

Load Pull with X-Parameters

A New Paradigm for Modeling and Design

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Tuners For RF Device Characterization



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Outline

- **Overview – Motivation and Solution**
 - **A New Paradigm for Modeling and Design**
- **Overview of X-Parameters**
- **Traditional Large Signal Model vs X-Parameter Model**
- **System Setup and Operation**
- **Results**
- **Quick Demo**
- **Summary**

Motivation

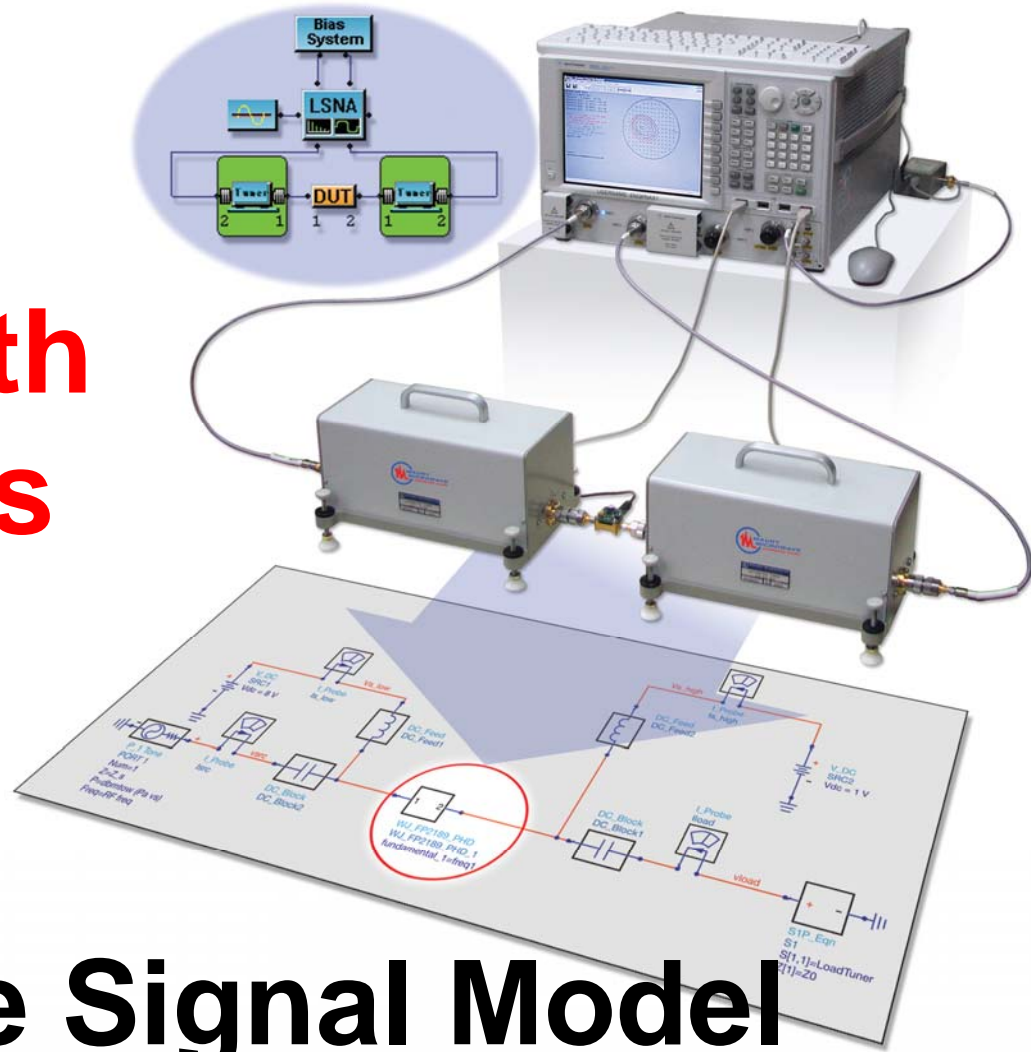
- **PA Design is Becoming More Complex**
 - Multi-Stage, Doherty, etc
 - More than Just Matching One Device
- **Large Signal Models are Needed**
 - Accurate
 - Fast Turn-Around

Prior Art

Separate Disciplines

- Load Pull
 - Determine Match for a Single Device
 - Verify Large Signal Models
- X-Parameters at 50 Ohms
 - Good to simulate system with 50 Ohm blocks
 - But Power Devices are far from 50 Ohms
 - Measurement was not Easy

Solution: Load Pull with X-Parameters



Instant Large Signal Model

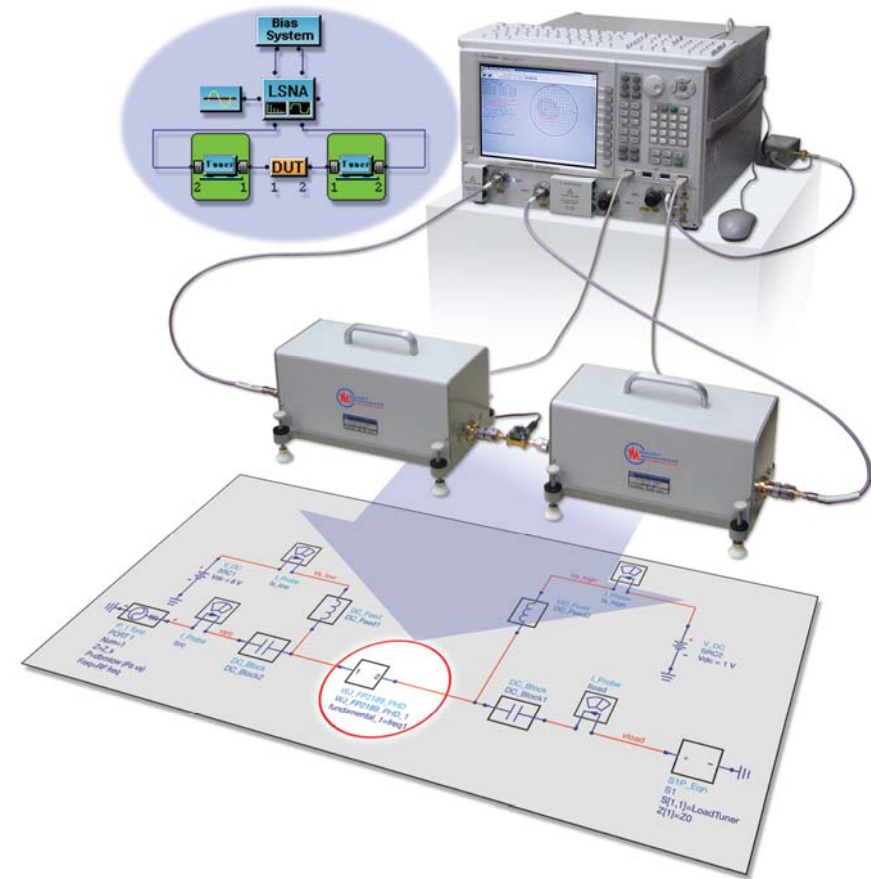
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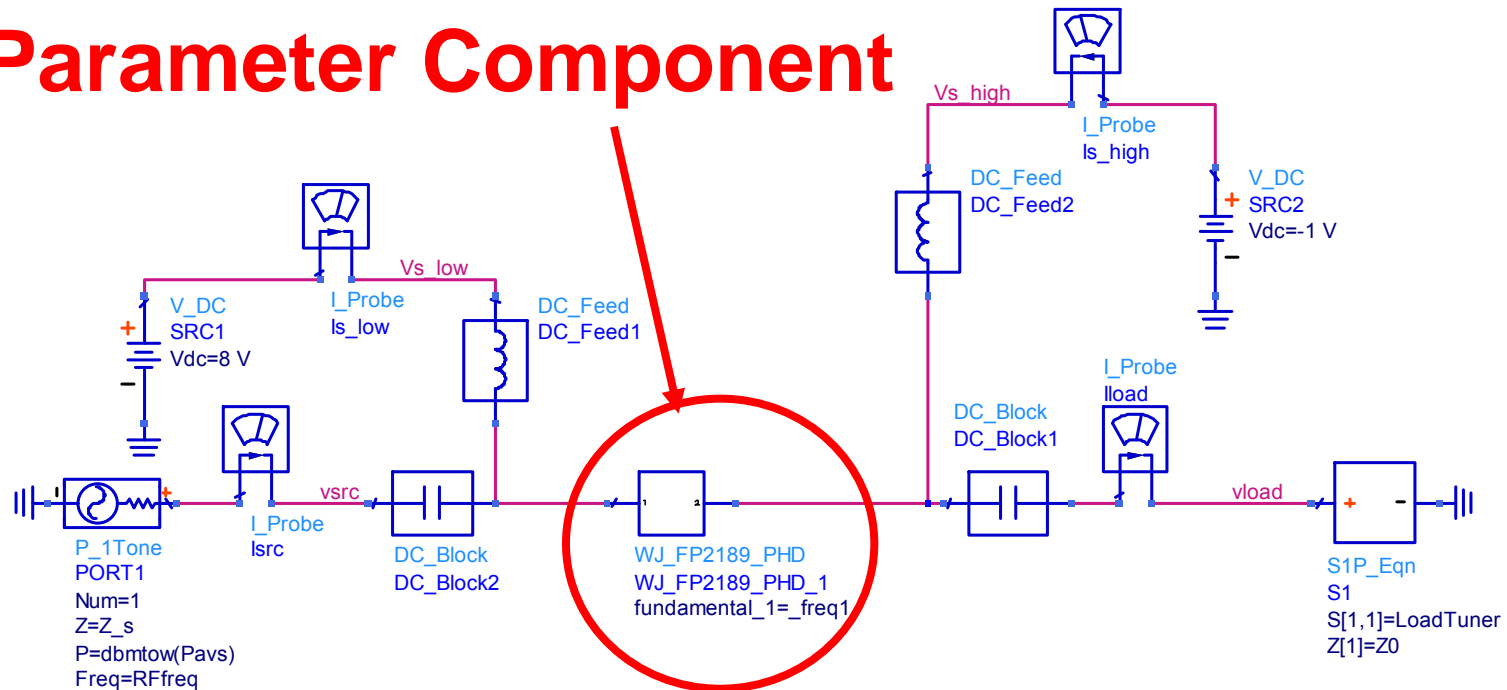
Instant Large-Signal Model

