Using X-Parameters* to Generate IBIS Models

Tom Comberiate

and José Schutt-Ainé

University of Illinois

at Urbana-Champaign

tcomber2@illinois.edu

European IBIS Summit

May 15, 2013

Paris, France

*X-Parameters is a registered trademark of Agilent Technologies.

Outline

- Motivation

- Background

- IBIS Model Construction
  - X-parameter File Generation
 - Simulations to Produce IBIS Model

- Conclusions/Comments

- Future Work

Motivation

- IBIS models can be difficult to generate, especially without revealing IP to the model generator.
  - NC State's s2ibis3 [1] is still the open-source standard for simulated IBIS generation [2].
- X-parameters [3]:
  - Are behavioral, protect IP.
  - Are the large-signal extension of S parameters.
  - Can describe nonlinear effects.
  - Can be measured with an NVNA [4].
- Would like for designers to be able to exchange .xnp files and generate IBIS models from them.

Polyharmonic Distortion (PHD) Model [5]

- Linearization of a nonlinear function around a large-signal tone $A_{1,1}$ applied at the input.
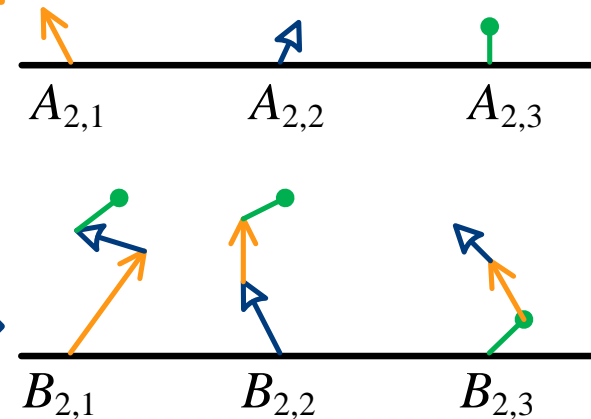
Multiple harmonic inputs with dominant fundamental
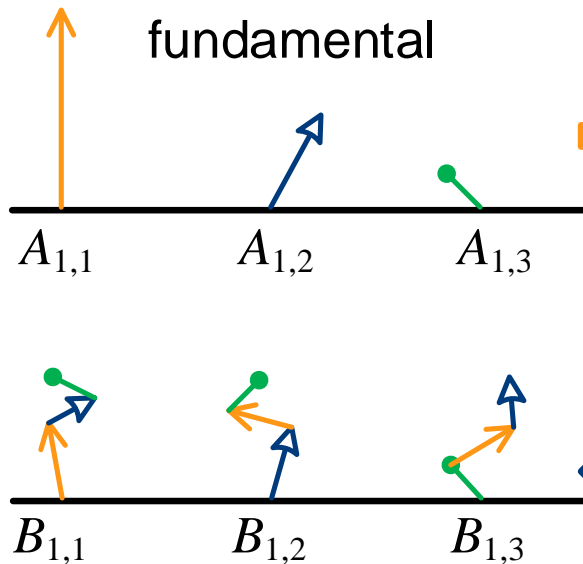
Fundamental behaves nonlinearly

Harmonics follow superposition and contribute to the others.

$A_{1,1}$ $A_{1,2}$ $A_{1,3}$

Nonlinear 2-Port Device

$A_{2,1}$ $A_{2,2}$ $A_{2,3}$

$B_{1,1}$ $B_{1,2}$ $B_{1,3}$

$B_{2,1}$ $B_{2,2}$ $B_{2,3}$

X-Parameters Formalism [5]

Approximates

Incident Waves   **Scattered Waves**

$$B_{p,k}(DC, A_{1,1}, A_{2,1}, A_{1,2}, A_{2,2}, A_{1,3}, A_{2,3}, \ldots)$$
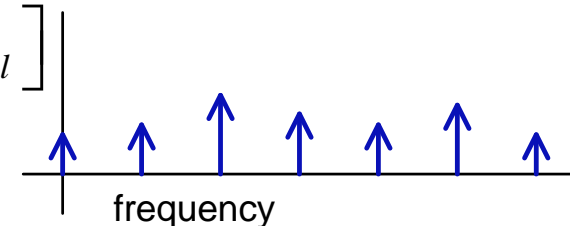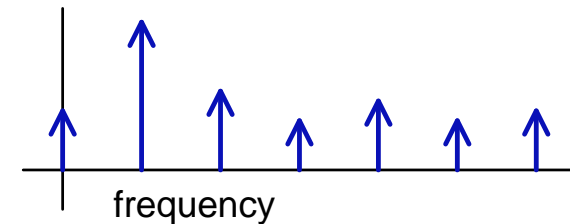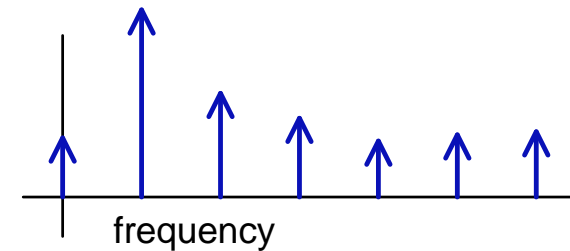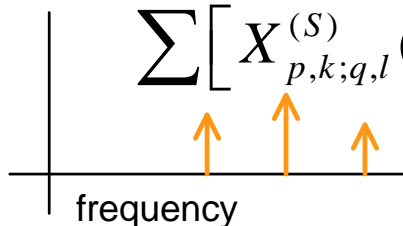
Nonlinear Mapping

$$\approx$$

$$X_{p,k}^{(FB)}(DC, A_{1,1}, 0, 0, \ldots)$$

$A_{1,1}$ Large-Signal

Simple Nonlinear Mapping

$$+$$

$$\sum \left[X_{p,k;q,l}^{(S)}(DC, A_{1,1}) \cdot A_{q,l} + X_{p,k;q,l}^{(T)}(DC, A_{1,1}) \cdot A_{q,l}^{*} \right]$$
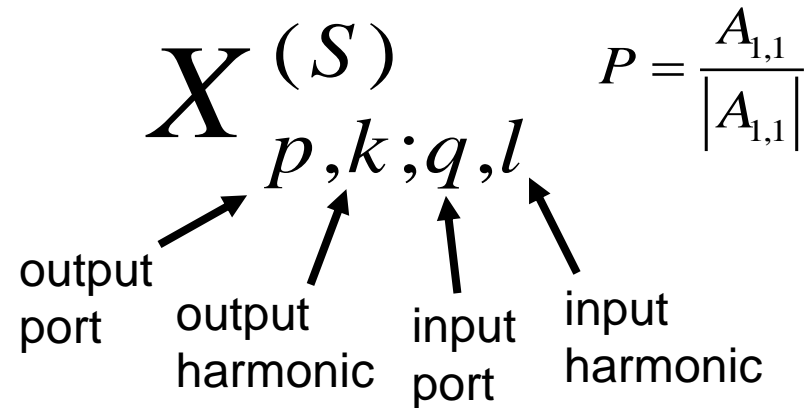
Nonanalytic Harmonic Superposition
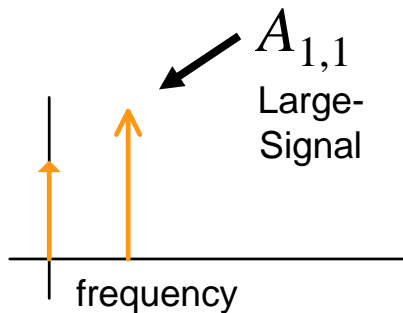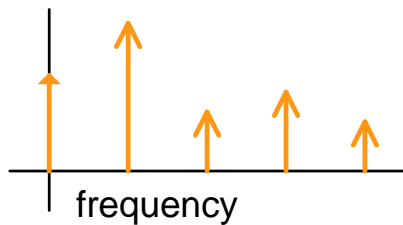
X-Parameters Formalism [5]

$$B_{p,k} \approx X_{p,k}^{(FB)} \cdot P^k + \sum_{\substack{q=1,\, l=1 \\ (q,l)\neq(1,1)}}^{q=N,\, l=K} X_{p,k;q,l}^{(S)} \cdot A_{q,l} \cdot P^{k-l} + \sum_{\substack{q=1,\, l=1 \\ (q,l)\neq(1,1)}}^{q=N,\, l=K} X_{p,k;q,l}^{(T)} \cdot A_{q,l}^{*} \cdot P^{k+l}$$

Simple nonlinear map

Linear harmonic map function of incident wave

Linear harmonic map function of conjugate of incident wave

$B_{p,k}$ and $A_{q,l}$ are harmonic wave components.

