Using X-Parameters* to Generate IBIS Models

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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 mathematical superset of S parameters.
  - Can describe nonlinear effects.
  - Can be measured with NVNAs [4].
- Would like for designers to be able to exchange .xnp files and generate IBIS models from them.

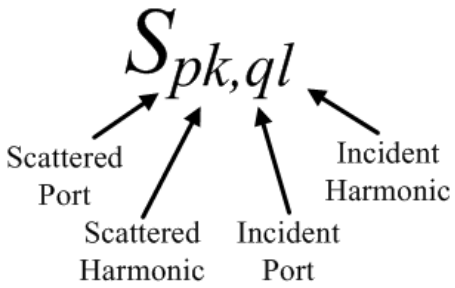
Polyharmonic Distortion (PHD) Model [5]

- "Black-box" behavioral model of a nonlinear component defined in the frequency domain.
- Large-signal tone A_{11} is applied to the input.
- Additional "small" harmonic frequency components respond linearly but can also contribute to each other.

X-Parameters Formalism [5]

$$B_{pk} = \sum_{q,l} S_{pk,ql}(|A_{11}|, f, V_{DC}) \cdot P^{k-l} \cdot A_{ql} + \sum_{q,l} T_{pk,ql}(|A_{11}|, f, V_{DC}) \cdot P^{k+l} \cdot A_{ql}^{*}$$

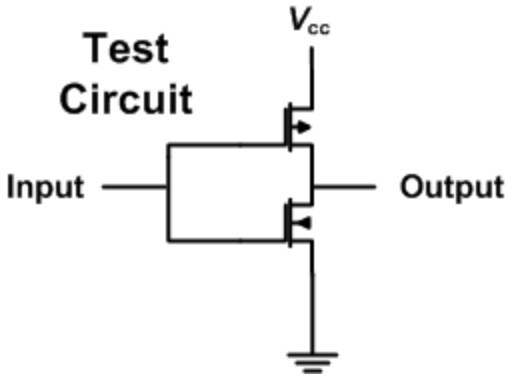
$$T_{p1,q1} = 0 \;\forall\; p, q$$



- Harmonic components of scattered waves are determined by the incident waves and their conjugates.
- S and T parameters are functions of frequency, fundamental magnitude, and DC bias.