- Maury Load Pull
- Agilent NVNA
- SW in PNA-X
- Run Sweep Plan
- Save X-Param File
- Simulate in ADS



Instant Large Signal Model

X-Parameter Component



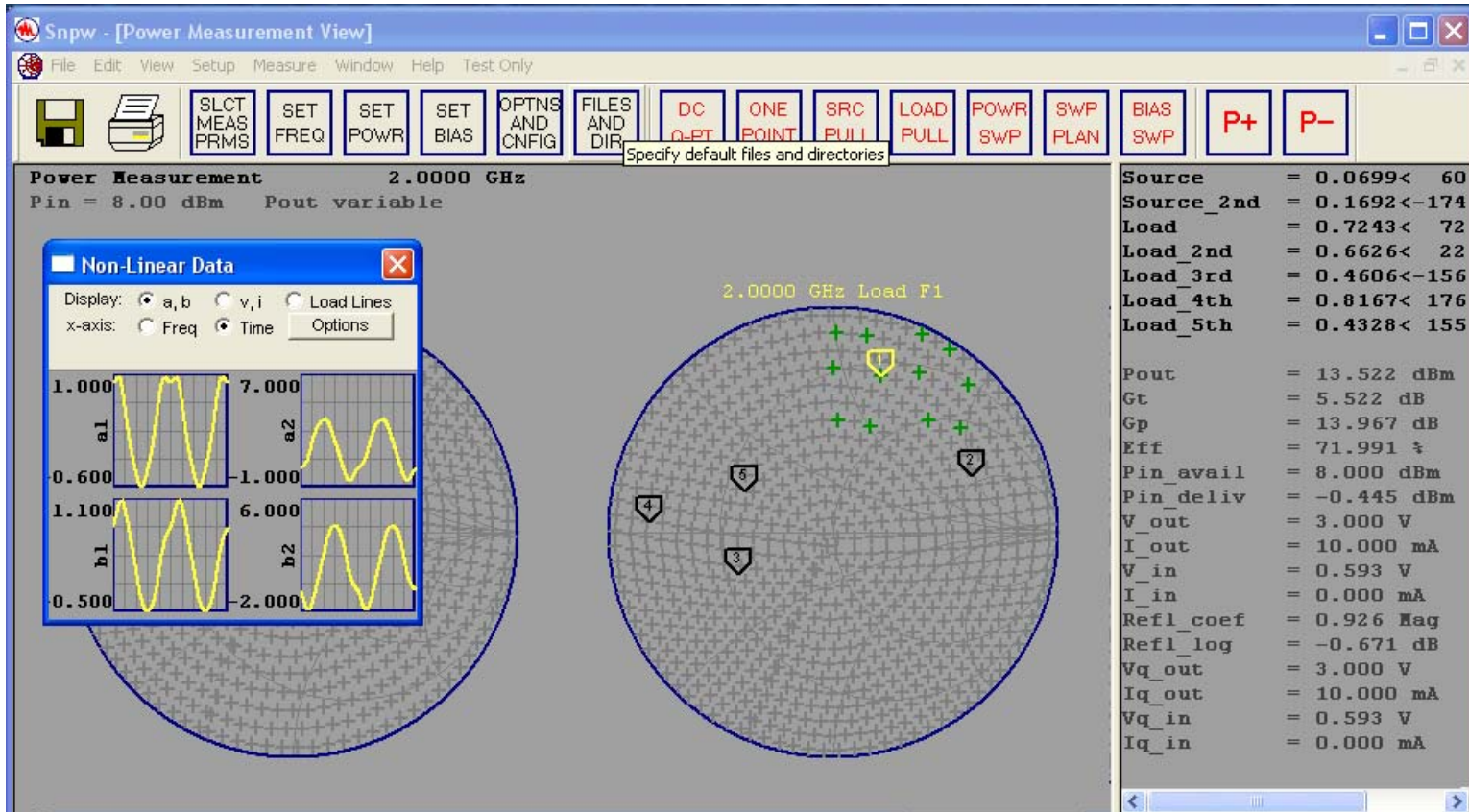
Industry Breakthrough

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Load Pull with LSNA Time Domain



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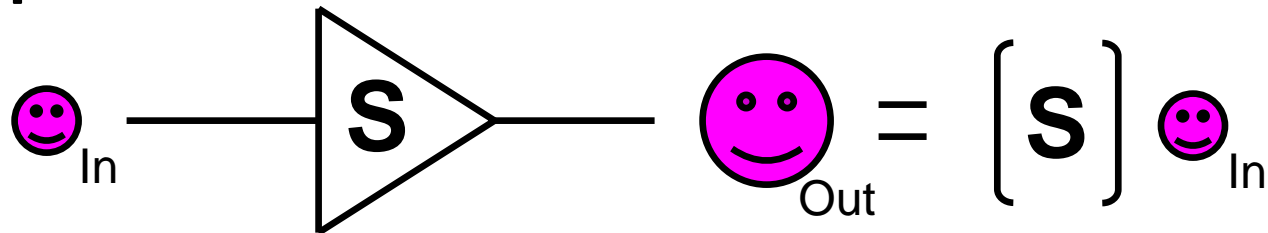
NVNA

- **“Nonlinear Vector Network Analyzer”**
- Superset of LSNA
- 3-Step Calibration
 - Vector Cal – Similar to standard VNA Cal
 - Power Cal – Use a power meter
 - Phase Cal – Use a comb generator as a Harmonic Phase Reference
- **Measures Time-Domain and X-Parameters**
 - X-Parameters are Unique to Agilent NVNA