FB-, S-, and T-parameters are functions of
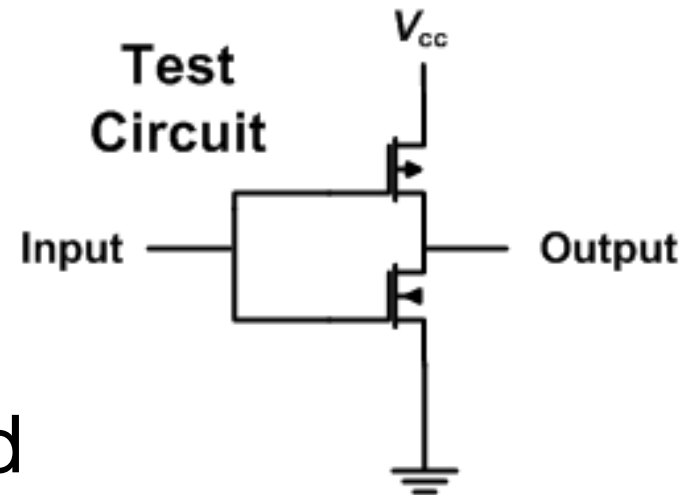- frequency
- large-signal magnitude $/A_{1,1}/$
- DC bias

$$X_{p,k;q,l}^{(S)} \qquad P = \frac{A_{1,1}}{|A_{1,1}|}$$

output port

output harmonic

input port

input harmonic

IBIS Model Construction

- Starting point: SPICE netlist for basic inverter, $V_{cc} = 2.5$ V.

- Goal: IBIS file of output mod
  - Include I-V and V-t curves.
  - Exclude parasitics, clamps, and AMI [6].

Rules/Guidelines

- Only generating X-parameter data that could be measured with a real NVNA.

- Using the IBIS Cookbook v4.0 as a guide to generate I-V and V-t curves [7].

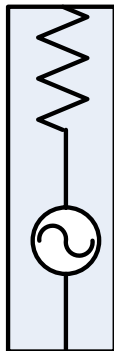- Comparing results to those generated with s2ibis3.
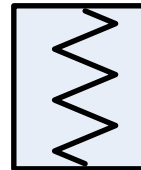
x2ibis Flowchart
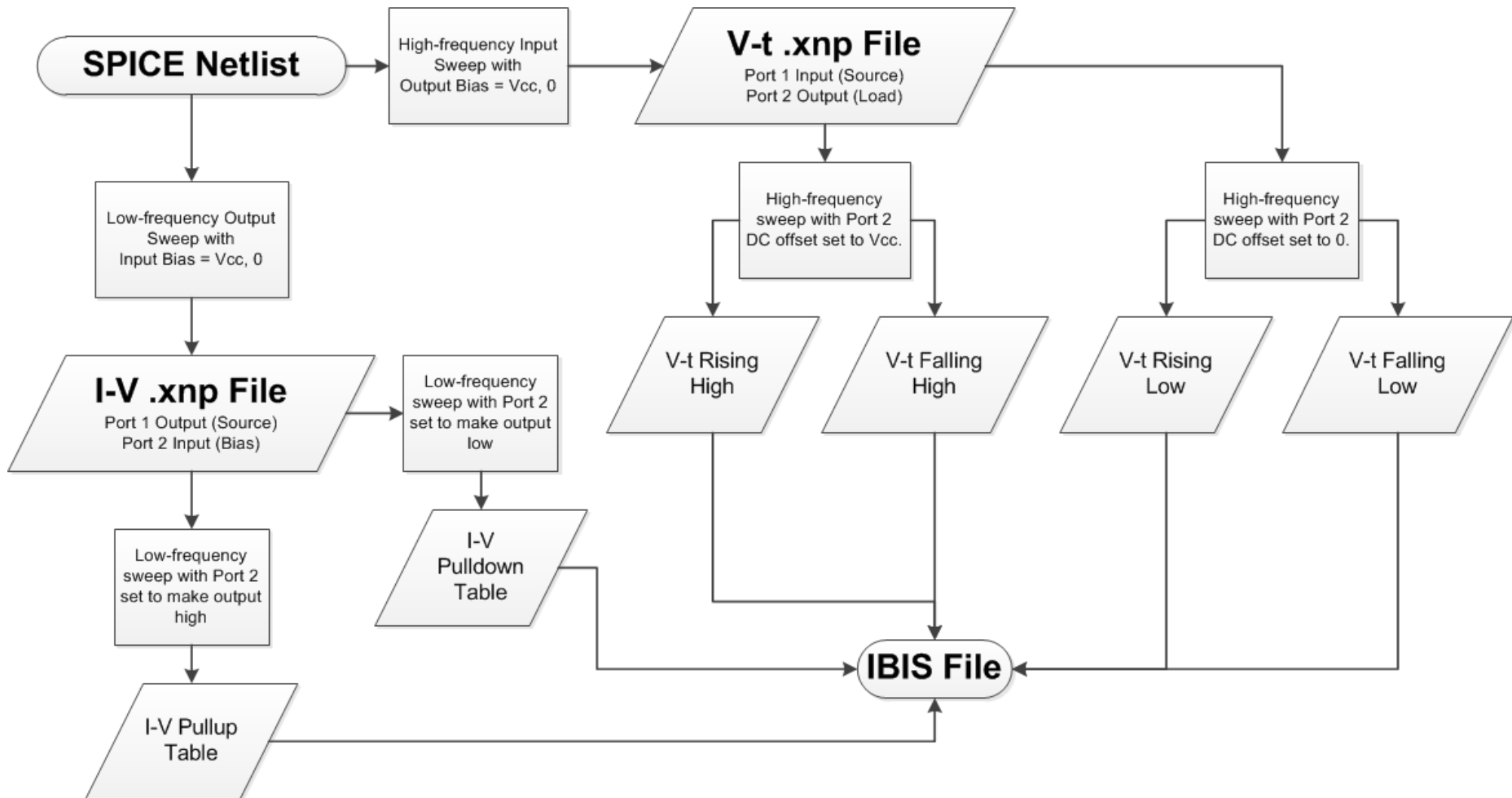
Generating X-Parameters

