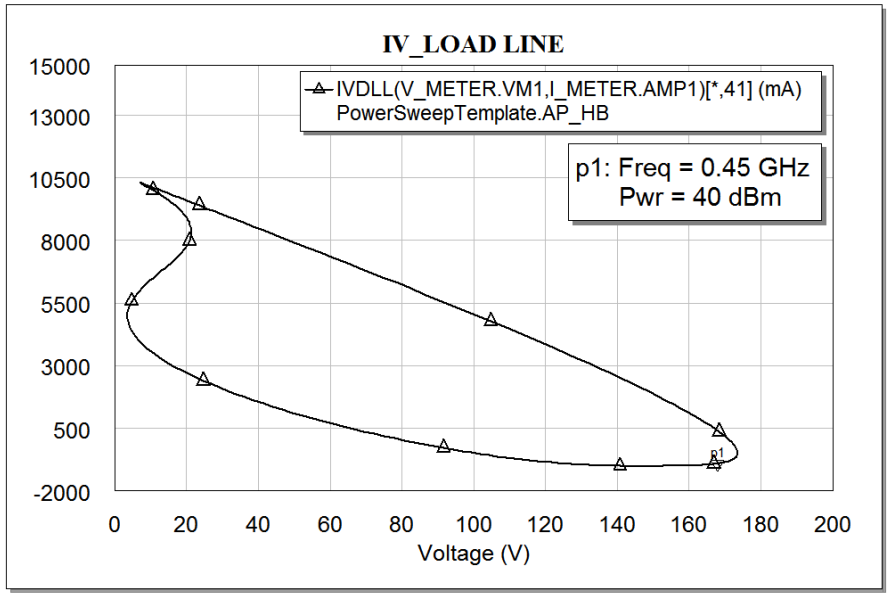
Power Sweep
Power Optimum F0
Model Verification

- Dynamic Load-line

Measurement



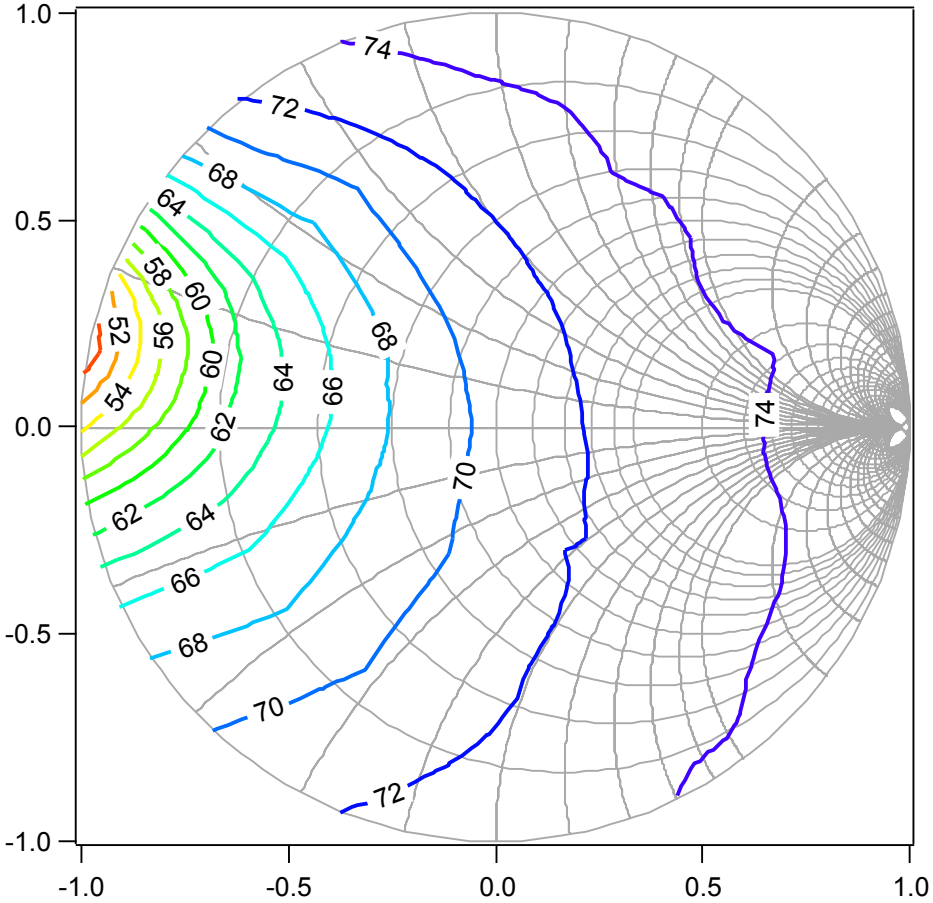
Simulation



Compare Data
With Pav=40dBm

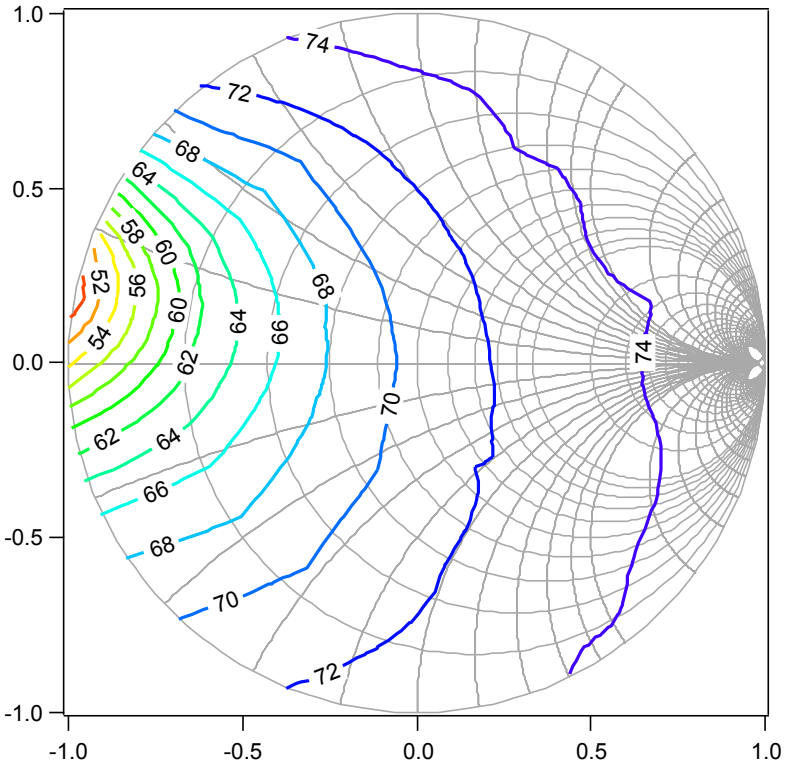
2F0 Sweep
F0 held Compromise Point

- 2F0 Drain efficiency contour

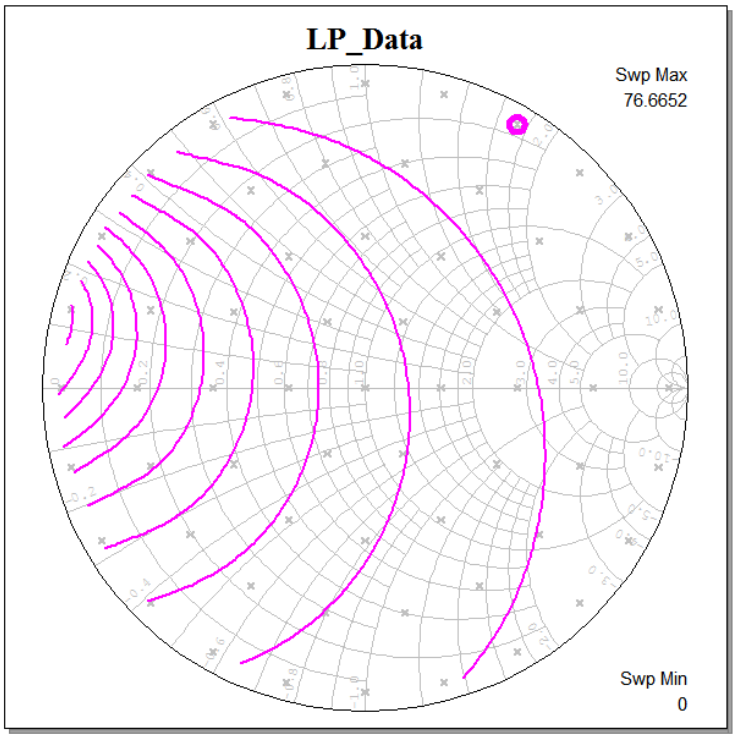


2F0 Sweep
F0 held Compromise Point
Model Verification

- 2F0 Drain efficiency contour.