IBIS Model Construction

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

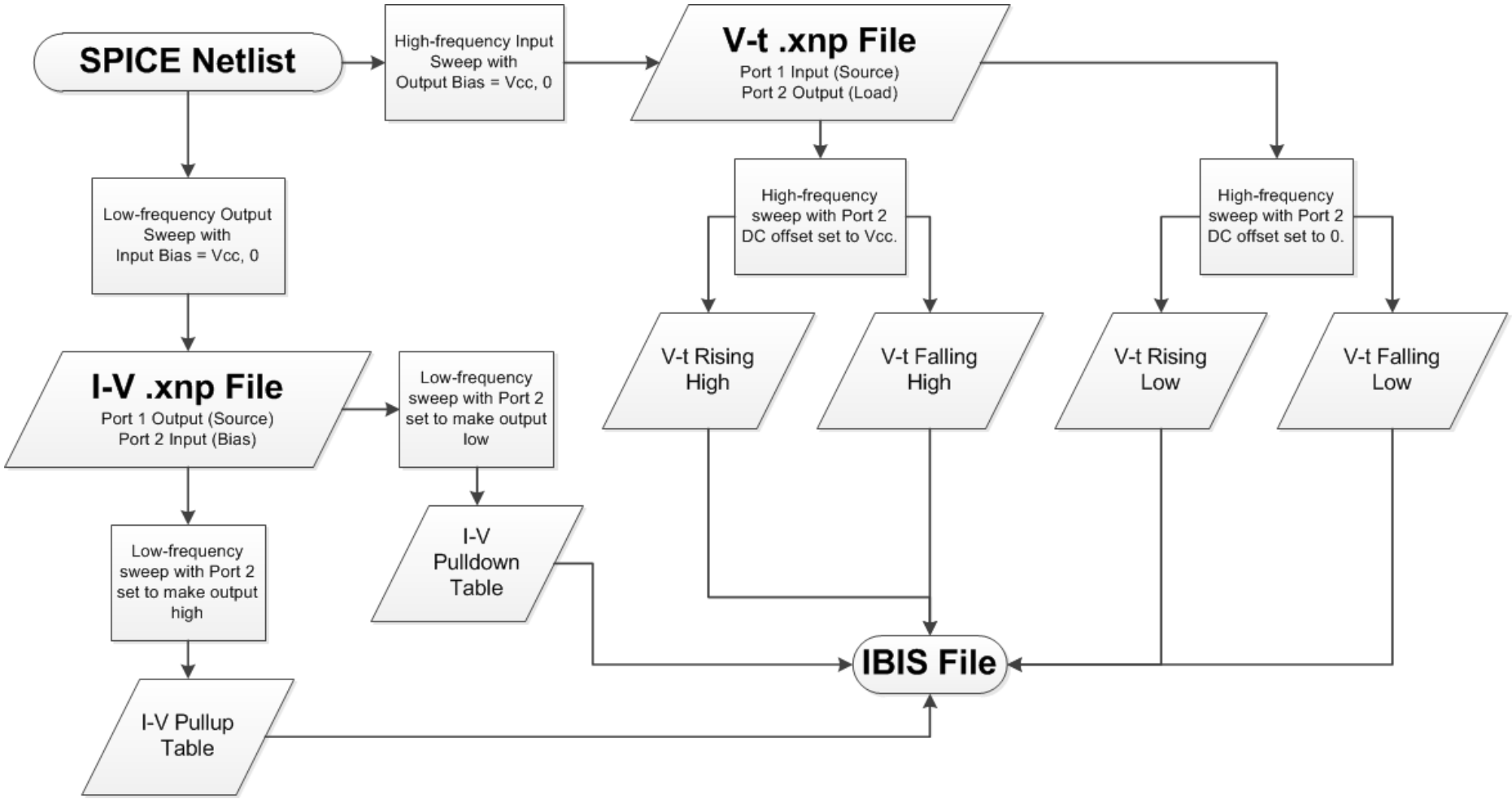


- Goal: IBIS file of output model with no parasitics, clamps, or AMI [6].

Rules/Guidelines

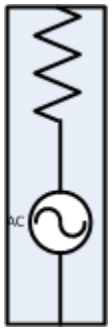
- Only generating X-parameter data that could be measured with a real NVNA.
- Using the IBIS Cookbook v4.0 as a guide to generate I-V and V-t curves [7].
- Comparing results to those generated with s2ibis3.