- X-parameters generated with Harmonic Balance simulation. Need to set proper values for:
  - Frequency range
  - Fundamental power
  - DC bias
- X-parameter measurements are unidirectional because of large-signal fundamental $/A_{1,1}/$ on one port.
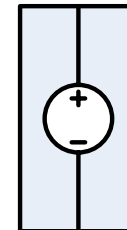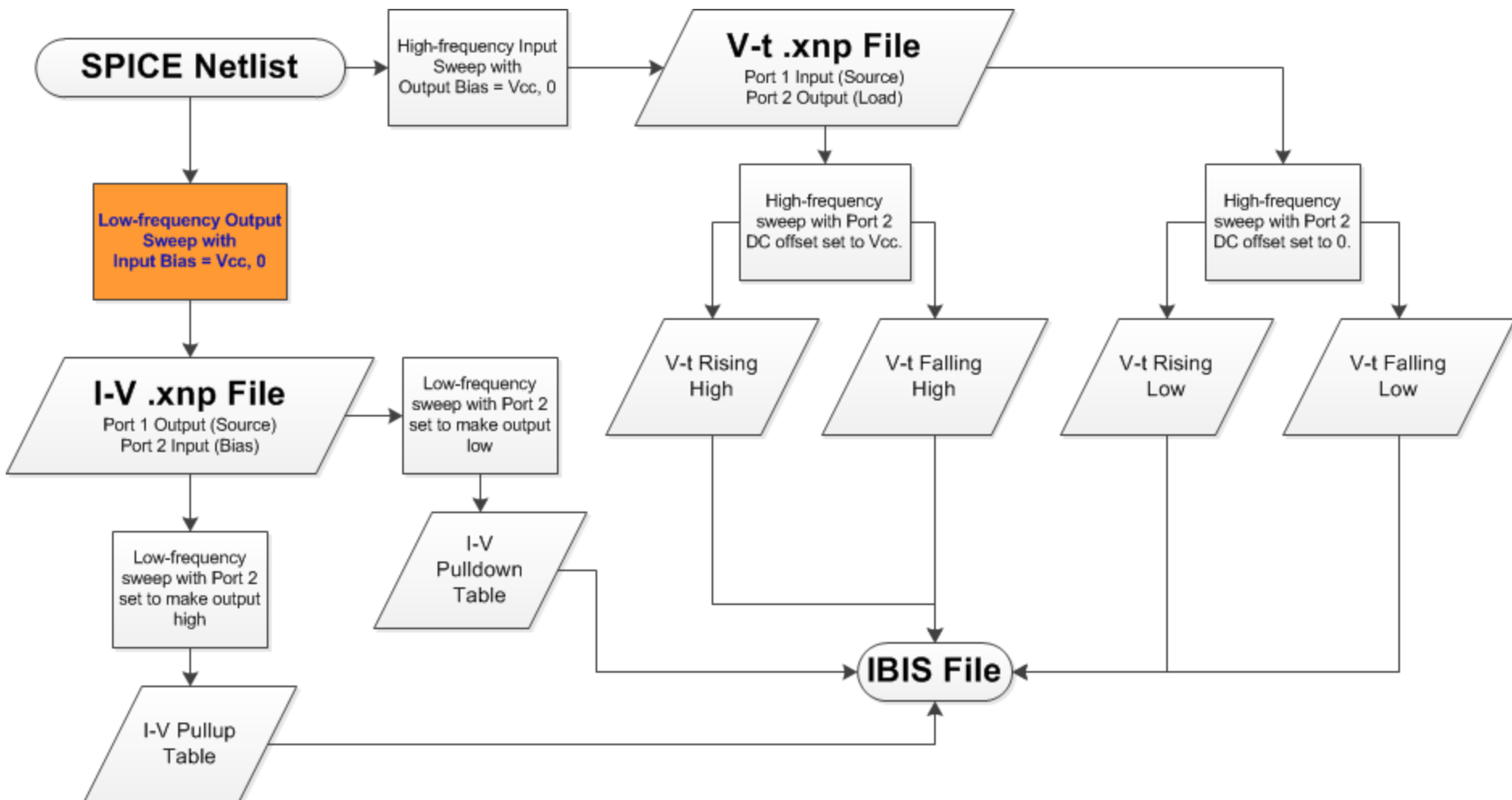- Different types of X-parameter ports [8]:

Source

Load

Bias

x2ibis Flowchart

I-V Curve Generation

Test Circuit

In   Out

Z_c

DC Voltage Bias

X-Parameter Source

Voltage Stimulus

$+2V_{cc}$

$k|A_{1,1}|$

DC Bias = $+0.5V_{cc}$

$-V_{cc}$
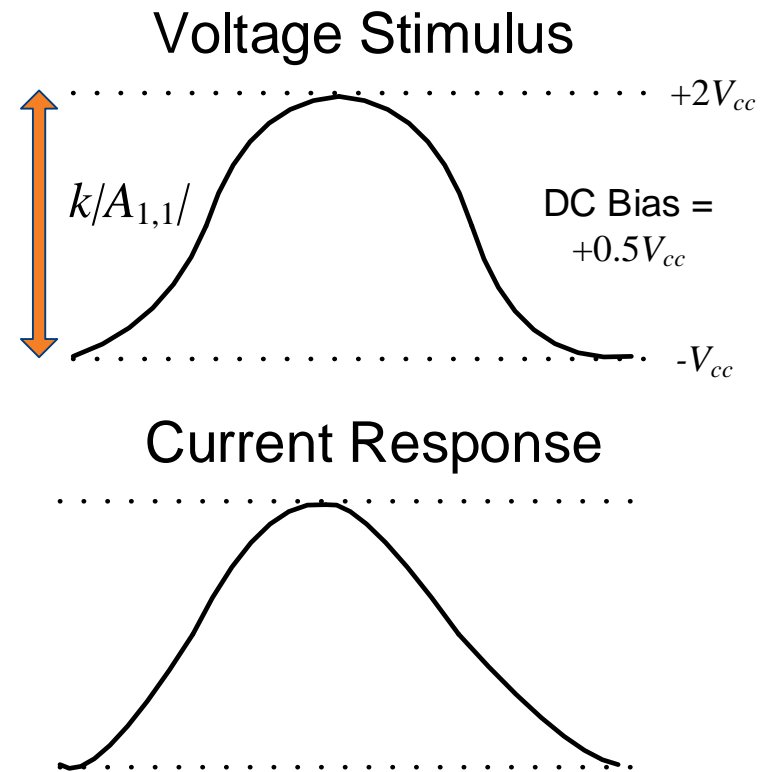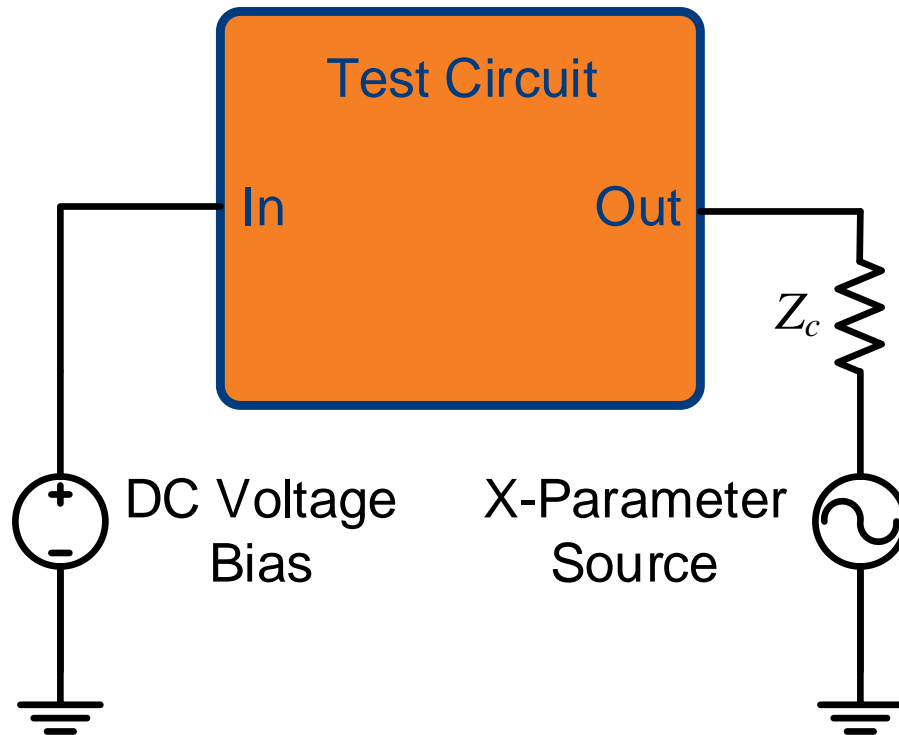
Current Response