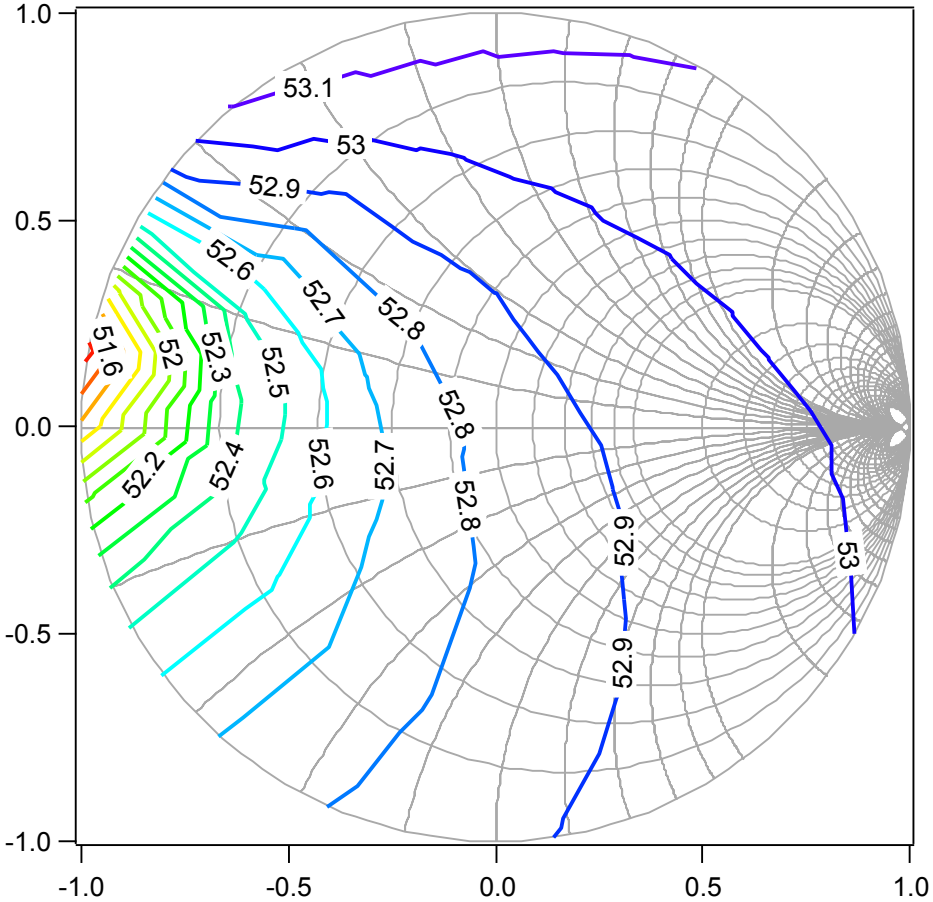
Measured Max – 75.39%
Measured Min – 48.46%



Simulation Max – 76.67%
Simulation Min – 51.7%

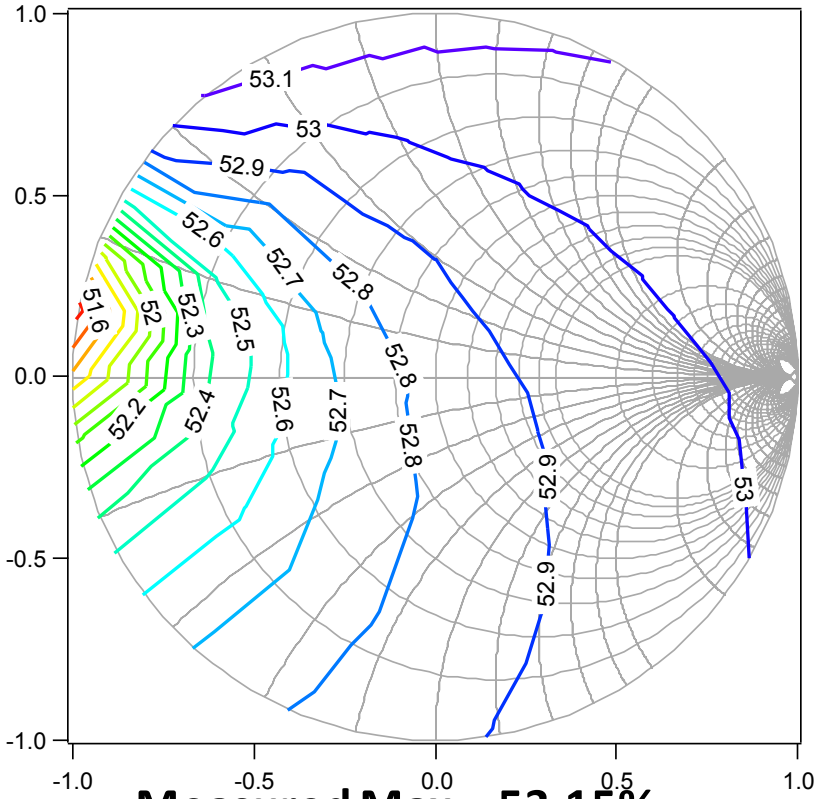
2F0 Sweep
F0 held Compromise Point

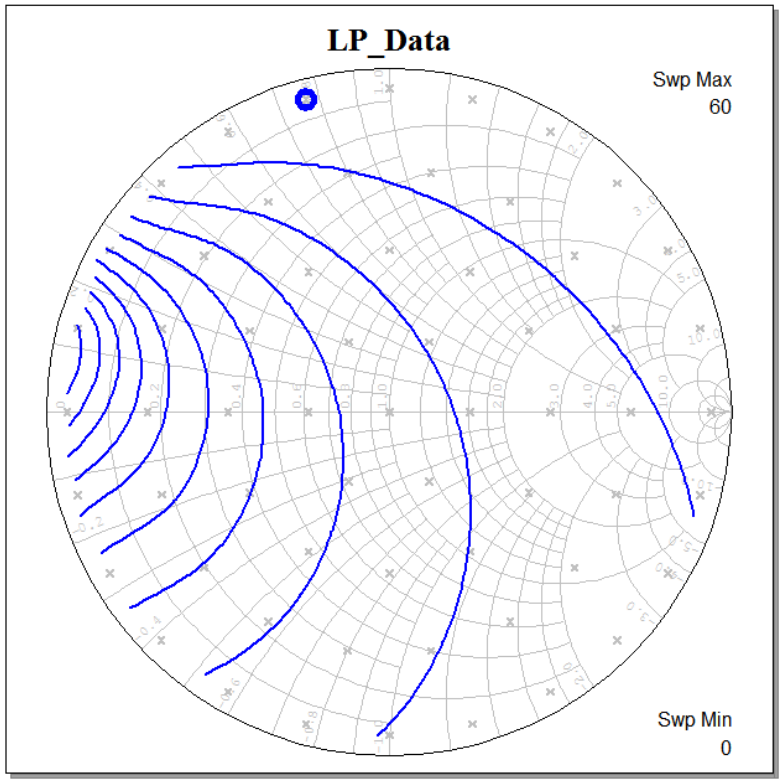
- 2F0 power contour.



2F0 Sweep
F0 held Compromise Point
Model Verification

- 2F0 Power contour.