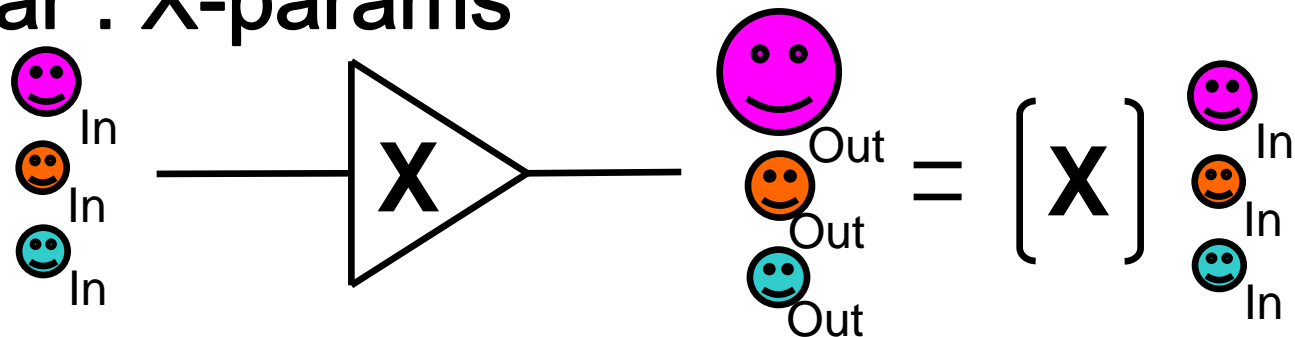
X-Parameter Overview

X-params are to non-linear devices like S-params to linear devices.

linear : S-params

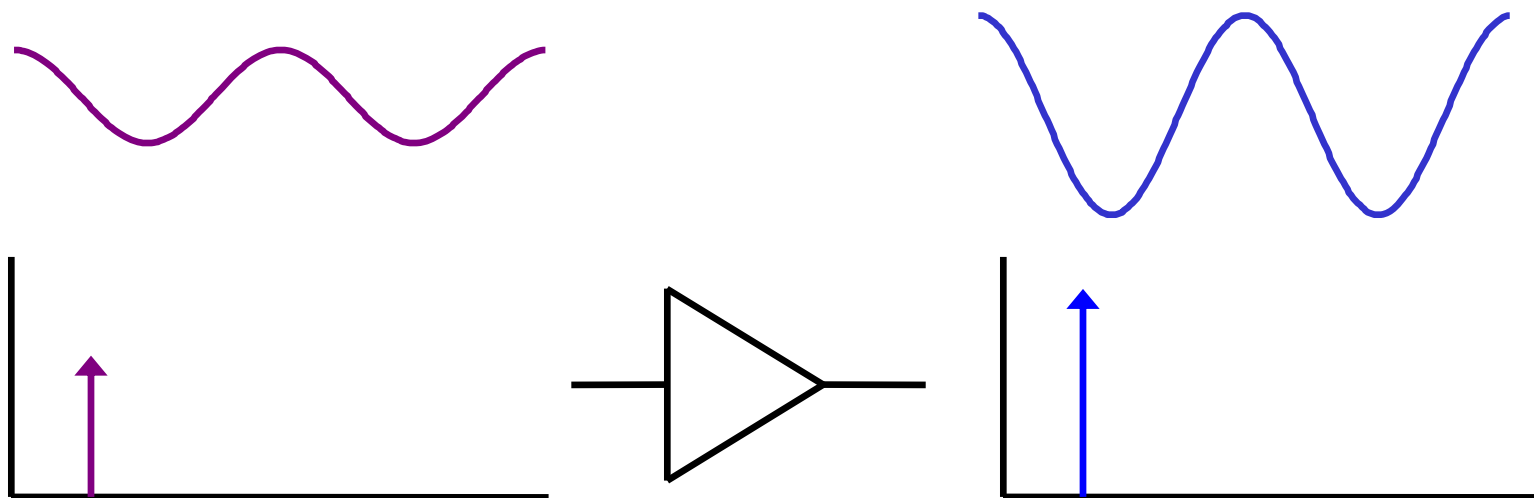


non-linear : X-params



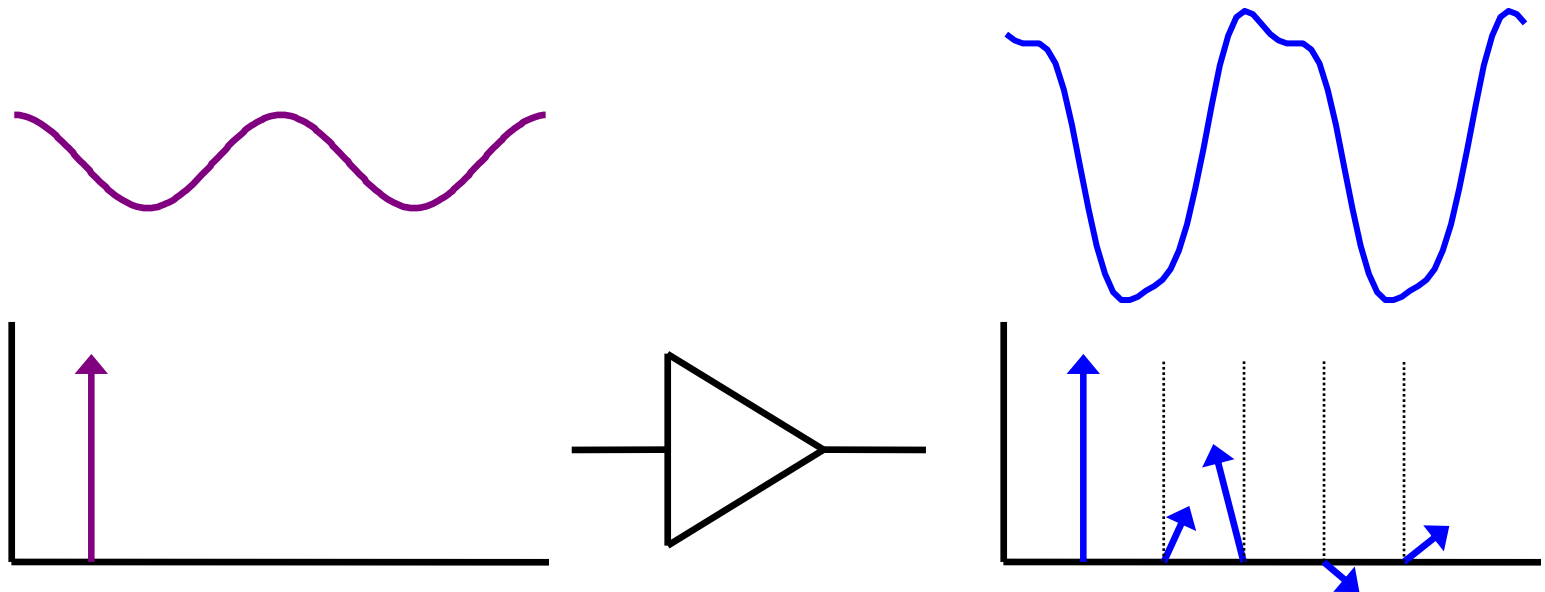
S-Parameters

VNA measures amplitudes and phases of Linear signals.



X-Parameters

NVNA measures amplitudes and phases of harmonic distortion signals.



Phases of distortions can be measured.