- Approximate DC with low frequency voltage sweep and measure current response.

x2ibis Flowchart

Comberiate IBIS Summit
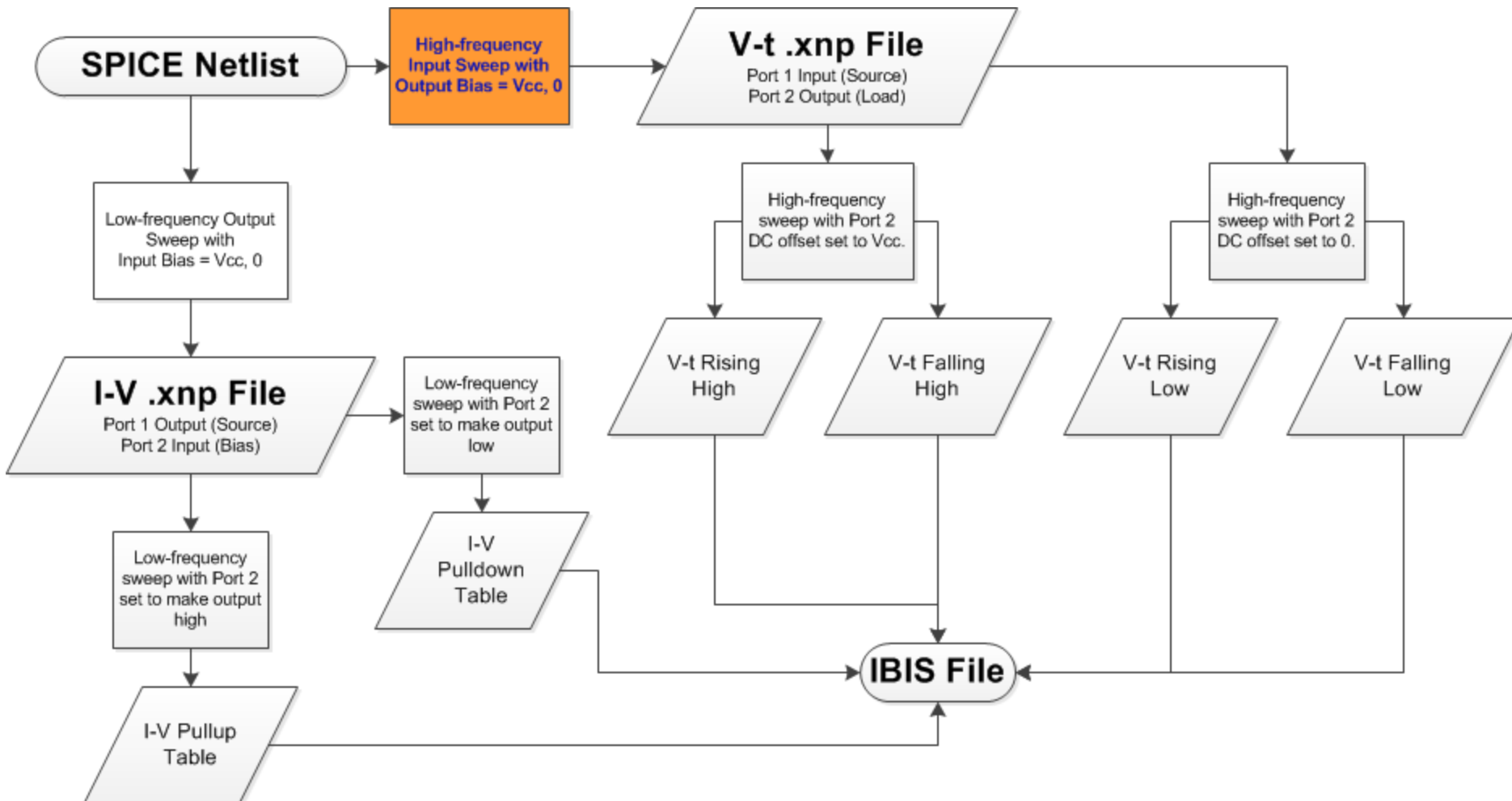
V-t Curve X-Parameter Generation

X-Parameter Stimulus

$k|A_{1,1}|$

DC Bias = +0.5Vcc

+Vcc

Falling **Rising**

Gnd

Response

Inverting Buffer

Rising **Falling**

Test Circuit

In Out

Z_c

X-parameter Source

X-parameter Load

Z_c
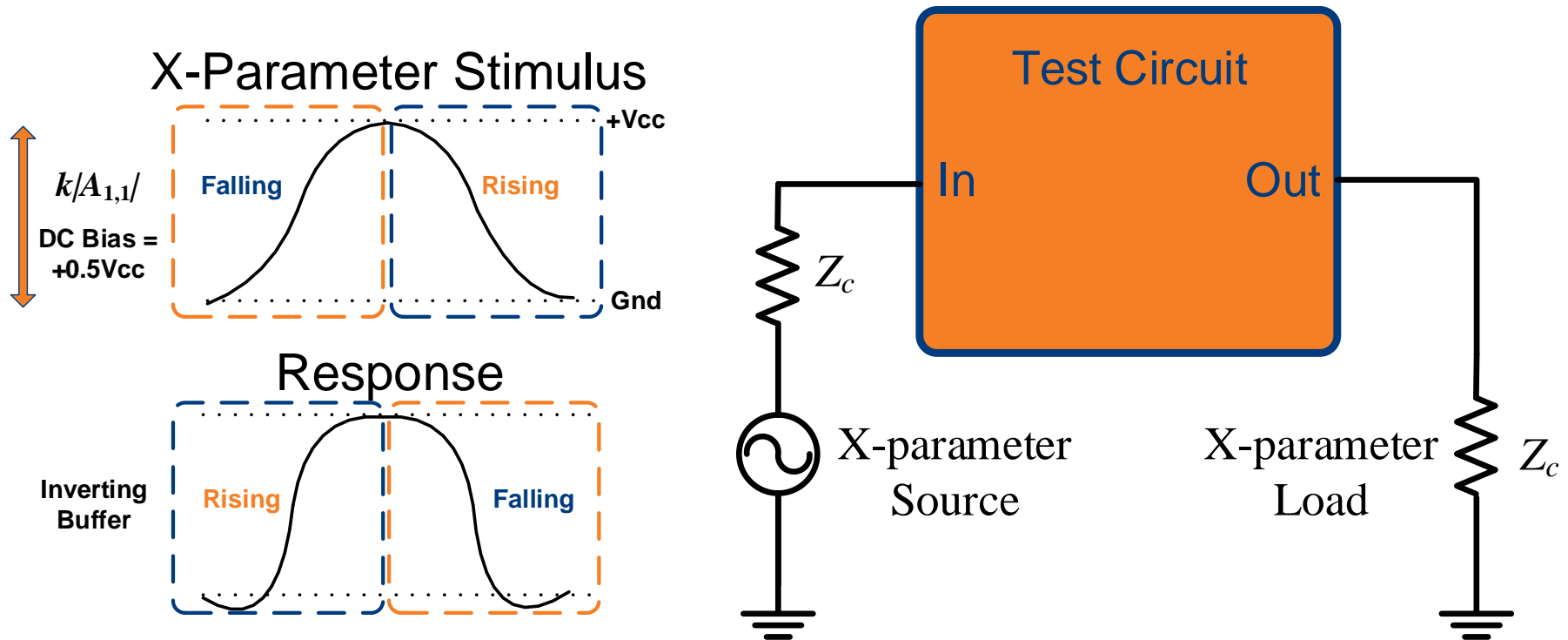
- Approximate step functions with rising and falling portions of a sinusoid.