Measured Max – 53.15%

Measured Min – 51.46%

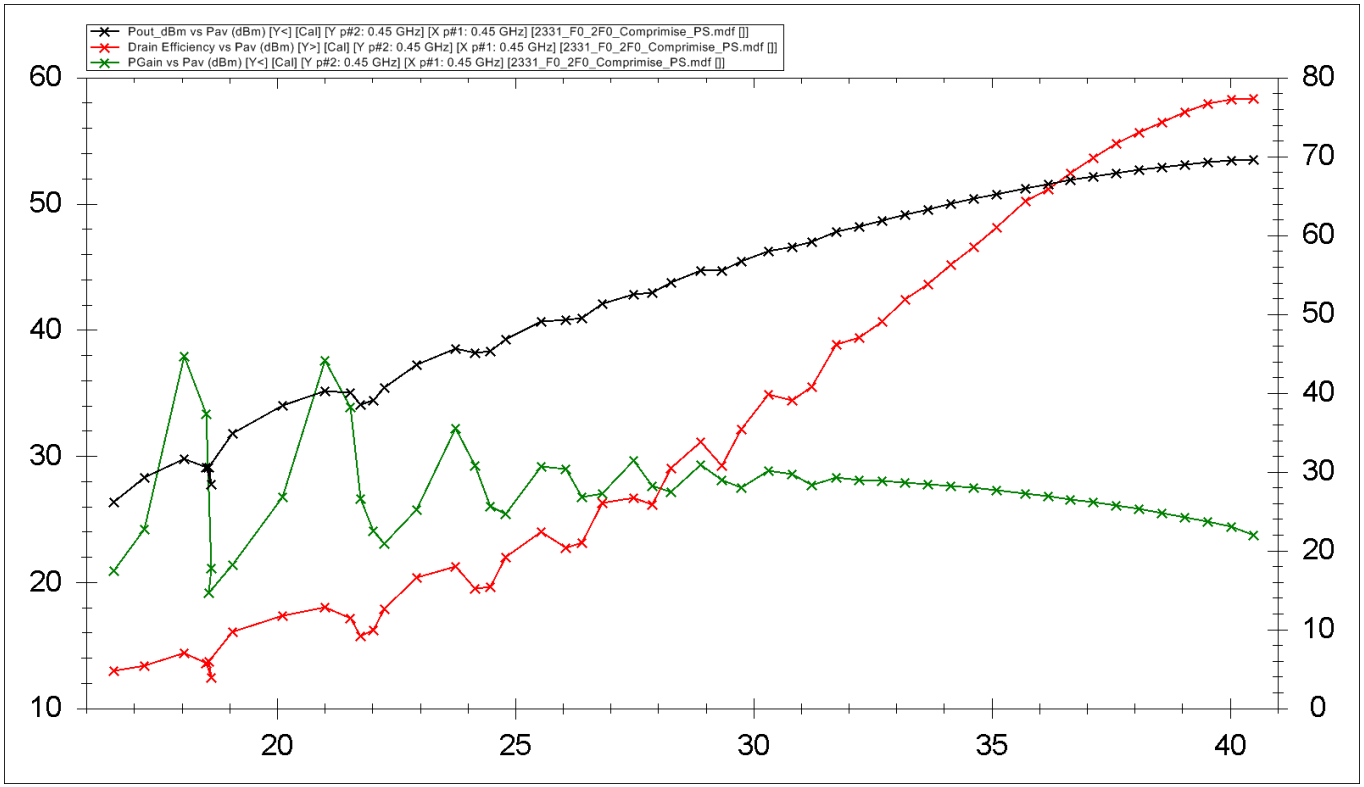
Simulation Max – 53.22dBm

Simulation Min – 51.7%

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Power Sweep
F0+2F0 Compromise Point

- Power Sweep, F0 held at compromise point, 2F0 at optimum impedance.



Pout Max – 53.51dBm
- 224W

Drain Eff Max – 77.37%

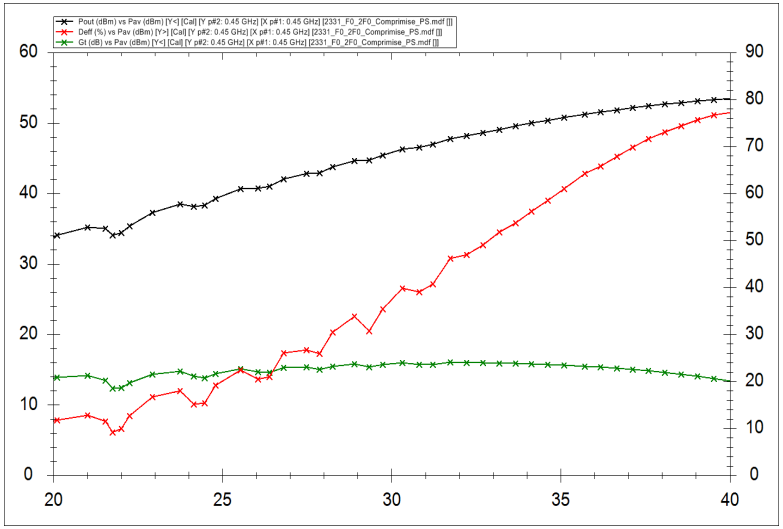
F0 – 0.618<159
2F0 – 1<59

2F0 Stability Problem!!!!!

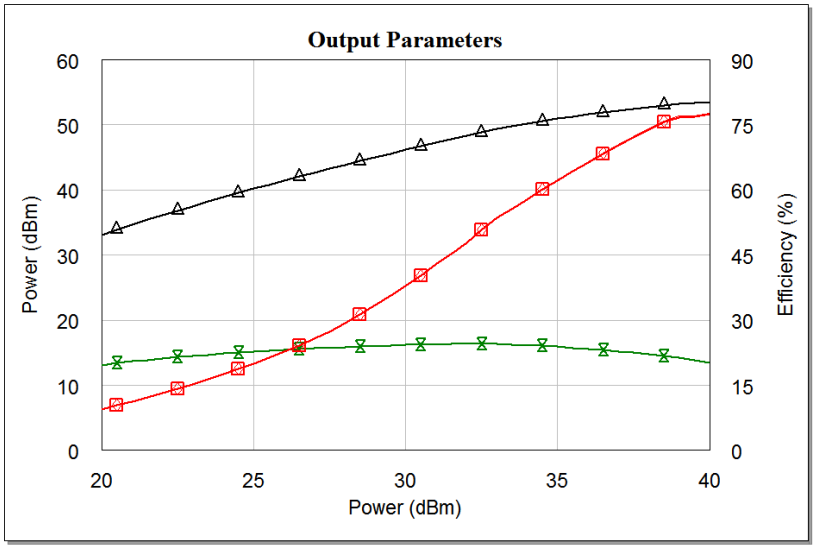
Power Sweep
Compromise Point F0&2F0
Model Verification

- Power Sweep, F0 held at compromise point, 2F0 at optimum impedance.

Measurement



Simulation



Pout – 53.44dBm
Drain Eff – 77.23%

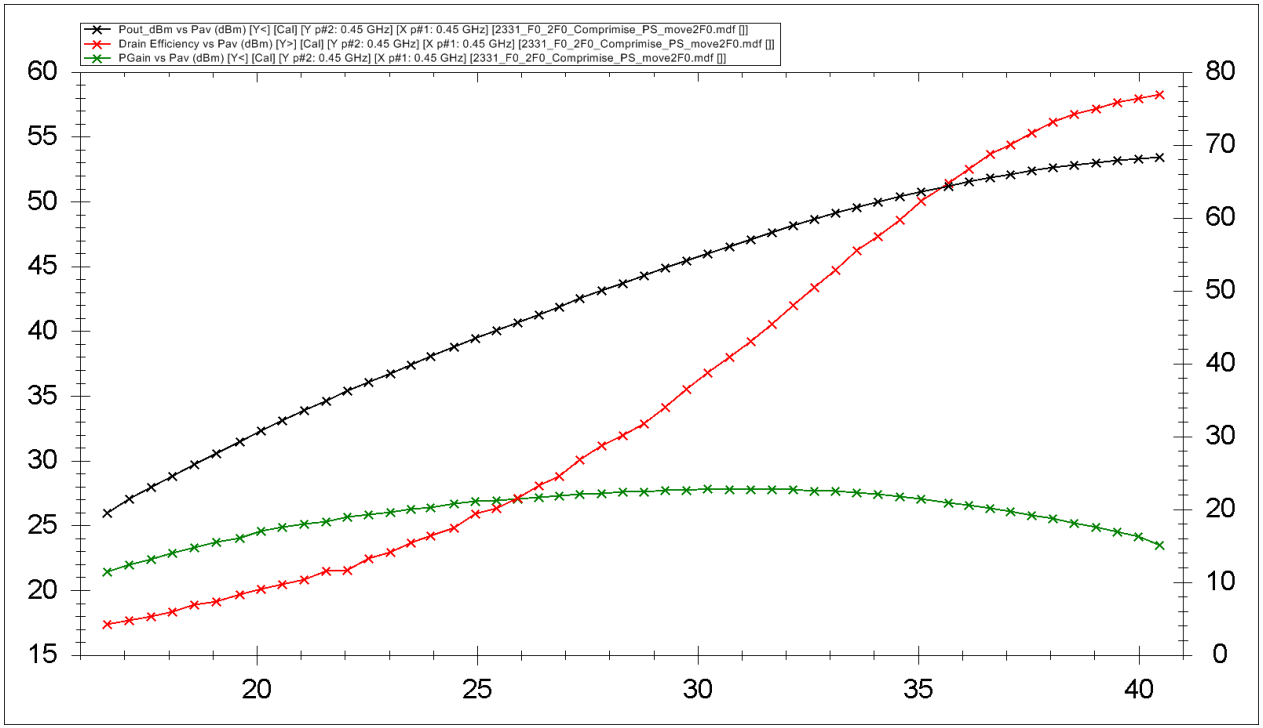
Compare Data With Pav=40dBm

Pout – 53.49dBm
Drain Eff – 77.72%

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Power Sweep
F0+2F0 Compromise Point
Rotate 2F0 from 60 to -60 degrees

- Power Sweep, F0 held at compromise point, 2F0 moved to avoid instability.



