Agilent NVNA and X-Parameter Simulation in ADS

X-Parameters Enable Model Generation from Simulation or Measurement for Fast Development
Wouldn’t it be nice if you could measure and display the full amplitude and phase information of each spectral component?

Wouldn’t it be even nicer to then use it directly in ADS harmonic balance or circuit envelope simulation or Ptolemy system simulator?
What are X-Parameters?

X-parameters are the mathematically correct superset of S-parameters, applicable to both large-signal and small-signal conditions, for linear and nonlinear components.

The math exists!

We can measure, model, & simulate with X-parameters. Each part of the puzzle has been created. The pieces now fit together seamlessly.
Nonlinear Vector Network Analyzer (NVNA)
The new industry standard for nonlinear measurements

*Fast, Accurate, and Easy to Use!*

Network Analyzer + Phase Reference + Software = NVNA

*The most innovative HP/Agilent instrument in 25 years!*
*Co-developed by CTD and HFTC*

NVNA = PNA-X + Phase Ref. ckt.
+ Application SW and calibration (mag and phase)
+ ADS-simulation application with X-parameter measurement option

NVNA measures *Magnitude and Phase* of all relevant frequency components (cross-frequency coherence) necessary to measure X-parameters!
X-Parameters Come from the Poly-Harmonic Distortion (PHD) Framework

\[ B_{1k} = F_{1k} (D C, A_{11}, A_{12}, \ldots, A_{21}, A_{22}, \ldots) \]
\[ B_{2k} = F_{2k} (D C, A_{11}, A_{12}, \ldots, A_{21}, A_{22}, \ldots) \]

Port Index  \rightarrow Harmonic (or carrier) Index

Spectral map of complex large input phasors to large complex output phasors
Black-Box description holds for transistors, amplifiers, RF systems, etc.

\[ B_{e,f} = X^{(F)} (|A_{11}|) P^{f} + \sum_{g,h} X^{(S)} (|A_{11}|) P^{f-h} \cdot A_{gh} + \sum_{g,h} X^{(T)} (|A_{11}|) P^{f+h} \cdot A_{gh} \]

Simplest X-parameters \rotatebox{90}{approximate general} \rotatebox{90}{mapping}
X-Parameter Concept:
Approx. to NL Mapping

\[ B_k (D C, A_1, A_2, A_3, \ldots) \]
Multi-variate NL map

\approx

\[ X_k^{(F)} (D C, A_1, 0, 0, 0, \ldots) \]
Simpler NL map

+ 

\[ \sum \left[ X_{k_j}^{(S)} (D C, A_1) A_j + X_{k_j}^{(T)} (D C, A_1) A_j^* \right] \]
Results: Design of Cascade vs. Measurement of Cascade

Objective: Design nonlinear circuits in ADS from NVNA-measured X-parameter component data

X-parameters are superior to Hot S22

Cascaded Measurement
Cascaded Design with X-parameters
Cascaded Design with “Hot S-parameters” but No $X^{(T)}$ terms

Similar results hold at harmonics

“X-parameters enable predictive nonlinear design from NL data”
X-Parameters: Why They are Critical
Predict performance of cascaded NL components

\[ B_{e,f} = X_{ef}^{(F)}(|A_{11}|)P_f^f + \sum_{g,h} X_{ef,gh}^{(S)}(|A_{11}|)P^{f-h}_{g,h} \cdot A_{gh} + \sum_{g,h} X_{ef,gh}^{(T)}(|A_{11}|)P^{f+h}_{g,h} \cdot A_{gh}^* \]

\[ P = e^{i\varphi(A_{11})} \]

Cascaded Nonlinear Amplifiers:
Nonlinear effects of mismatch versus drive

- Unambiguously identifiable (simple, automated extraction) from automated set of measurements
- Fully nonlinear vector quantities (Magnitude and phase of all harmonics)
- Extremely accurate for high-frequency, distributed nonlinear circuits
- Cascadable (correct behavior in mismatched environment)
Black-Box Characterization & Behavioral Modeling

- Measurement-Based Model
  - Circuit models don’t exist
  - Completely protect design IP

- Actual Amp Circuit

- Generate Behavioral Model

- Detailed Circuit Model (SPICE/ADS) of IC

- Design of Module or Instrument Front End
PHD Framework: Simulating with Measured Data

Once measured, the X-parameters can be *immediately* used for design in ADS.

**ADS**
- **Harmonic Balance:** Captures magnitude and phase of harmonics, frequency dependence, and mismatch effects

**PHD Framework:**
- Works in HB and Envelope, *Not* in Transient

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NVNA Application
- Take X-parameter measurements
- Memory Interface
- Export model file

Agilent PHD Code
- Extract X-parameters
- MDIF File
- Script generates PHD model component

DUT
- Measure X-Parameters
- Ref

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Agilent Technologies
Example: X-Parameters Verification

Amplifier component models from individual measured X-parameters
Results Cascaded Simulation vs. Measurement

Red: Cascade Measurement
Blue: Simulation of Cascaded Models

“X-parameters enable predictive nonlinear design from NL data”
Third Order Intercept Simulation

- **V_1Tone SRC18**
  - V=2*A11*N*cos(2*PI*Fmod*time)  
  - Freq=fundamental

- **VAR VAR1**
  - Fmod=5 MHz  
  - 20=50  
  - NoFFTpts=500  
  - NoModPer=10  
  - fundamental=2.0 GHz  
  - A11N= 0

- **Envelope Env1**
  - Freq[1]=fundamental  
  - Order[1]=9  
  - Slope=NoModPer[1]/Fmod  
  - Step=NoModPer[1]/Fmod/NoFFTpts

Graphs showing fundamental and IM3 vs. Pin, TOI vs. power vs. Pin.
Input / Output Spectrums & ACPR

Spectral Re-growth

Transmitted Spectrum

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<tr>
<th>TransACPR(1)</th>
<th>TransACPR(2)</th>
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<tr>
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<table>
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PA Linearization using X-Parameters in ADS Digital Pre-Distortion Linearization Design Guide
Summary

- X-parameters are a mathematically correct superset of S-parameters for nonlinear devices under large-signal conditions.
- X-parameters (for two-port devices under large-signal excitation from a single large input tone in this offering) can be accurately measured by automated set of experiments on the new Agilent NVNA instrument.
- Together with the PHD Framework, measured X-parameters can be used in ADS to design nonlinear circuits.
- All pieces of the puzzle are available and they fit together!