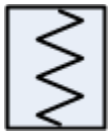
x2ibis Flowchart

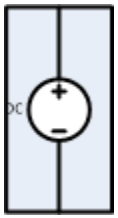


Generating X-Parameters

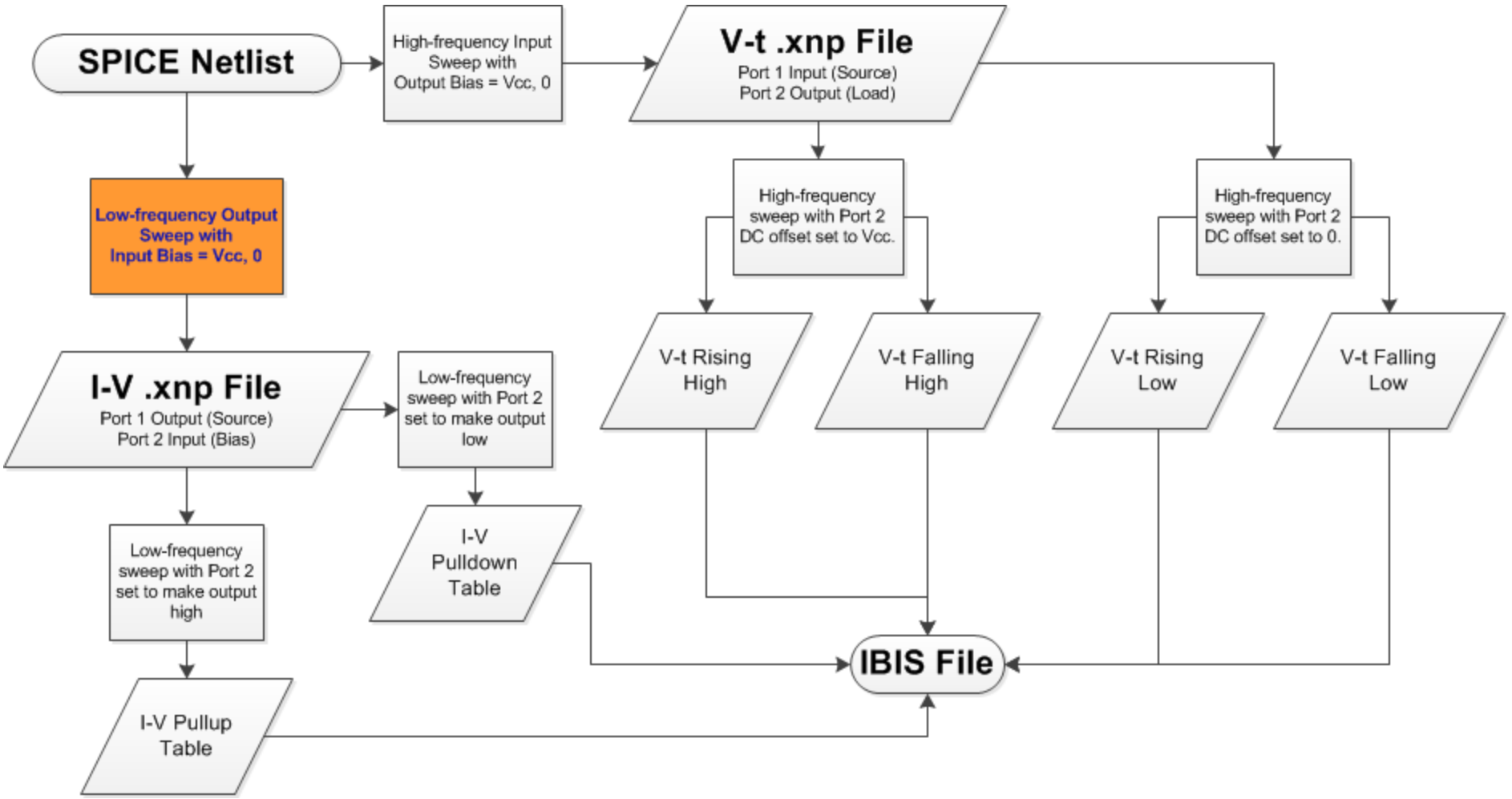
- X-parameters generated with Harmonic Balance simulation. Need to set proper values for:
  - Frequency range
  - Fundamental power
  - DC bias
- X-parameter measurements are unidirectional because of large-signal fundamental $|A_{11}|$.
- Different types of X-parameter ports [8]:

Source 

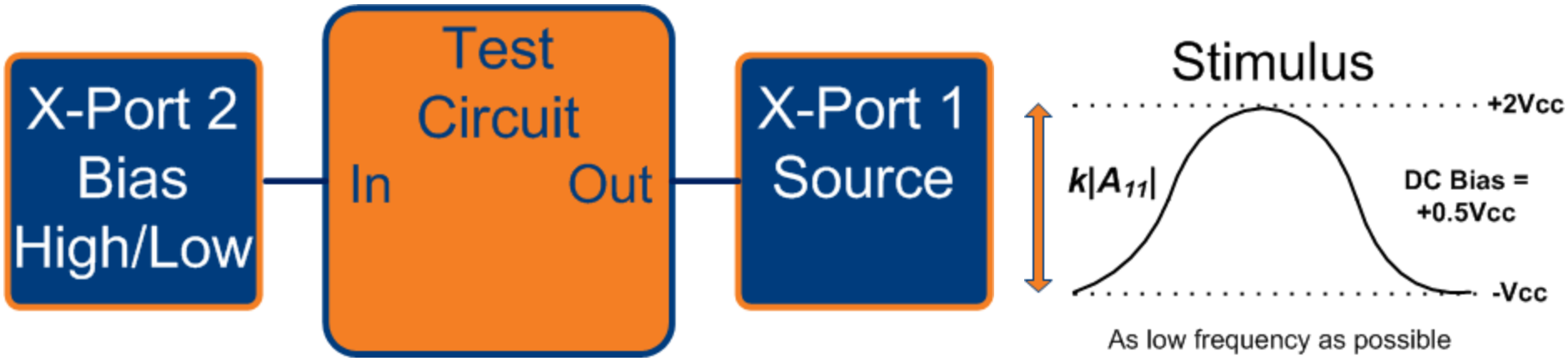
Load 

Bias 

x2ibis Flowchart

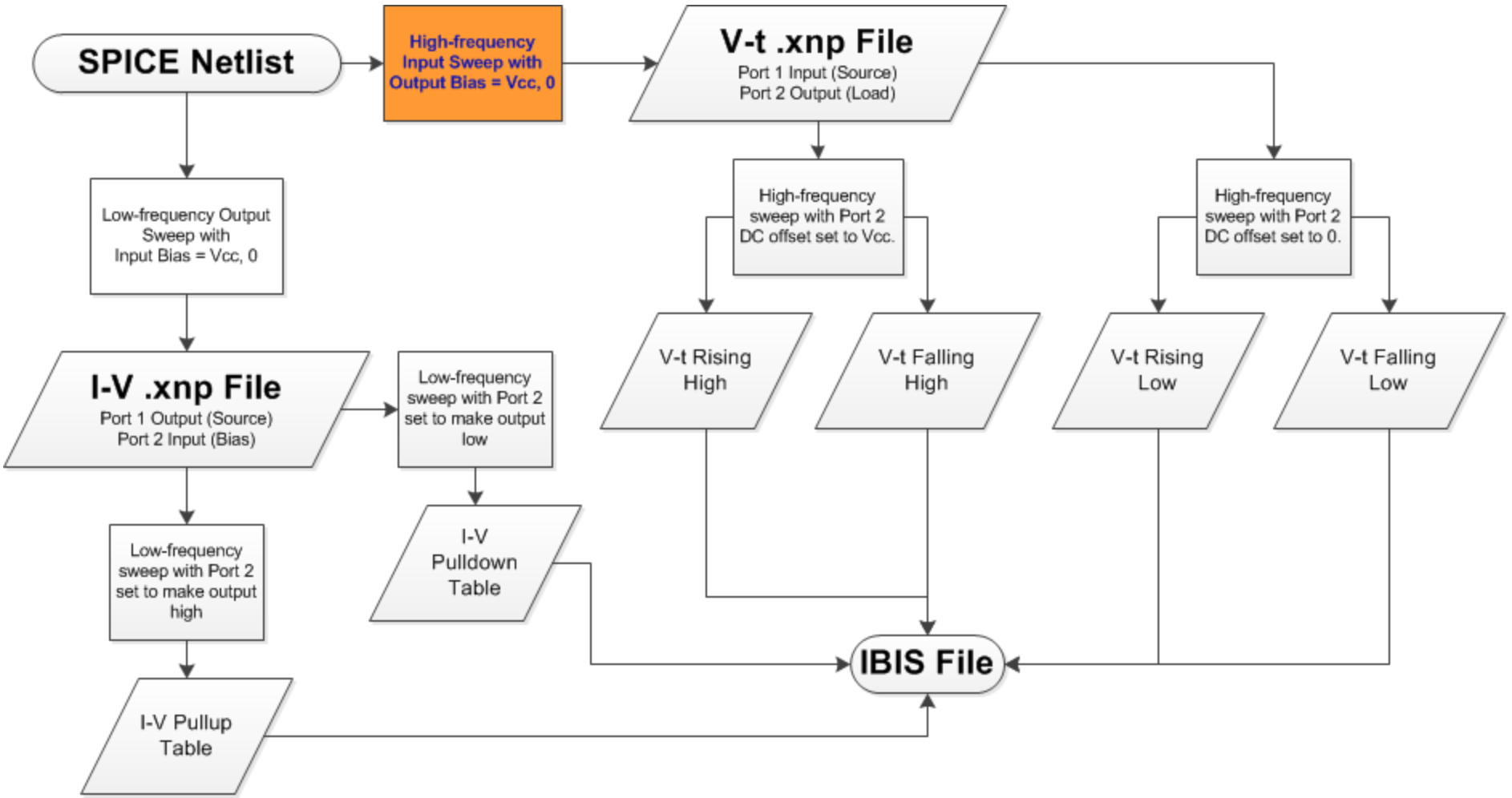


I-V Curve X-Parameter Generation

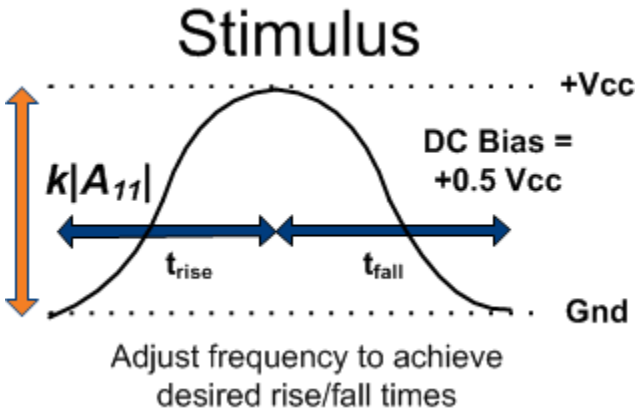


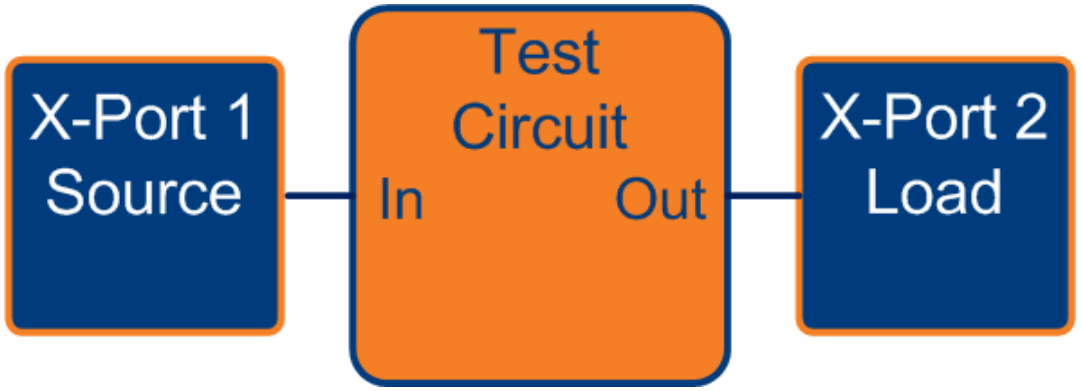
- Bias input port to activate pull-up or pull-down network.
- Sweep the output from –Vcc to 2Vcc to cover full range needed and extract current and voltage.
- Approximate steady-state response with low frequency sinusoidal stimulus.

x2ibis Flowchart



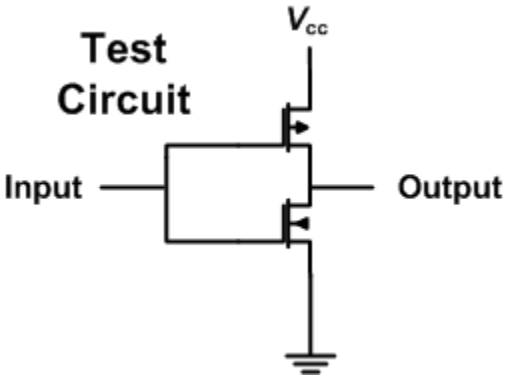
V-t Curve X-Parameter Generation





- Cookbook calls for ideal step stimuli with prescribed rise and fall times.
- Approximating the ideal step with a sinusoid.
- Load has Vcc V and 0 V DC biases.