What We Have

Test Circuit

- ## 2 .xnp files

I-V
.xnp file
1   2
Out   In/Bias

V-t
.xnp file
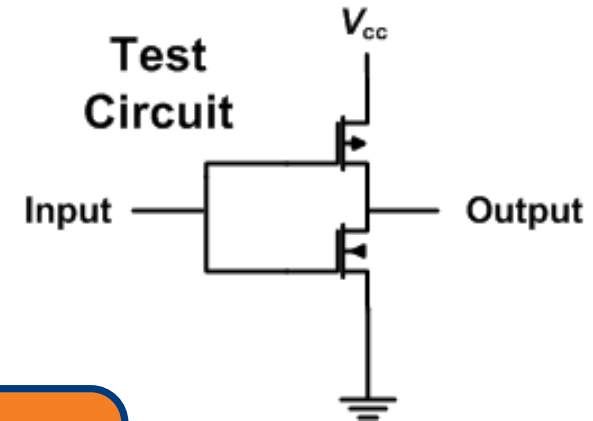1   2
In   Out

- 1-port measurement
- 1 fundamental frequency (low)
- 11 harmonics
- 1 power level, 2 input bias levels
- 26 kB
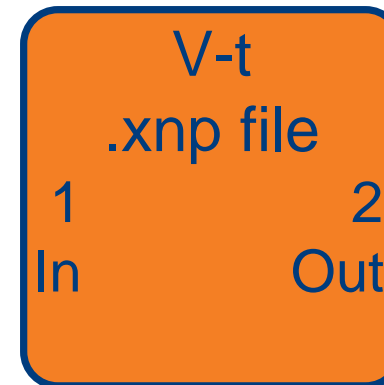
- 2-port measurement
- 1 fundamental frequency (high)
- 7 harmonics
- 1 power level, 2 input bias levels
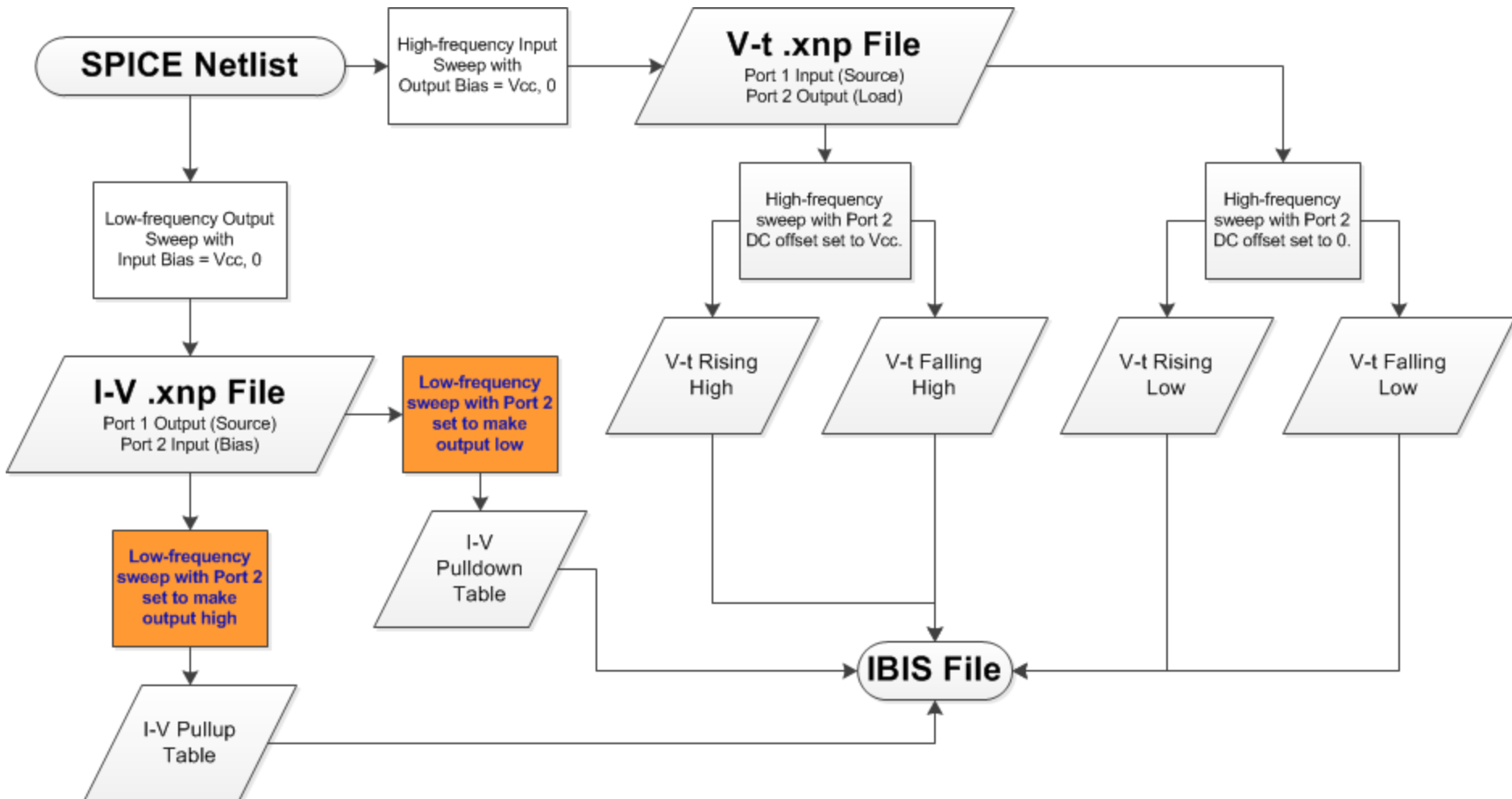- 39 kB

Simulating with X-Parameters

- Can only use X-parameter data in Harmonic Balance (HB) simulations, which are steady-state (periodic).

- Use scattered and incident waves to calculate voltage and current needed for IBIS tables.
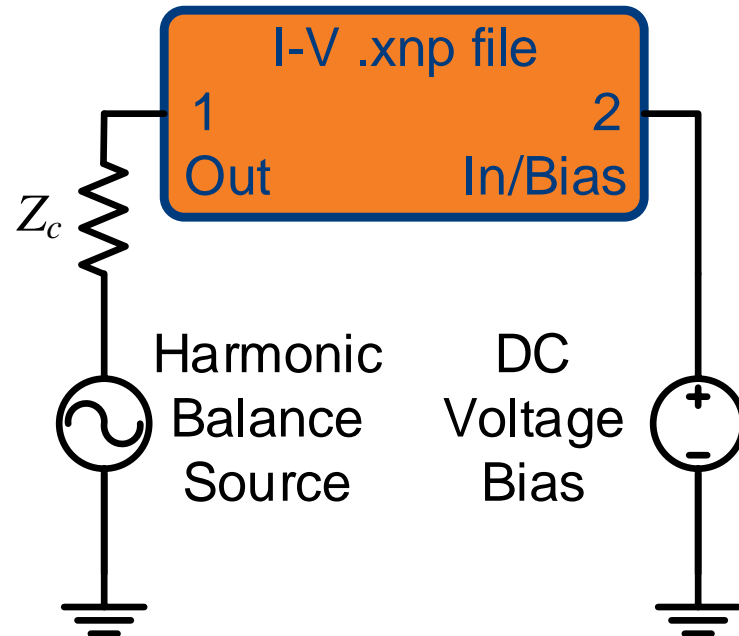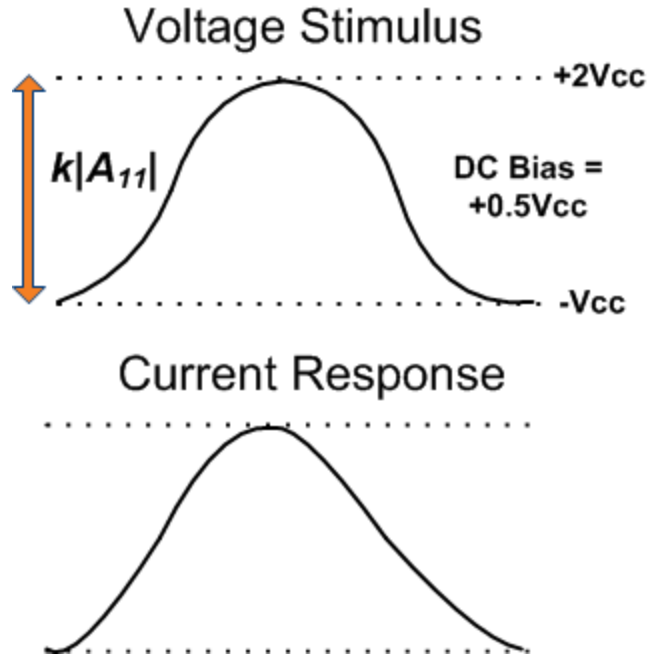
$$V_a = A_a + B_a$$