Pout Max – 53.4dBm
- 218.7W

Drain Eff Max – 76.92%

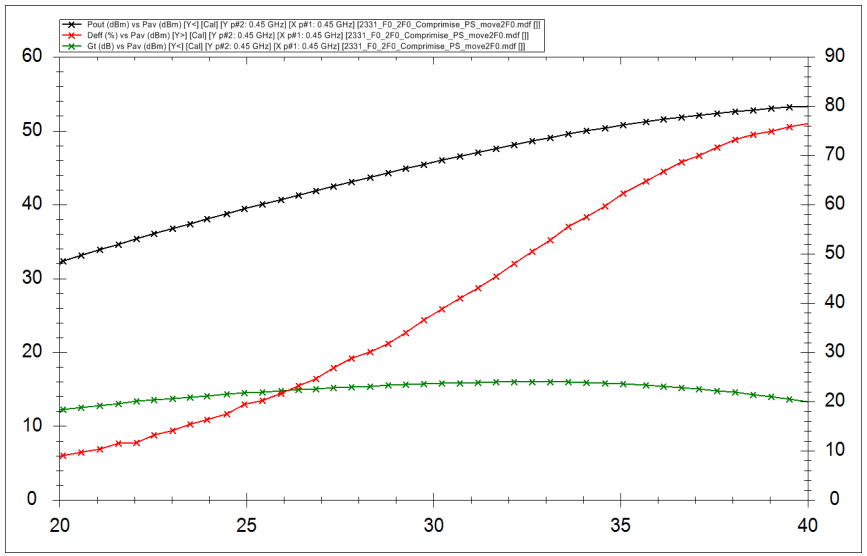
F0 – 0.618<159
2F0 – 1<-20

No 2F0 Stability Problem!!!!!

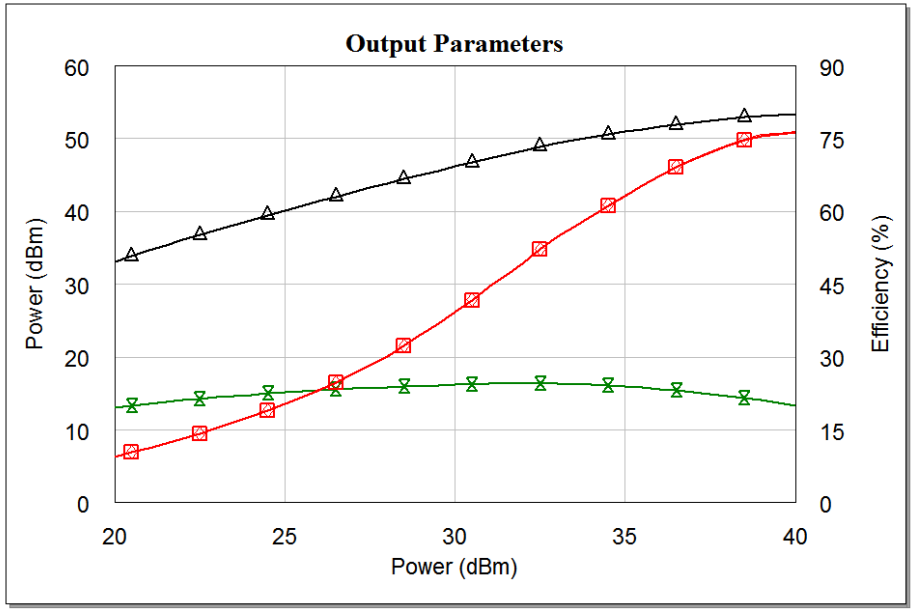
Power Sweep
Compromise Point F0&2F0(new)
Model Verification

- Power Sweep, F0 held at compromise point, 2F0 moved to more stable impedance.

Measurement



Simulation



Pout – 53.32dBm
Drain Eff – 76.4%

Compare Data With Pav=40dBm

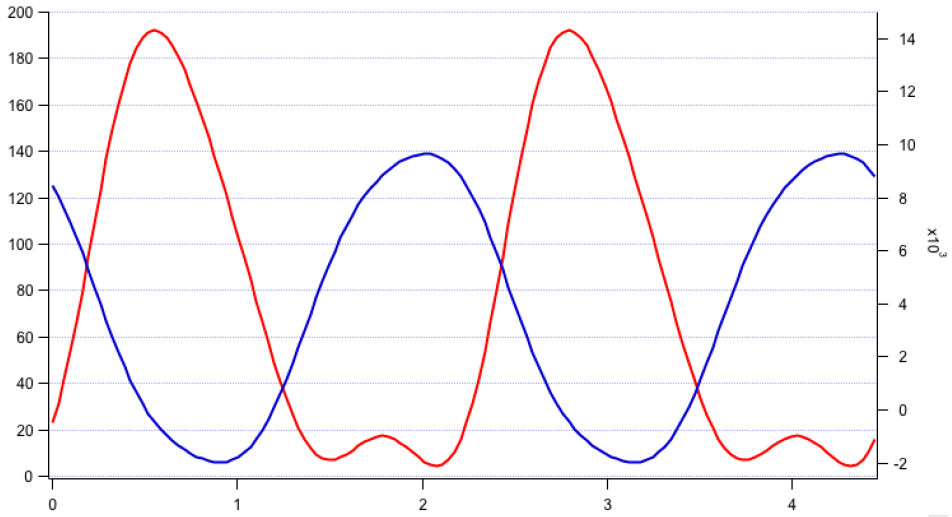
Pout – 53.38dBm
Drain Eff – 76.2%

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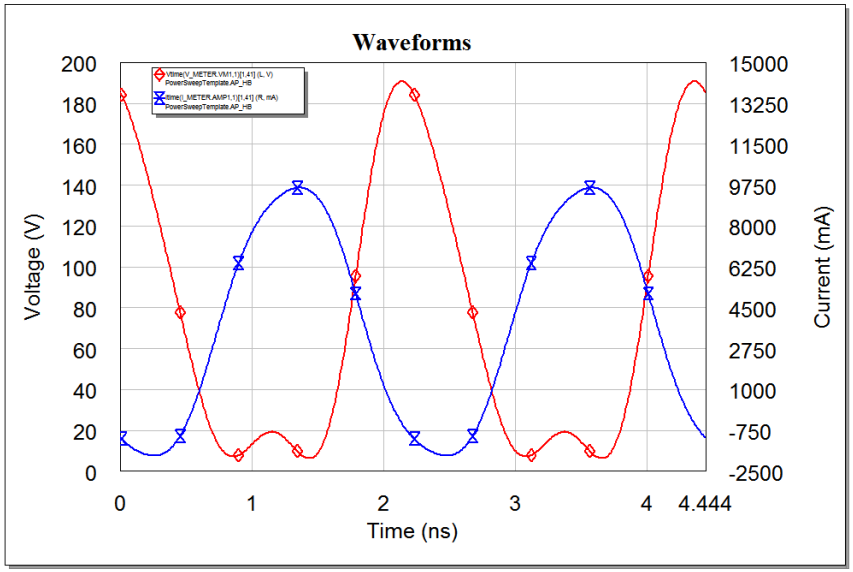
Power Sweep
Compromise Point F0&2F0(new)
Model Verification