X-Parameter Summary

- Non-Linear Generalization of S-Parameters
 - S-Parameters are special case where distortion = 0
- Frequency Grid Includes:
 - All Harmonics
 - All Intermods
 - Baseband
- Parameters at Each Freq
- Parameters Between Each Freq Combination
- Data covers one Large Signal Operating Point

Traditional Large-Signal Model

- **Use Small Signal and DC measurements**
 - Fit Model Parameters to Data
 - Time-Consuming
 - Accuracy Limited in Some Regions of Operation
 - Technology Dependent
 - Model is Extrapolated to Large Signal
- **Load Pull is Accuracy Reference**
 - Load Pull is Measured at Actual Large Signal

X-Parameter Large Signal Model

- Based on Large Signal Measurements of X-Parameter Data
- Includes all Parasitics up to Reference Plane
- Technology Independent
- Hides Design Details of Device
- Load Dependent Data for PA Design

X-Parameter Large Signal Model Over Entire Smith Chart

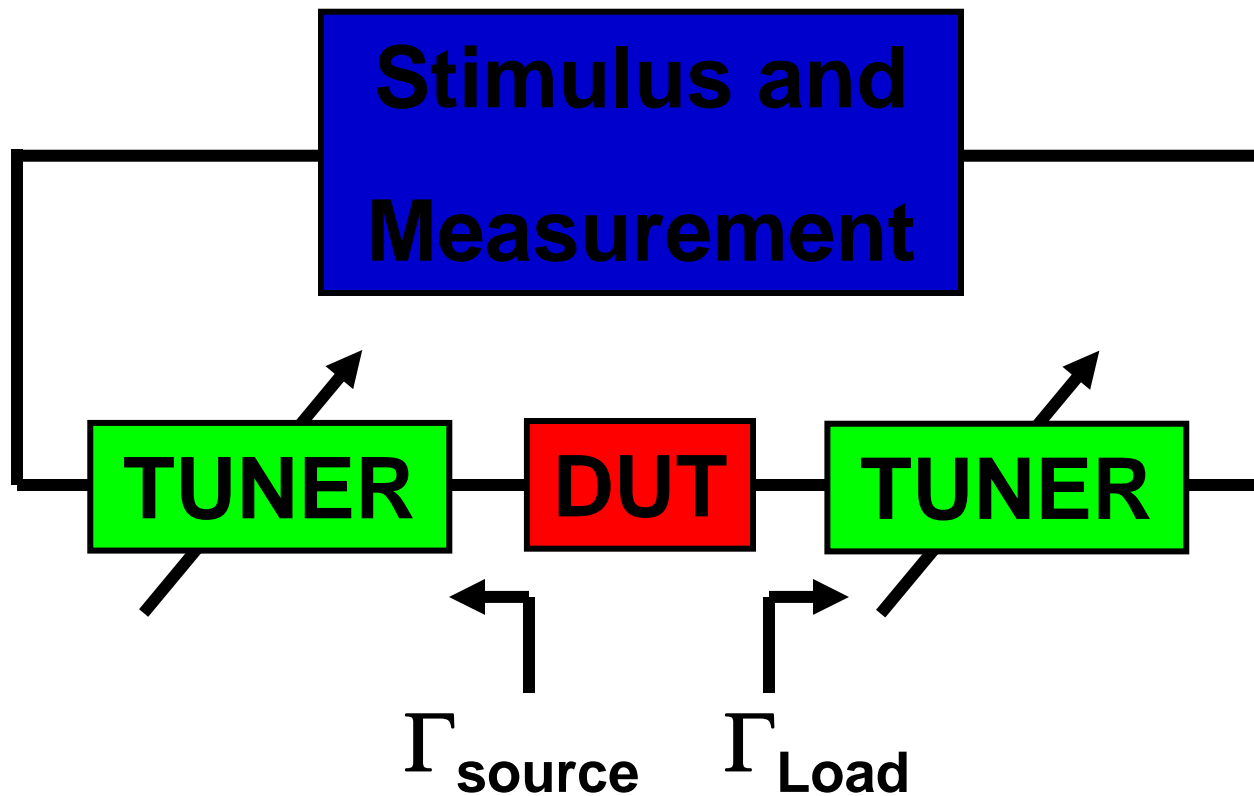
- In the Past, the X-Parameter model was only used at or near 50 Ohms
- New: **Load-Dependent X-Parameters**
 - Co-Developed by Maury and Agilent
- **New Paradigm for Modeling and Design**

X-Parameter Large Signal Model Over Entire Smith Chart

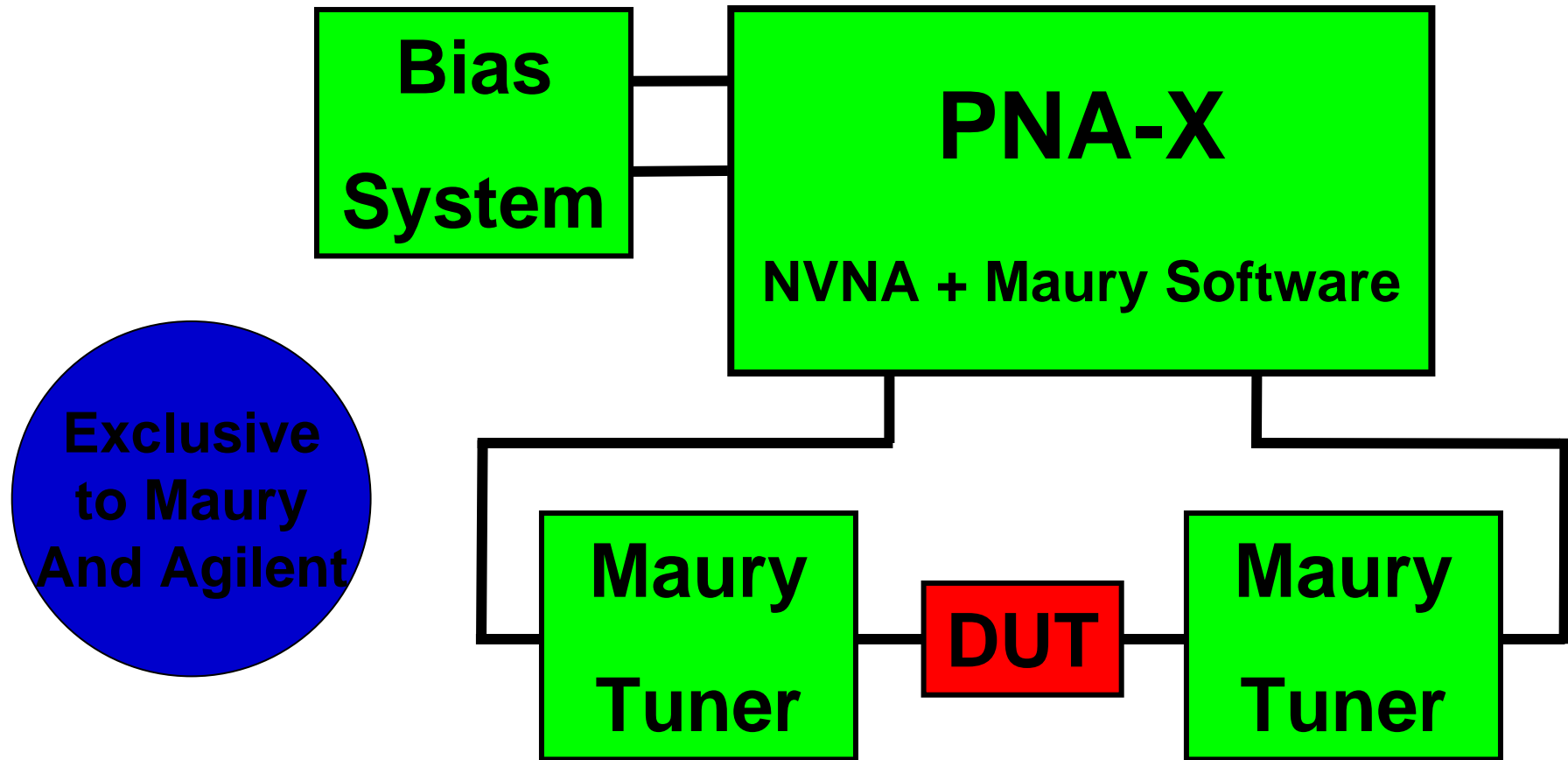
- Create Instantly from Load Pull Data
- Very Accurate
 - Based on Large Signal Load Pull Measurement
- Region of Validity
 - Sweep Plan Range Selected by User
 - Sweep Gamma, Power, Bias, Freq, Etc.
- **Simulate Complex PA Circuits**

What is Load Pull?