$$I_a = Z_0^{-1}(A_a - B_a)$$

x2ibis Flowchart

I-V Curve Calculation from X-Parameter Measurement

Voltage Stimulus

$k|A_{11}|$

+2Vcc

DC Bias = +0.5Vcc

-Vcc

Current Response

I-V .xnp file

1   2
Out   In/Bias

Z_c

Harmonic Balance Source
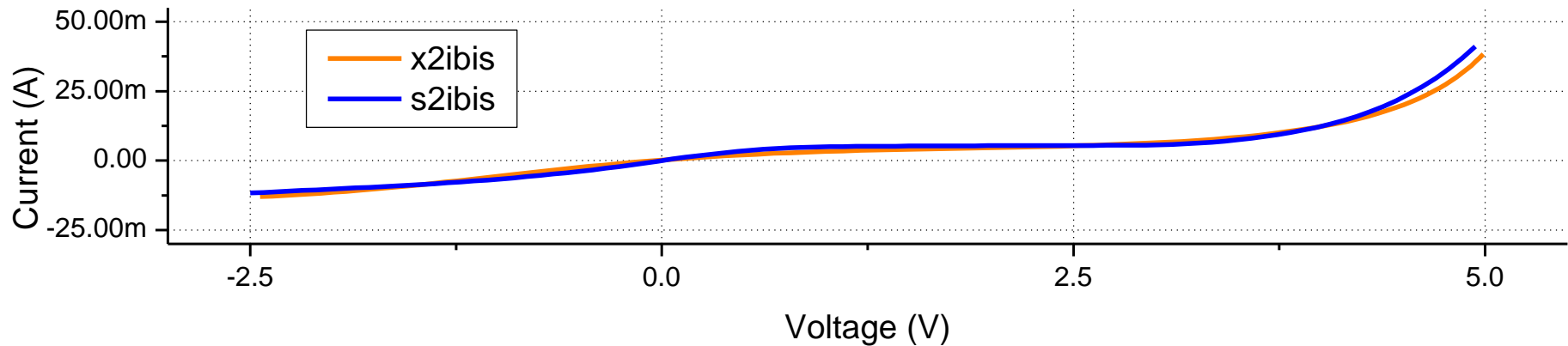
DC Voltage Bias

- Apply 1-tone voltage stimulus same as for generation.
- Measure input current and plot against input voltage.
- Normalize voltage so curve goes through (0 V, 0 mA).
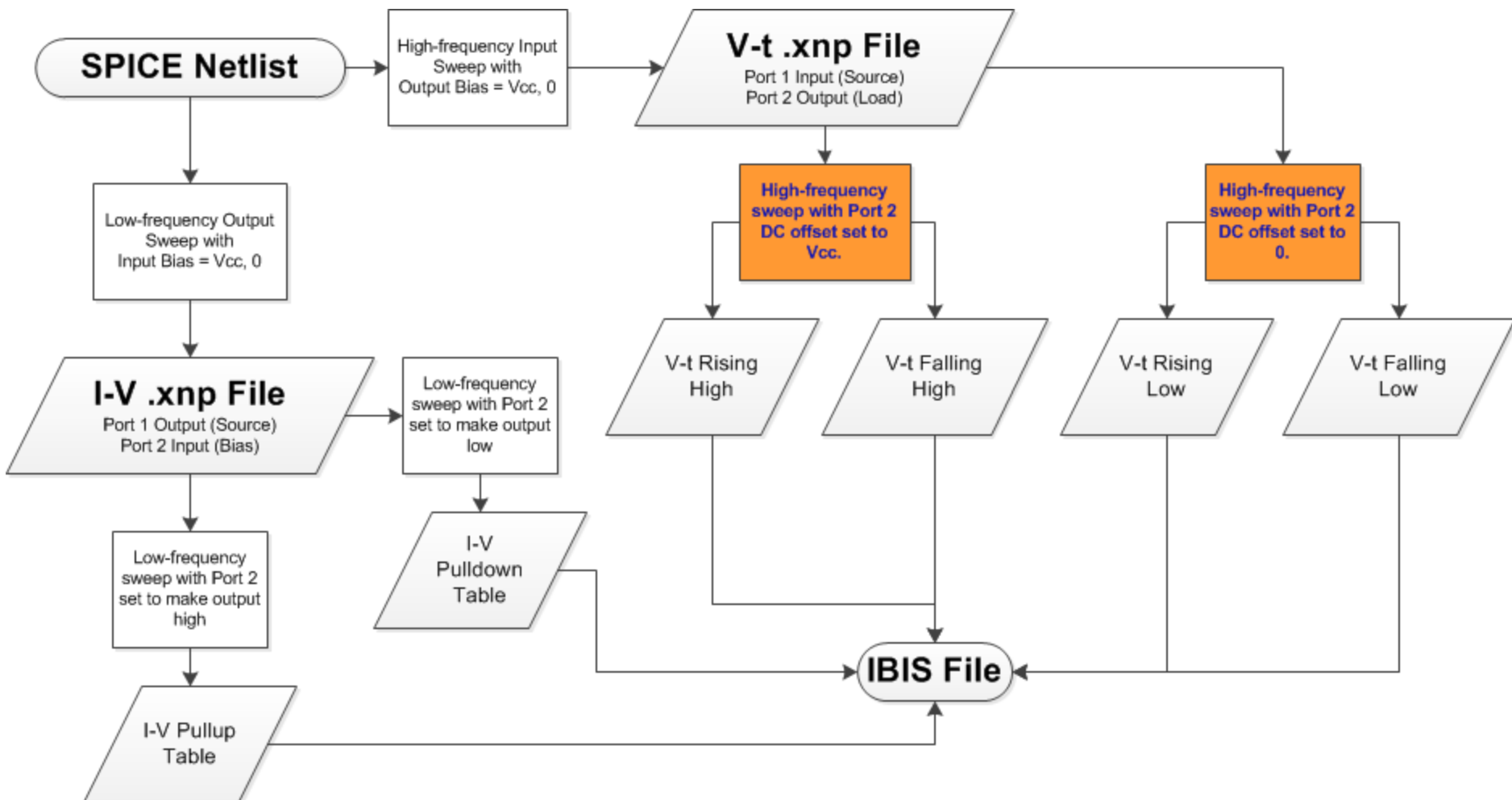
I-V Curve Generation Results
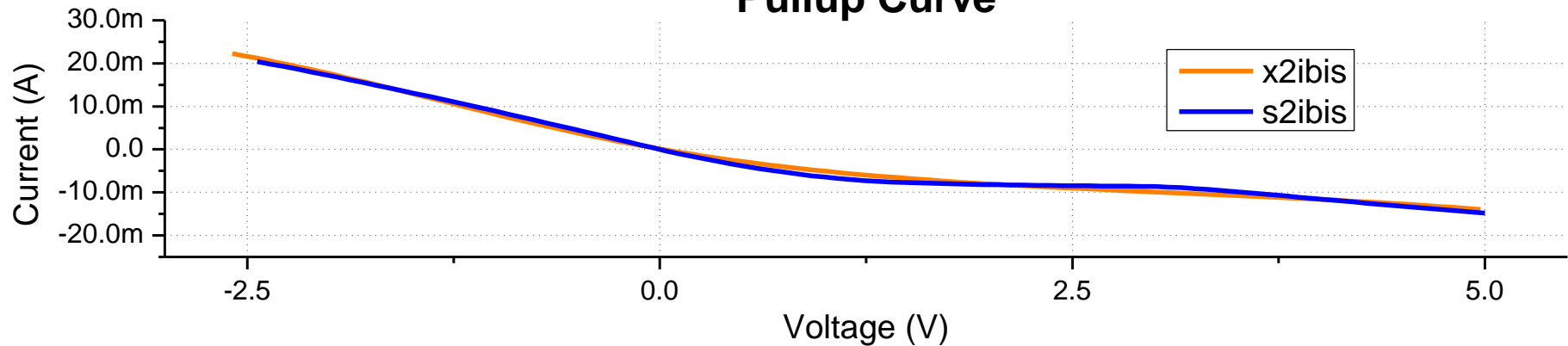
x2ibis and s2ibis have excellent match