- Waveforms

Measurement



Simulation

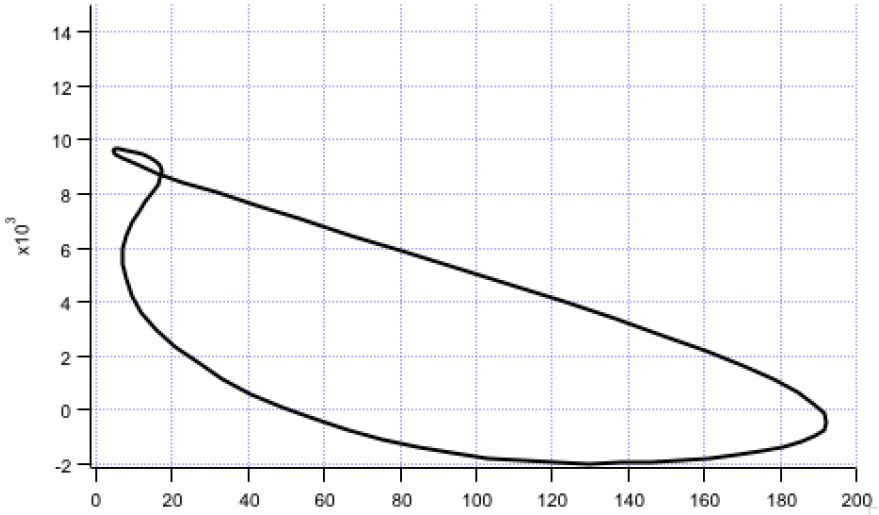


Compare Data
With Pav=40dBm

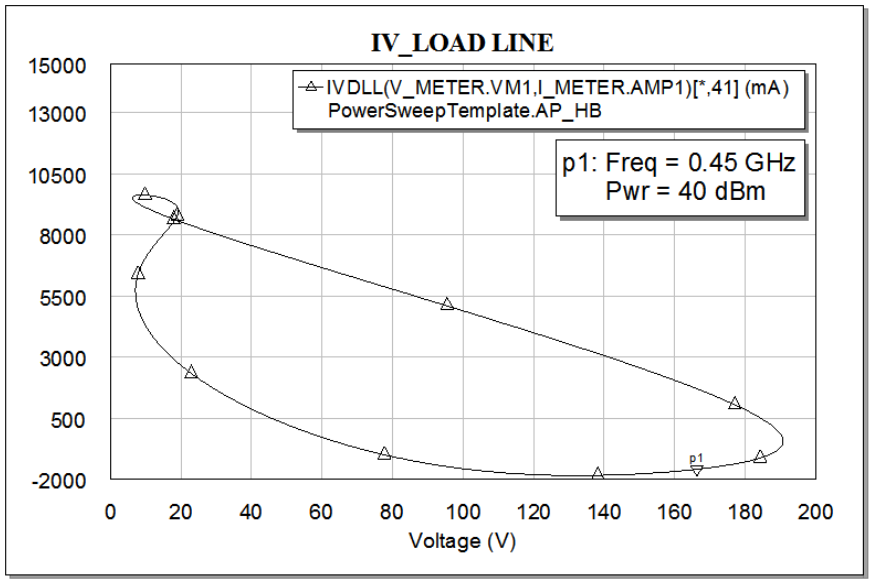
Power Sweep
Compromise Point F0&2F0(new)
Model Verification

- Dynamic Load-line

Measurement



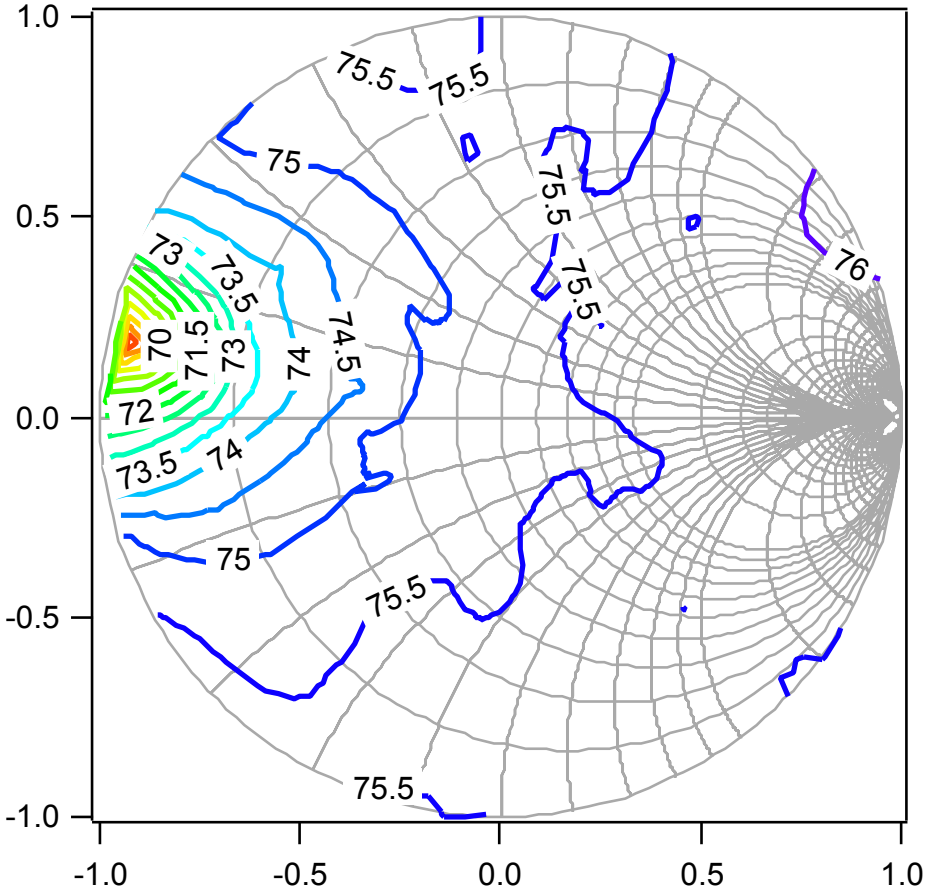
Simulation



Compare Data With Pav=40dBm

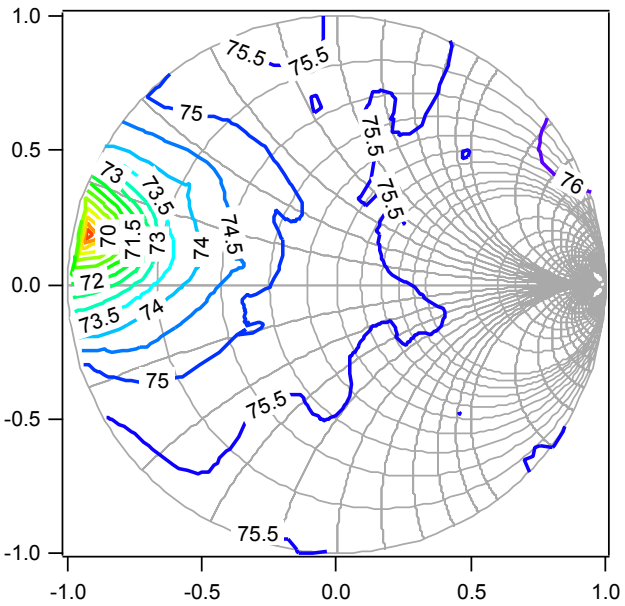
3F0 Sweep
F0 Compromise with 2F0 opt

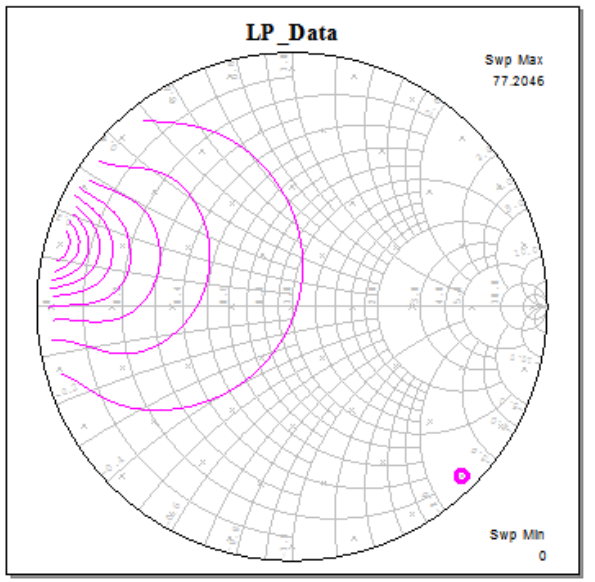
- 3F0 Efficiency contour



3F0 Sweep
F0 Compromise with 2F0 opt
Model Verification

- 3F0 Drain Efficiency contour.