Measurement vs. Impedance



Load Pull + X-Parameter Setup



Exclusive
to Maury
And Agilent

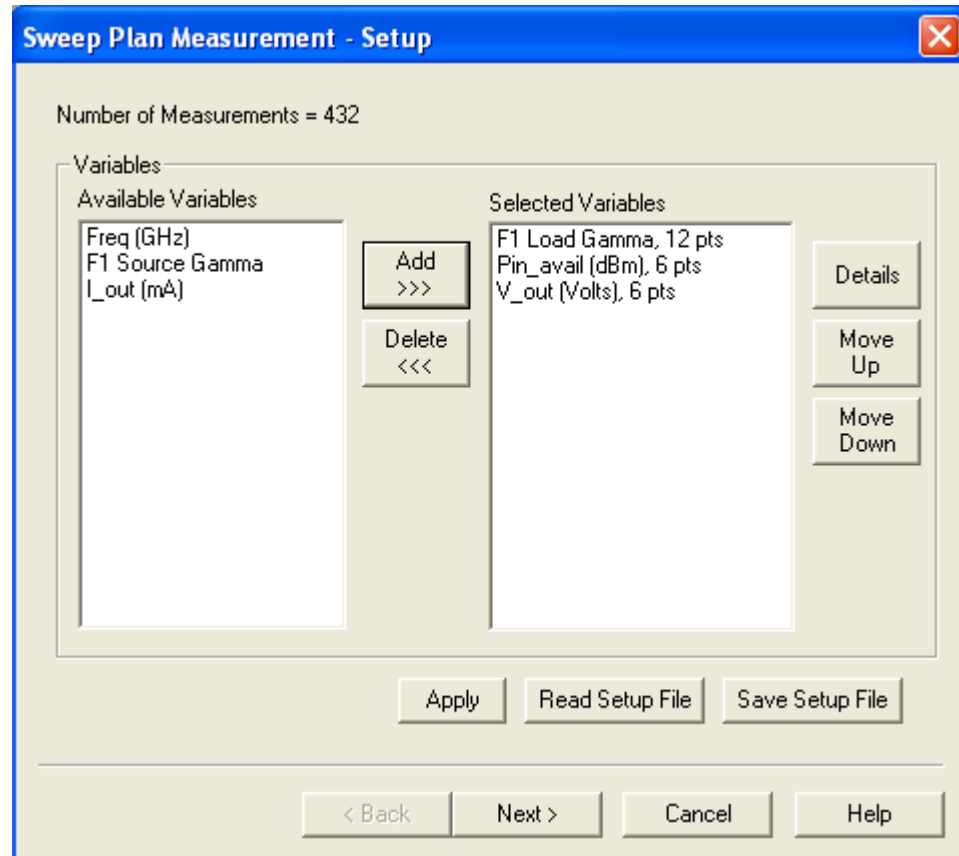
Load Pull to Circuit Simulation Sequence

1. Calibrate System, including Tuners
2. Calibrate NVNA at DUT Plane
3. Connect the DUT and Measure Sweep Plan
 - Sweep Gamma, Power, Bias, Freq, Etc.
4. Drag and Drop X-Param File into ADS
5. Simulate Circuit

System Operation - Measurement

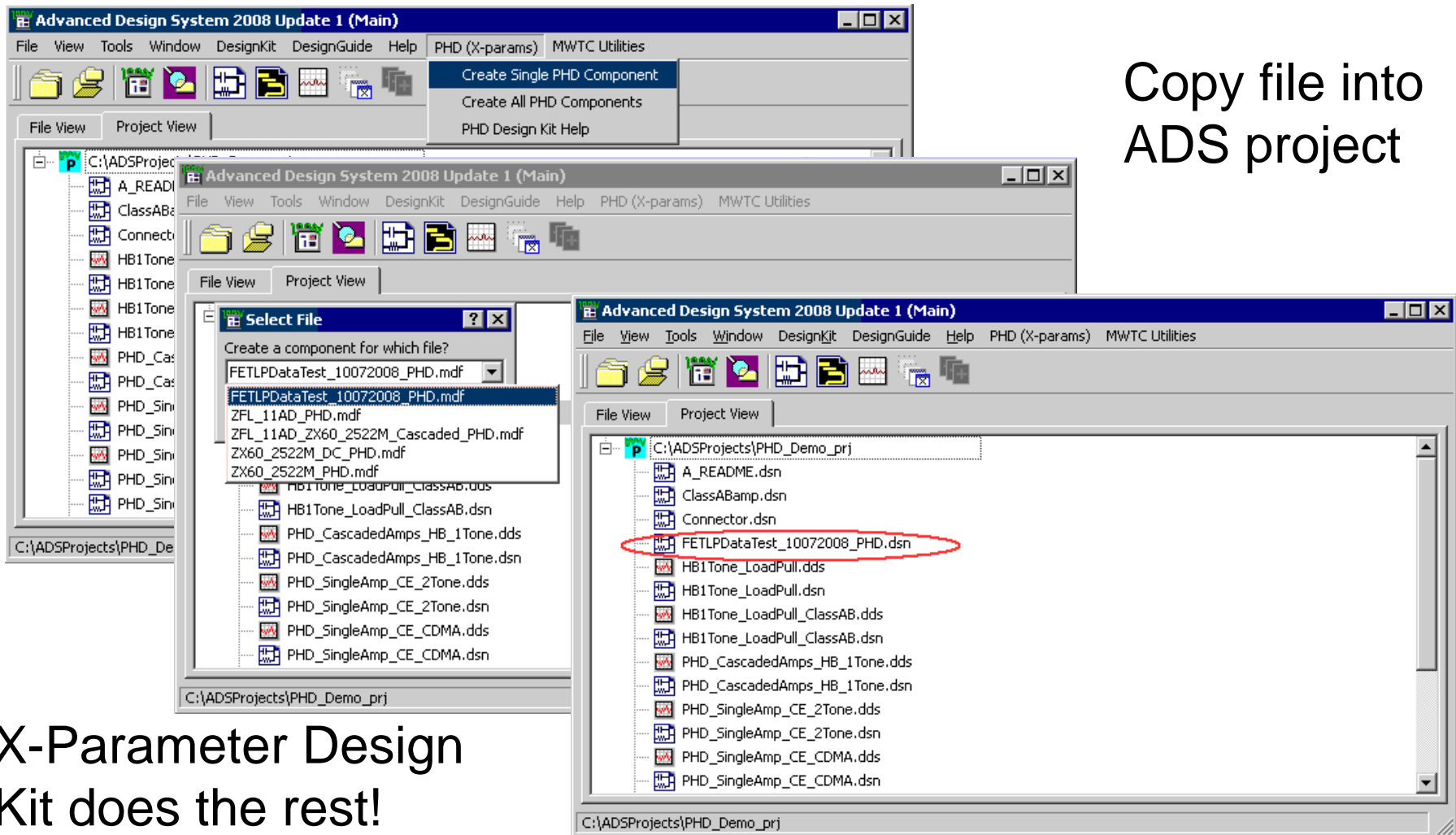
- Sweep Plan
- Up to 7 Variables
- Fully Automated Measurement