x2ibis Flowchart

V-t Curve Calculation from X-Parameter Measurement

Harmonic Balance Stimulus

$k|A_{1,1}|$

DC Bias = +0.5Vcc

+Vcc

Falling   **Rising**

Gnd

Response

Inverting Buffer

Rising   **Falling**

V-t .xnp file

1   2
In   Out

Z_c

Harmonic Balance Source

50 Ω
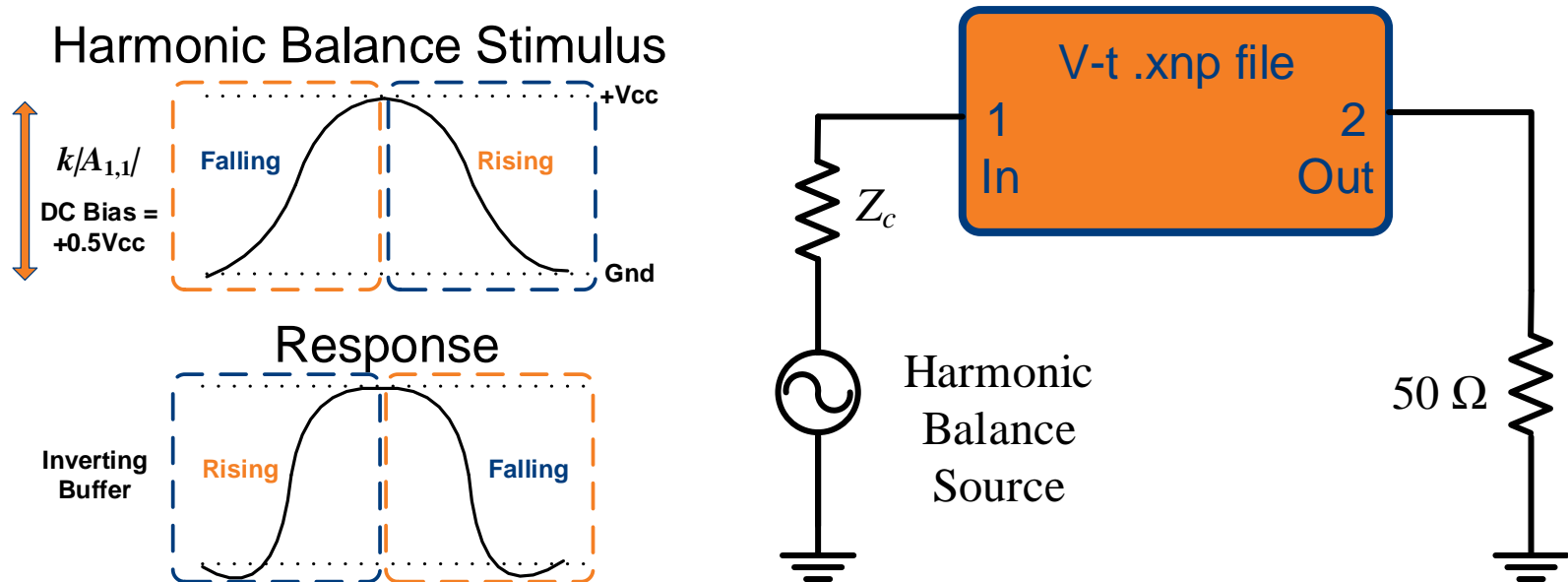
- Approximate a step function with a sinusoid.
- Generate V-t rising and falling curves from the corresponding portions of the response to the stimulus.
- Normalize beginning and end points to match I-V data.

V-t Curve Generation Results
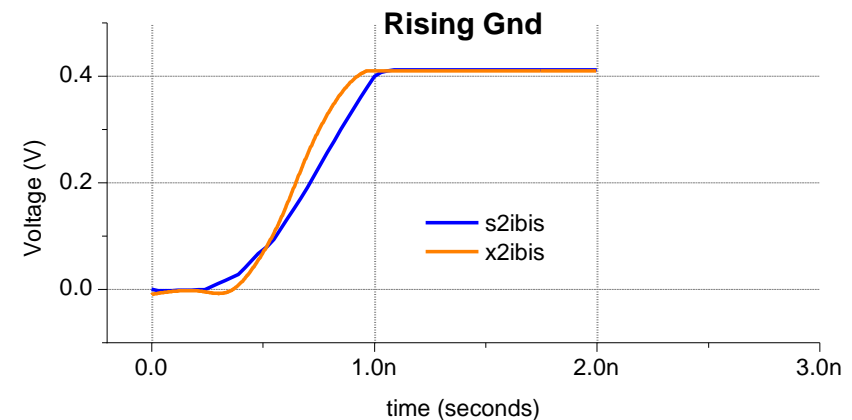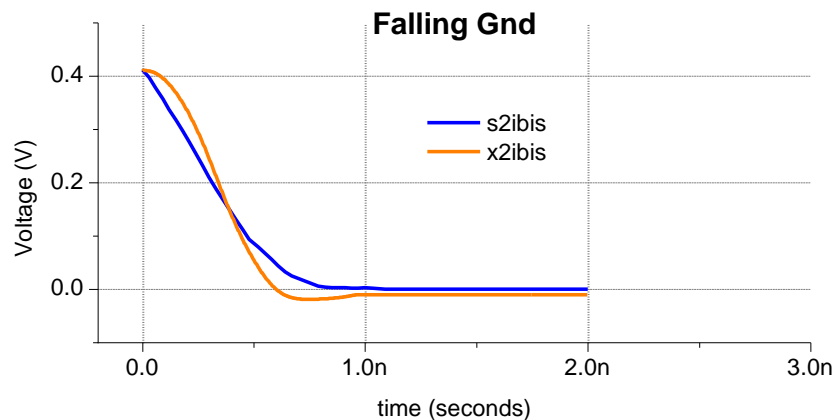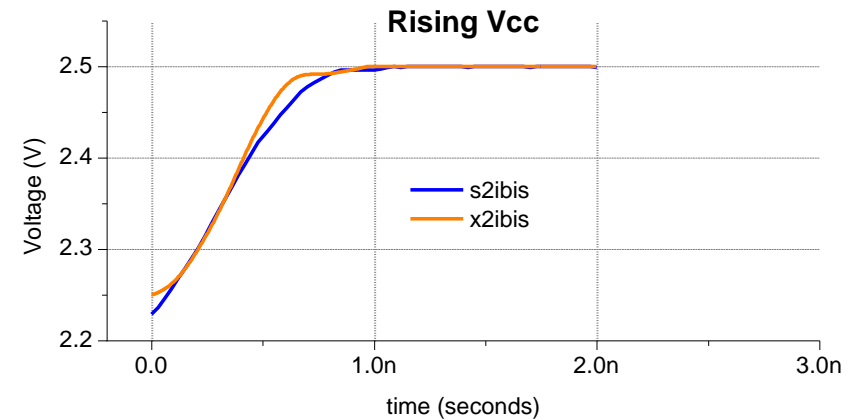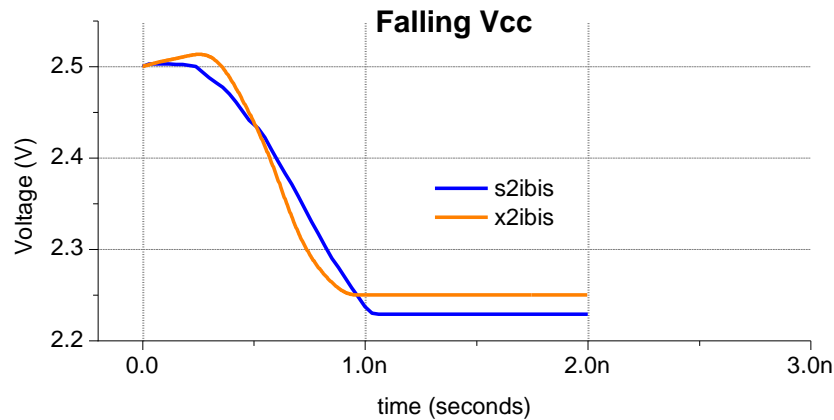
x2ibis and s2ibis have reasonable match