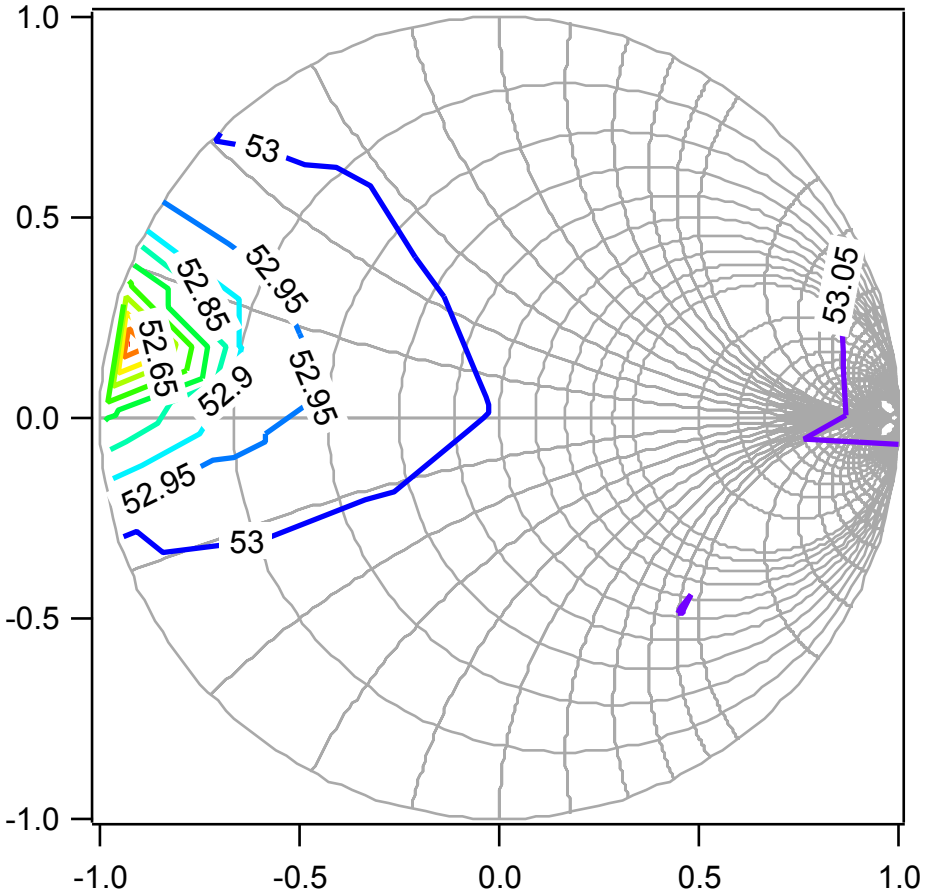
Measured Max – 76.21%
Measured Min – 68.00%

Simulation Max – 77.2%
Simulation Min – 69.78%

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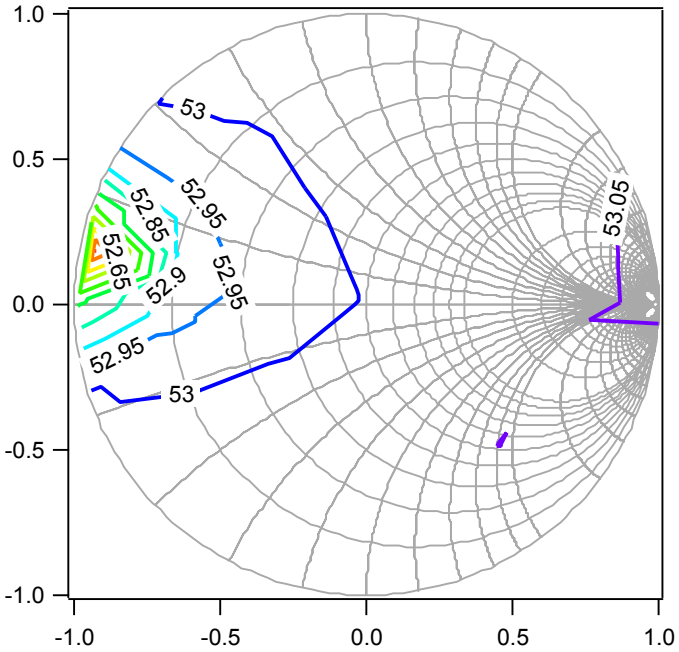
3F0 Sweep
F0 Compromise with 2F0 opt

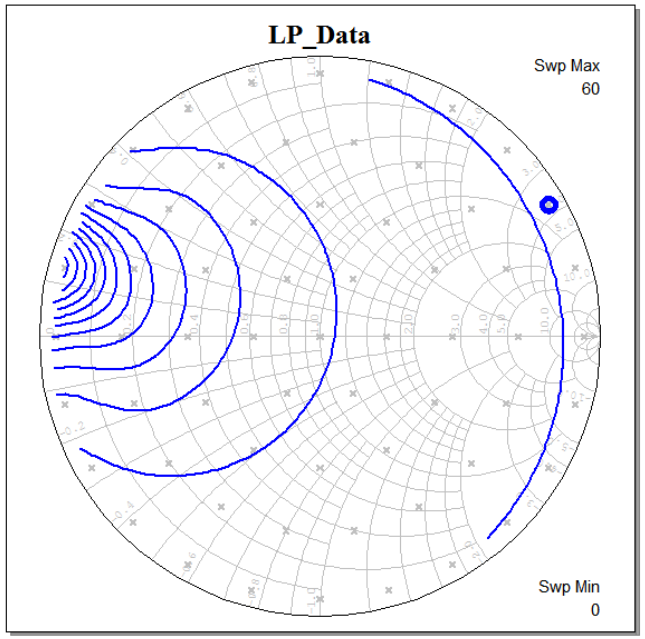
- 3F0 Power contour.



3F0 Sweep
F0 Compromise with 2F0 opt
Model Verification

- 3F0 power contour.



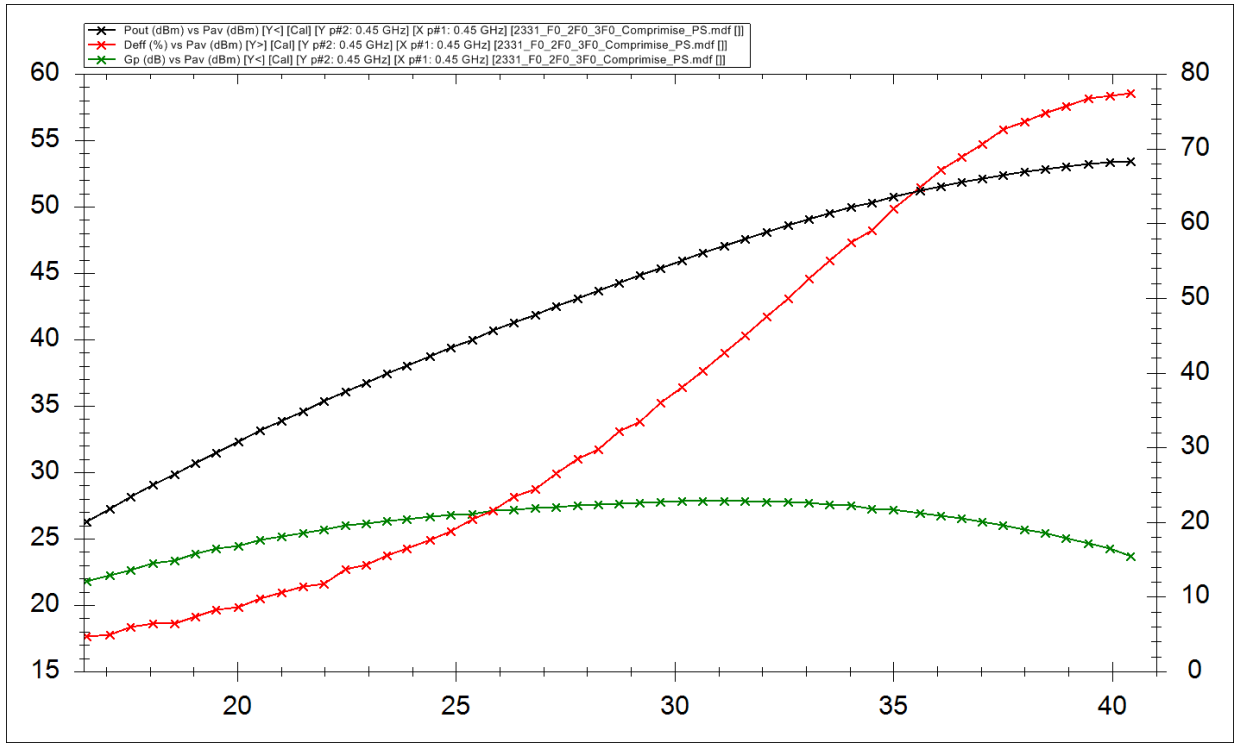


Measured Max – 53.06dBm
Measured Min – 52.55dBm

Simulation Max – 53.17dBm
Simulation Min – 52.83dBm

Power Sweep
F0,2F0,3F0 Compromise Point

- Power Sweep, F0 held at compromise point, 2F0 and 3F0 at optimum impedance.