- Measure over Full Range of Device Operation



System Operation - Simulation

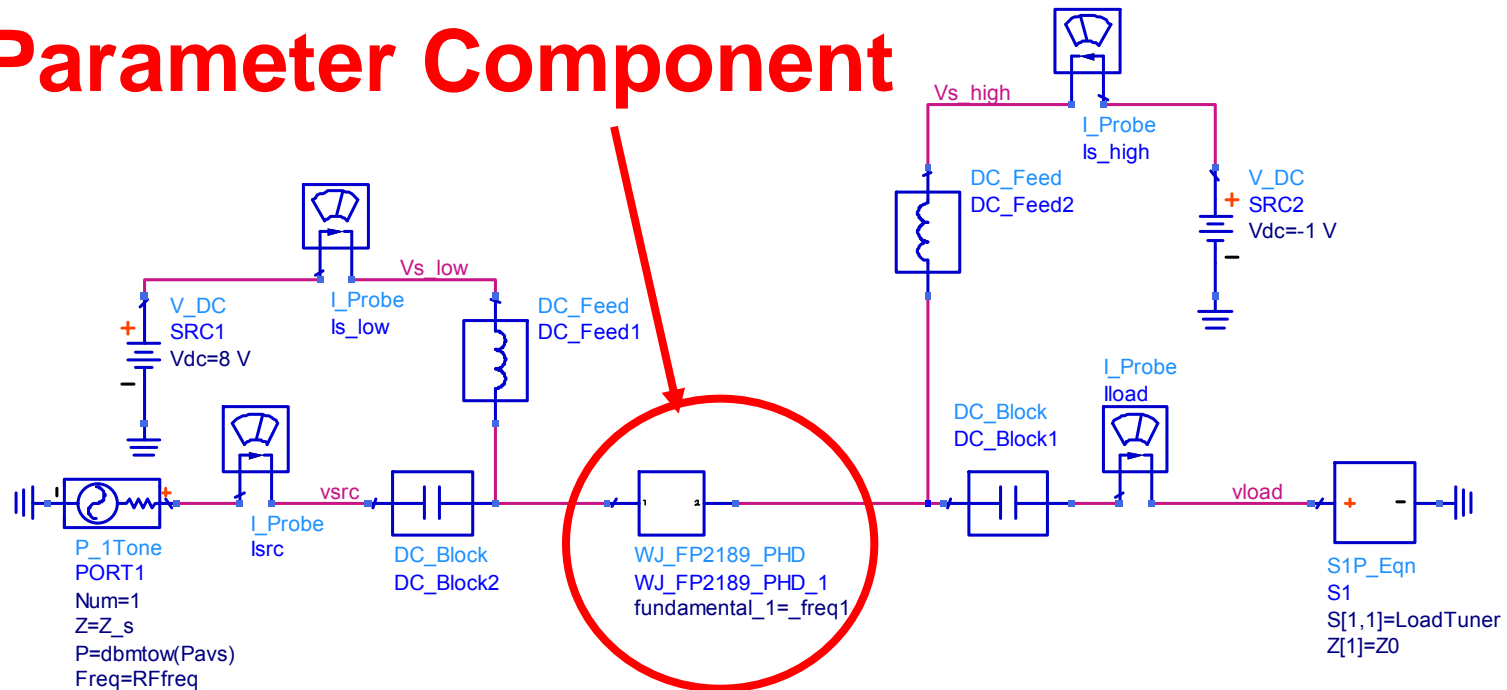
Copy file into
ADS project



X-Parameter Design
Kit does the rest!