Putting It All Together

Comparison of x2ibis and s2ibis models with PRBS stimulus:
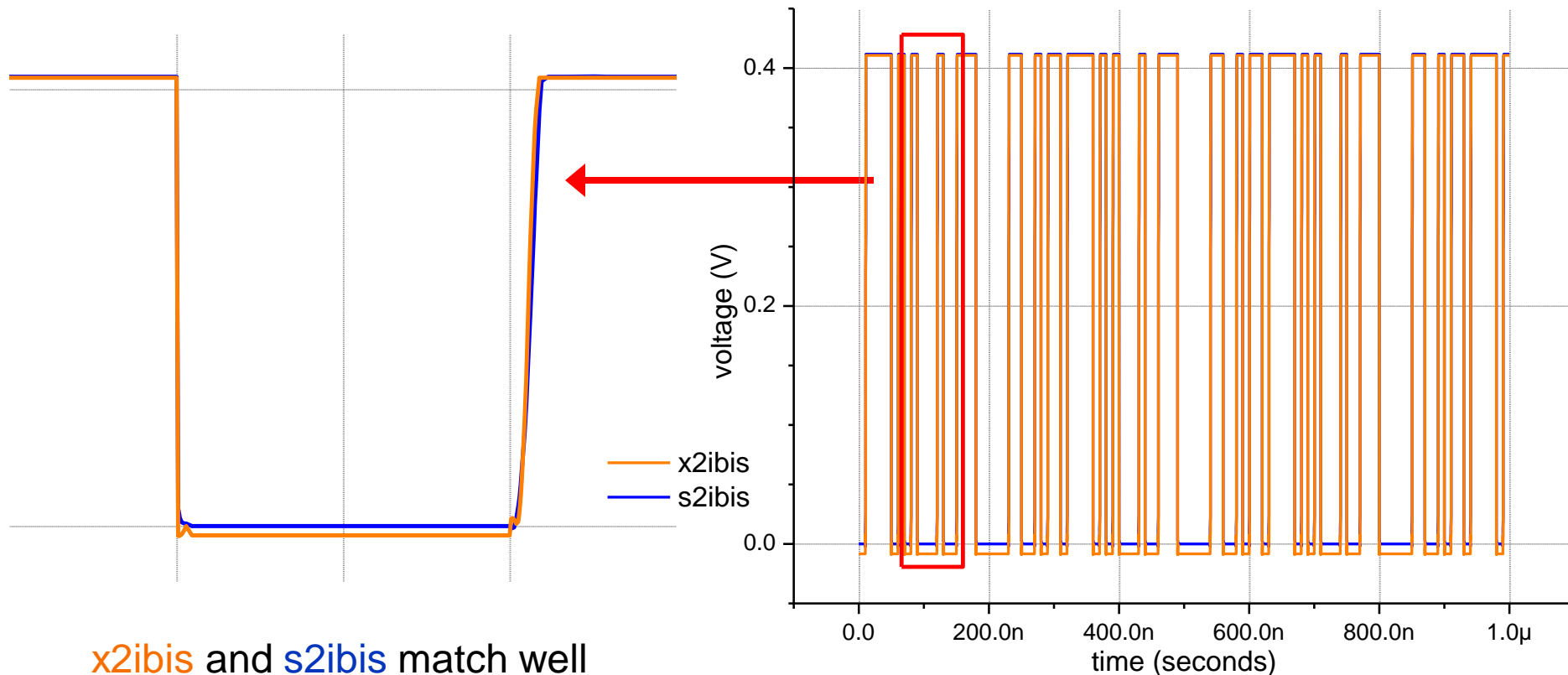
x2ibis and s2ibis match well

Conclusions/Comments

- Only 2 small X-parameter files needed, <100kB.

- IBIS data is generated in a seamless manner.

- Ability to include second-order effects to improve accuracy.

- Could include multiple frequencies in the V-t curve .xnp file to vary rise times.

- Ideally, these .xnp files could be sent to model developer instead of SPICE netlist.

Future Work

- Improve approximation of ideal step for V-t curve generation.

- Perform x2ibis on more complicated buffer circuits.

  - Include parasitics, clamps, etc.

  - Include equalizer blocks

- Develop transient simulation techniques for use with .xnp files.

- Implement BIRD releases (95 & 98)

Acknowledgments

- Signal Integrity Research Group at the University of Illinois at Urbana-Champaign.
  - Xu Chen
- Agilent Technologies, Inc. for providing the X-parameter platform.
  - Loren Betts
  - Steve Fulwider
  - David Root
  - Eric Iverson
- This research was made possible with United States Government support under and awarded by DoD, Air Force Office of Scientific Research, National Defense Science and Engineering Graduate (NDSEG) Fellowship, 32 CFR 168a and through the support of the National Science Foundation.

References

[1] s2ibis3 v1.1. Copyright © North Carolina State University. Last modified: March 27, 2006.

[2] C. Warwick, "What About the *.ibs File?" blog, 15 December, 2011; http://signal-integrity.tm.agilent.com/2011/what-about-the-ibs-file/.

[3] "X-Parameters Trademark Usage, Open Documentation and Partnerships," http://www.home.agilent.com/agilent/editorial.jspx?cc=US&lc=eng&ckey=1822138&id=1822138&cmpid=zzfindeesof-x-parameters-info.

[4] Agilent Technologies, "PNA-X Nonlinear Vector Network Analyzer (NVNA)," January 2013. http://www.home.agilent.com/en/pd-1381958/pna-x-nonlinear-vector-network-analyzer-nvna-options-510-514-518-and-520.

[5] L. Betts, Agilent Technologies, "X-Parameters & Nonlinear Vector Network Analysis (NVNA) Going Beyond S Parameters," May 9, 2009. [Online]. Available: http://www.ieee-sem.org/ChapterIV/090504_LorenBetts_NVNA.pdf.

[6] The IBIS Open Forum, "I/O Buffer Information Specification Version 5.1." Ratified August 24, 2012. IBIS homepage: http://www.eigroup.org/ibis/.

[7] The IBIS Open Forum, "IBIS Modeling Cookbook for IBIS Version 4.0," Copyright © 2005 Government Electronics and Information Technology Association and The IBIS Open Forum.

[8] Agilent Advanced Design System, Version 2011.10 Help Notes, "X-Parameter Generator Basics ADS help notes on X-parameter ports." Copyright © 1983-2011, Agilent Technologies.