Pout Max – 53.43dBm
- 220.29W

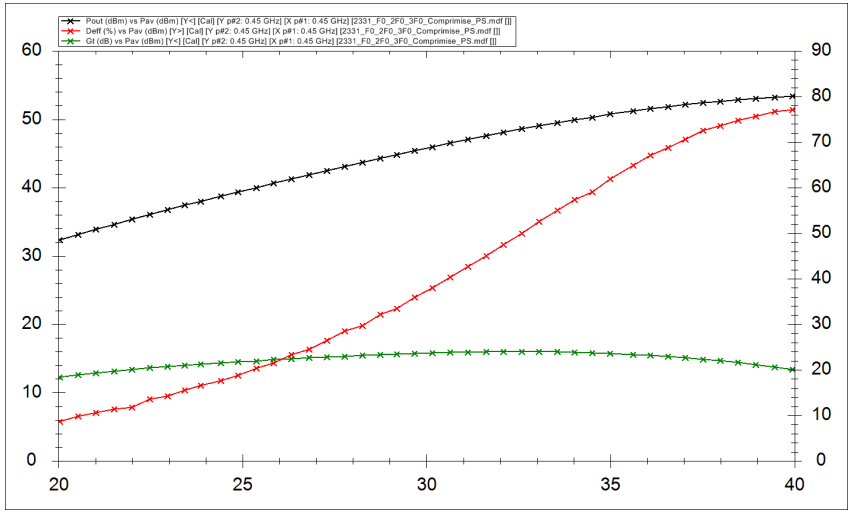
Drain Eff Max – 77.4%

F0 – <0.618<159
2F0 – 1<-20
3F0 – 1<30

Power Sweep
F0,2F0,3F0 Compromise Point
Model Verification

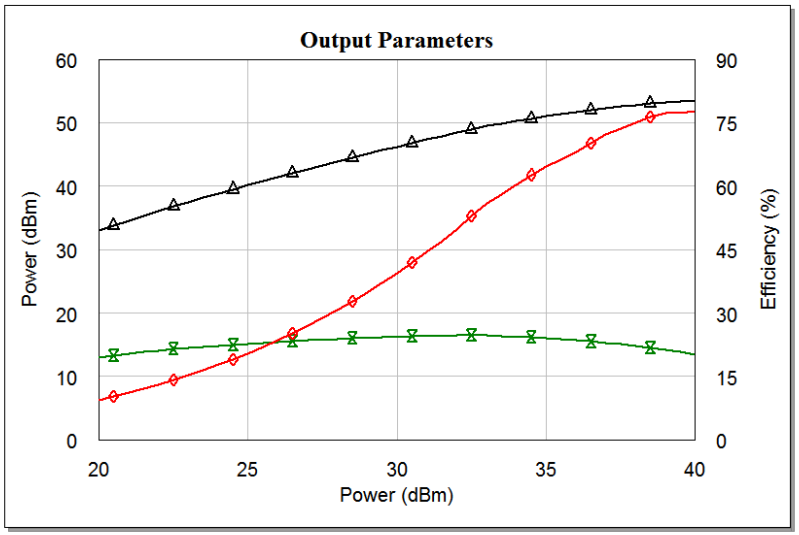
- Power Sweep, F0 held at compromise point, 2F0 and 3F0 at optimum impedance.

Measurement



Pout – 53.35dBm
Drain Eff. – 77.12%

Simulation



Pout – 53.46dBm
Drain Eff. – 77.12%

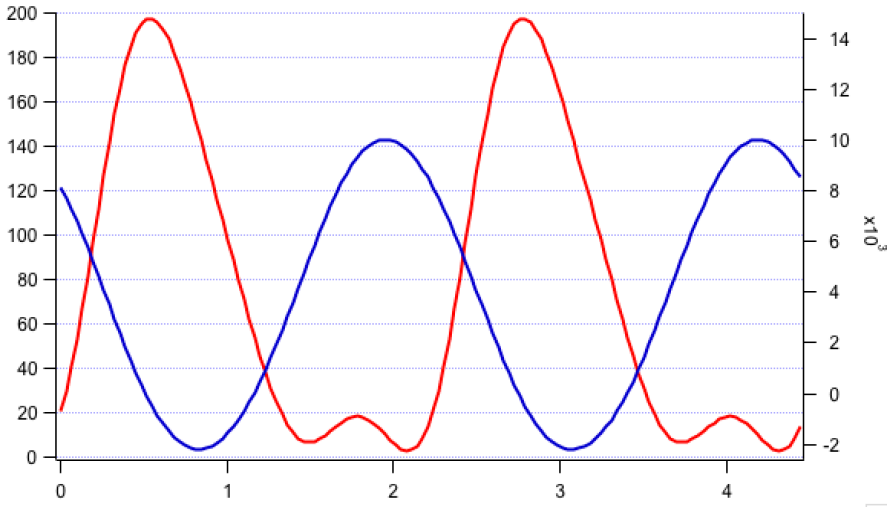
Compare Data With Pav=40dBm

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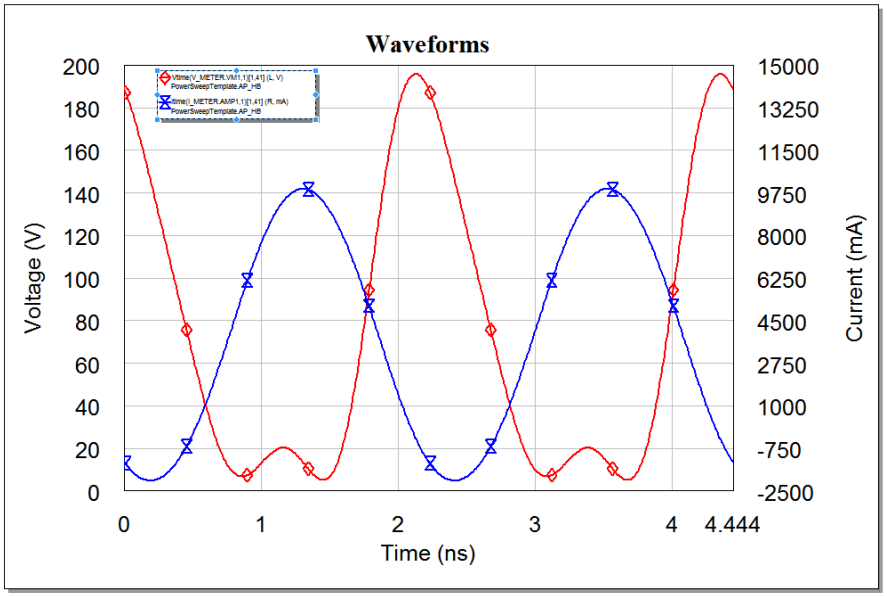
Power Sweep
F0,2F0,3F0 Compromise Point
Model Verification