Instant Large Signal Model

X-Parameter Component



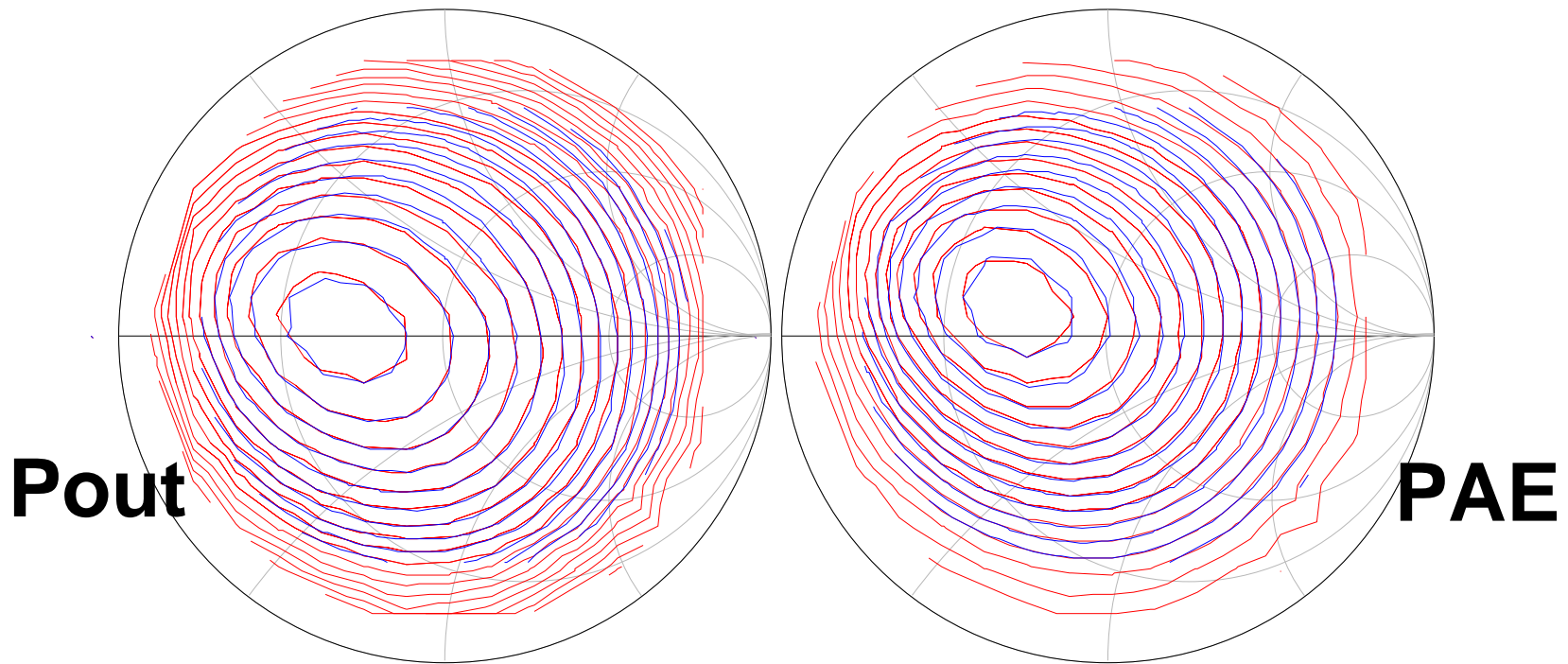
Industry Breakthrough

Tuners For RF Device Characterization



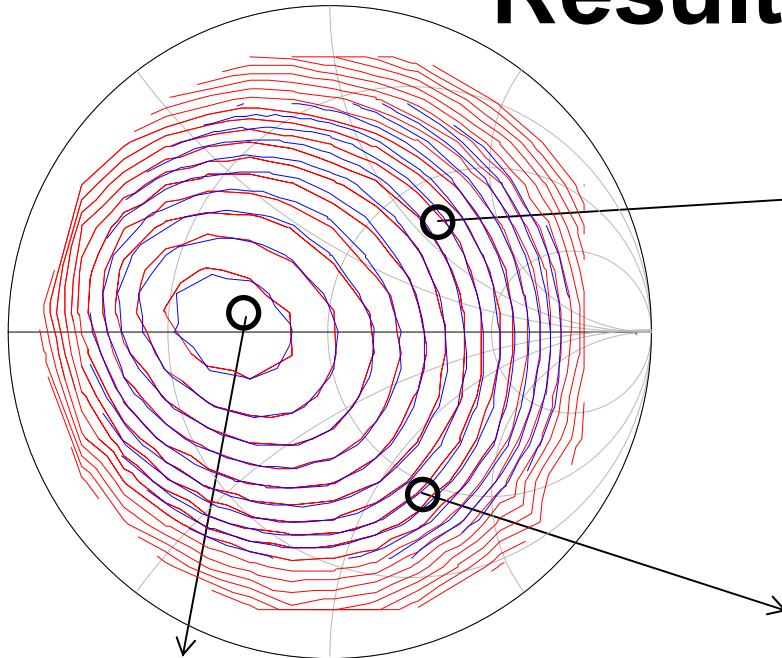
Results – Packaged FET

Extremely Accurate Agreement

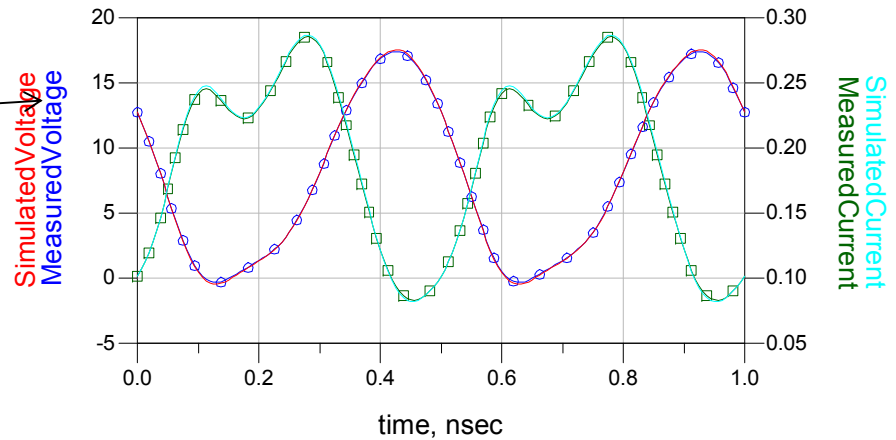


Blue – Simulated, Red - Measured

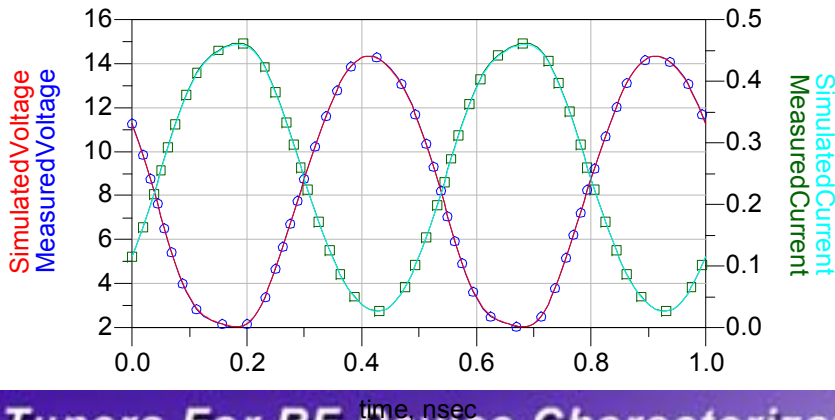
Results – Packaged FET



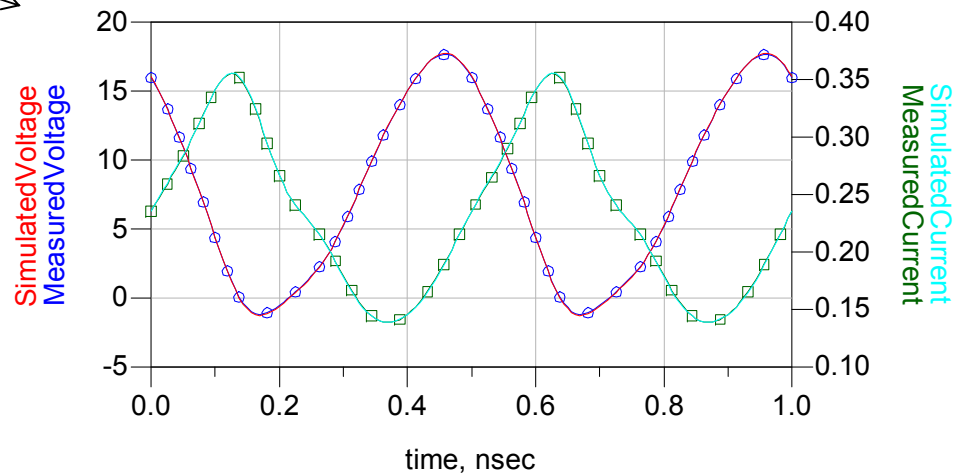
Measured and Simulated Voltage and Current Waveforms



Measured and Simulated Voltage and Current Waveforms

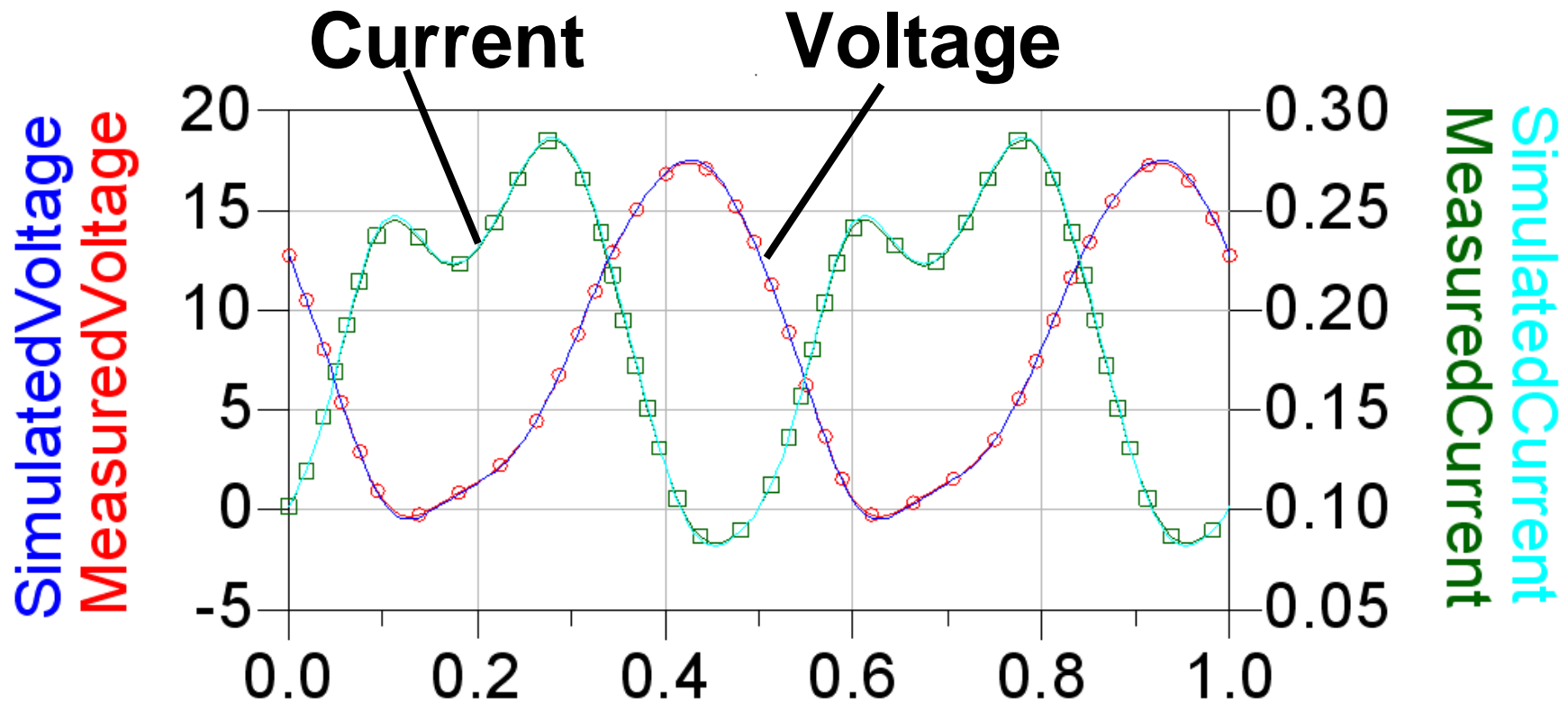


Measured and Simulated Voltage and Current Waveforms



Measured vs. Simulated

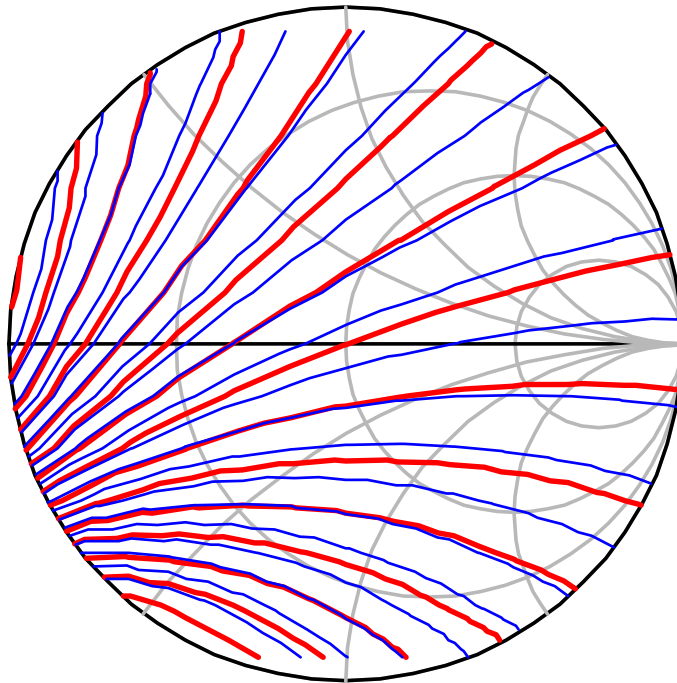
Extremely Accurate



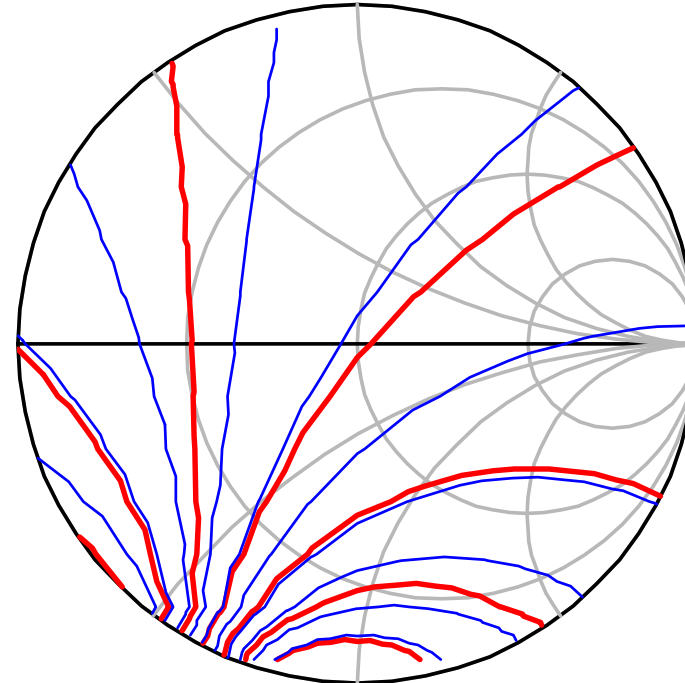
PAE and Pout vs. Harmonic Loads

PAE (red) and Pout (blue)

Second Harmonic Load



Third Harmonic Load



0.1% contour step for PAE,
0.01dBm contour step for delivered power

Demo

- Quick ADS Demonstration
- Drag and Dropping X-Parameter File into Schematic
- Simulate, See Results

Summary

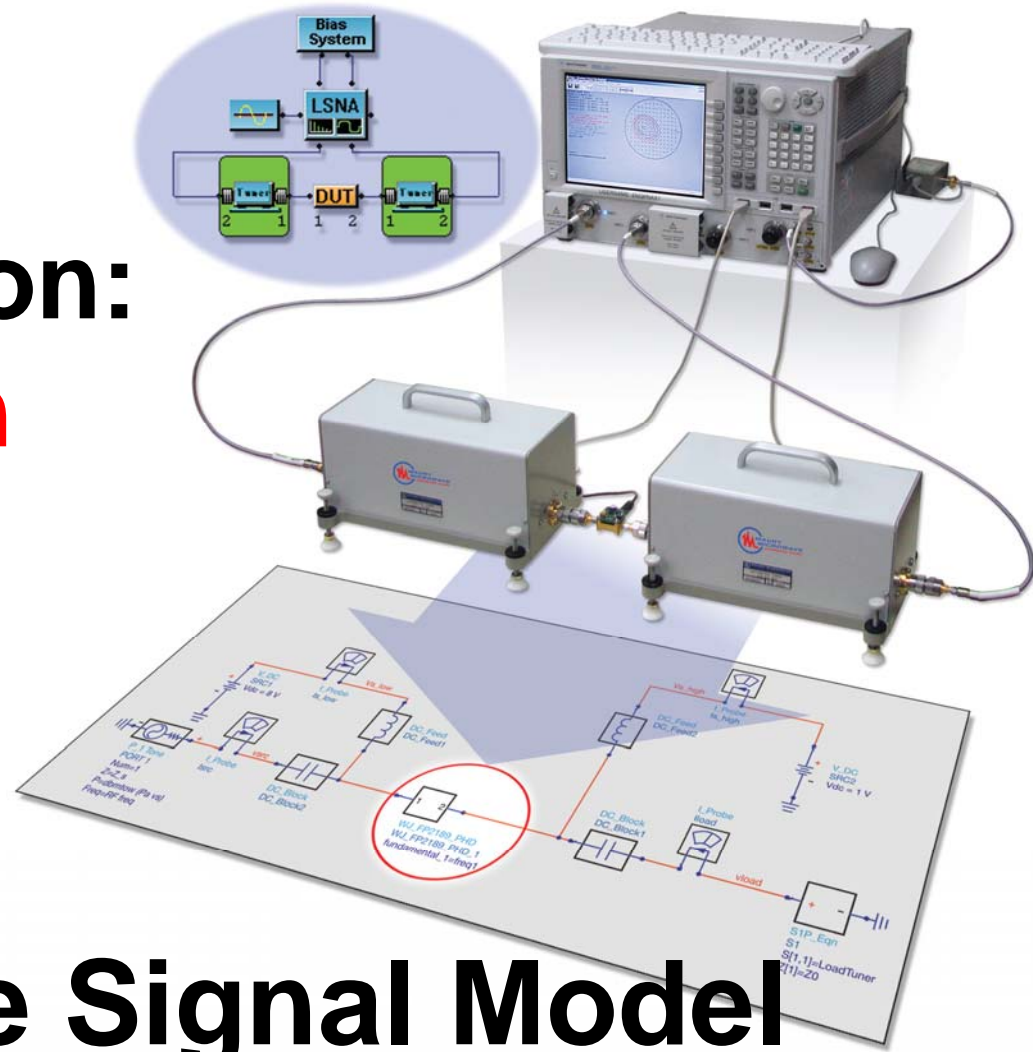
- **X-Parameters = Non-Linear Data**
- **Instant Large Signal Model**
- **Load Pull + NVNA + ADS**
 - Load Pull Produces X-Parameter File
 - Drag and Drop as Large Signal Model
- **Very Effective for Complex PA Design**

Summary

Load Pull with X-Parameters:

- **A Fast and Accurate Approach to Large-Signal Modeling and Simulation**
- **New Paradigm for Modeling and Design**
 - **Industry Breakthrough**

Complex PA Design Solution: Load Pull with X-Parameters



Instant Large Signal Model

Tuners For RF Device Characterization



References

- [1] J. Verspecht and D. E. Root, "Poly-Harmonic Distortion Modeling," in IEEE Microwave Theory and Techniques Microwave Magazine, June, 2006.
- [2] J. Verspecht, D. Gunyan, J. Horn, J. Xu, A. Cognata, and D.E. Root, "Multi-tone, Multi-Port, and Dynamic Memory Enhancements to PHD Nonlinear Behavioral Models from Large-Signal Measurements and Simulations," 2007 IEEE MTT-S Int. Microwave Symp. Dig., Honolulu, HI, USA, June 2007.
- [3] J. Horn, D. Gunyan , L. Betts, C. Gillease, J. Verspecht, and D. E. Root, "Measurement-Based Large-Signal Simulation of Active Components from Automated Nonlinear Vector Network Analyzer Data via X-Parameters," in 2008 IEEE COMCAS Conference, Tel Aviv, Israel, March, 2008
- [4] D. E. Root, J. Verspecht, D. Sharrit, J. Wood, and A. Cognata, "Broad-Band, Poly-Harmonic Distortion (PHD) Behavioral Models from Fast Automated Simulations and Large-Signal Vectorial Network Measurements," IEEE Transactions on Microwave Theory and Techniques Vol. 53. No. 11, November, 2005 pp. 3656-3664
- [5] G. Simpson, J. Horn, D. Gunyan, and D. E. Root, "Load-Pull + NVNA = Enhanced X-Parameters for PA Designs with High Mismatch and Technology-Independent Large-Signal Device Models", 72nd ARFTG Conference, Dec 9-12, 2008