- Waveforms

Measurement



Simulation

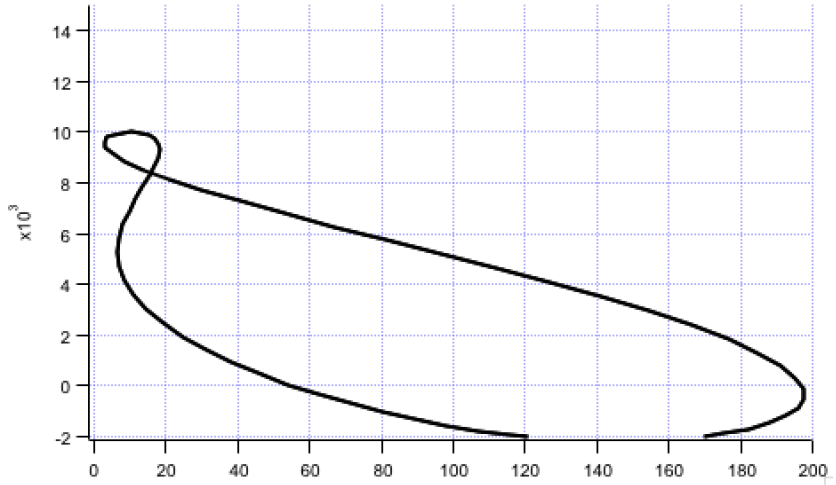


Compare Data
With Pav=40dBm

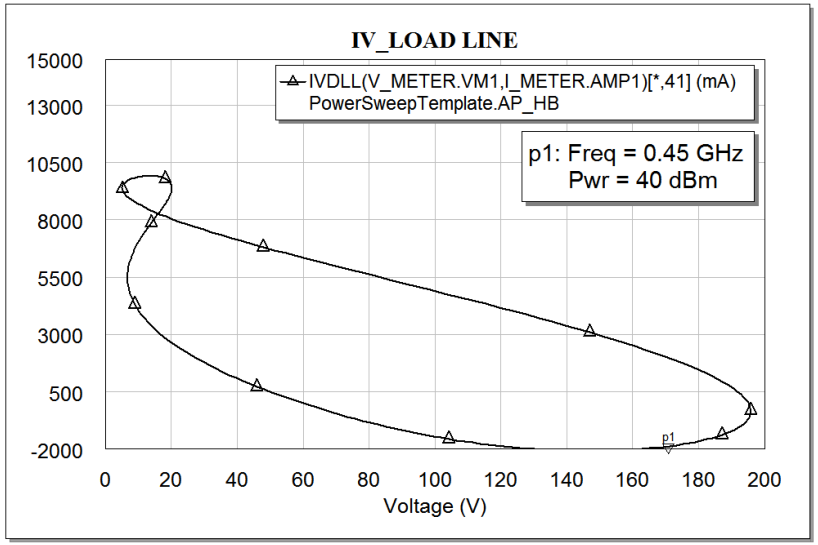
Power Sweep
F0,2F0,3F0 Compromise Point)
Model Verification

- Dynamic Load-line

Measurement

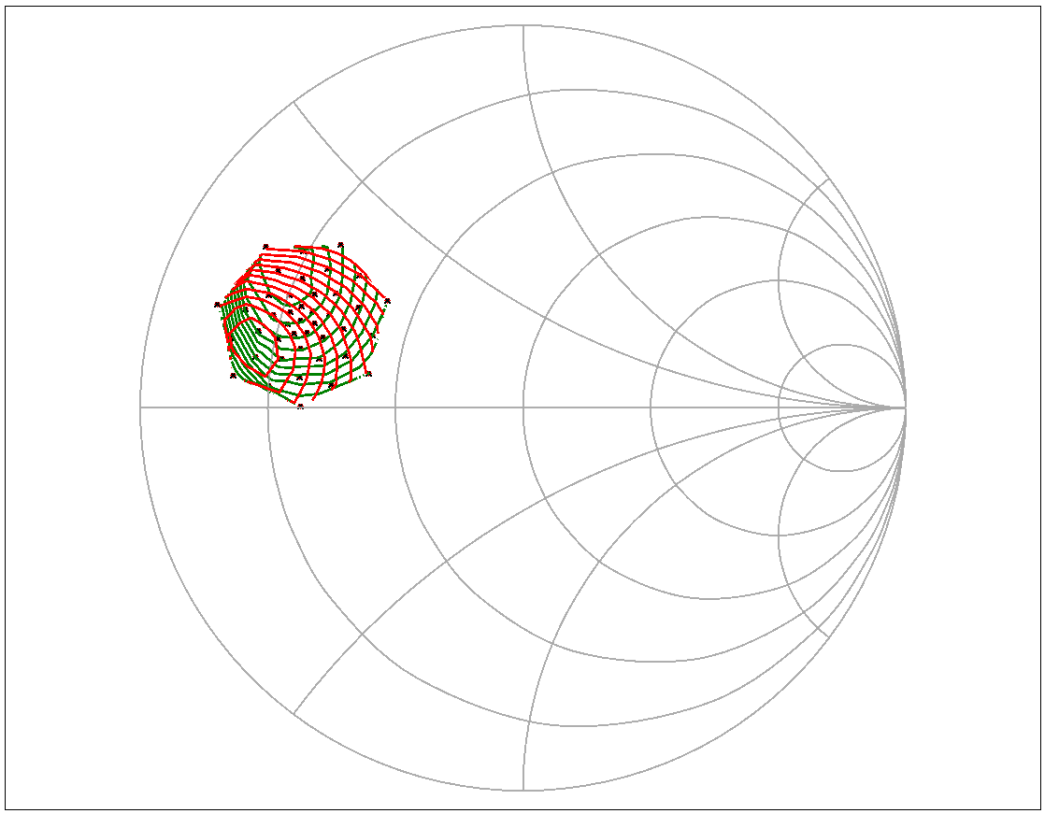


Simulation



Compare Data With Pav=40dBm

F0 Sweep
2F0, 3F0 held



Min Pout_dBm = 50.71
Mag = 0.64
Phase = 137.99 degs

Max Pout_dBm = 54.06
Mag = 0.71
Phase = 169.16degs

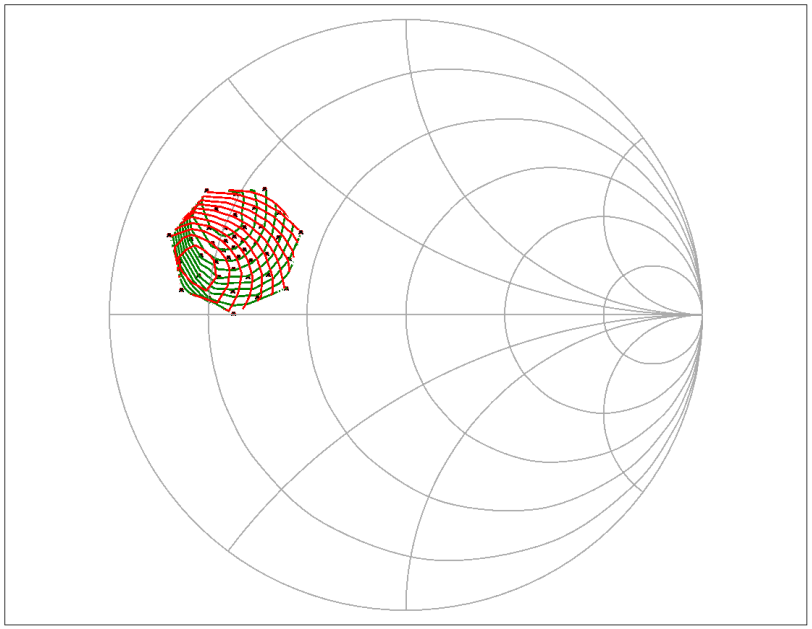
Min Drain Efficiency = 55.66
Mag = 0.76
Phase = 173.73 degs

Max Drain Efficiency = 80.04
Mag = 0.73
Phase = 150.73degs

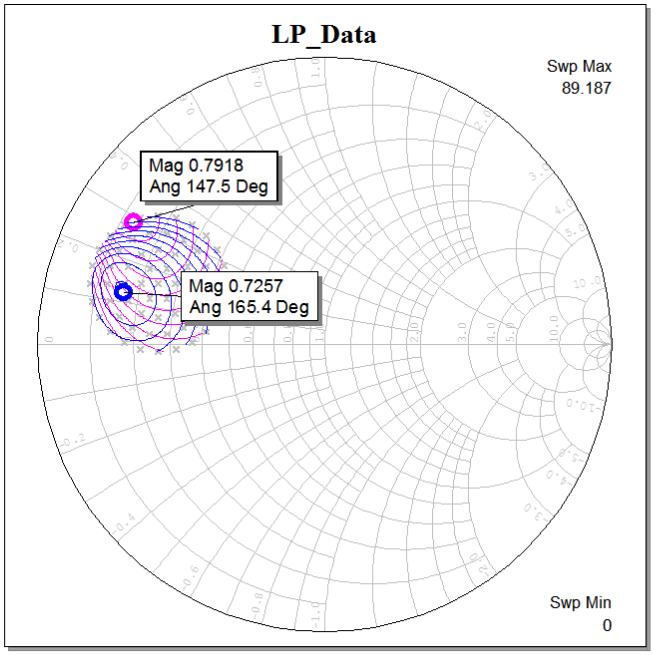
F0 Sweep
2F0, 3F0 held
Model Verification

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Measurement



Simulation



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