What We Have



- 2 .xnp files

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

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

V-t
.xnp file
1 2
In Out

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

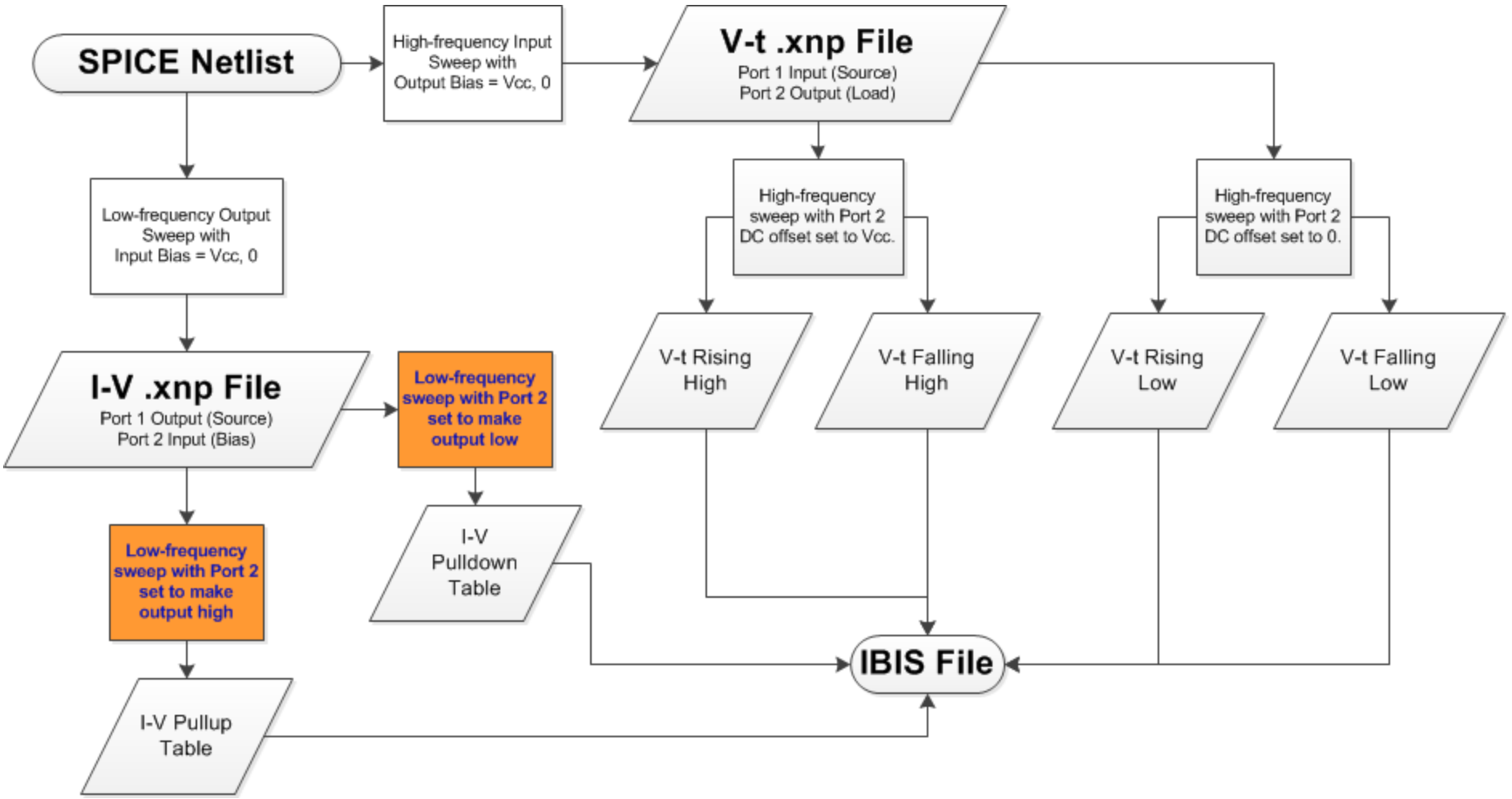
Simulating with X-Parameters

- 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.

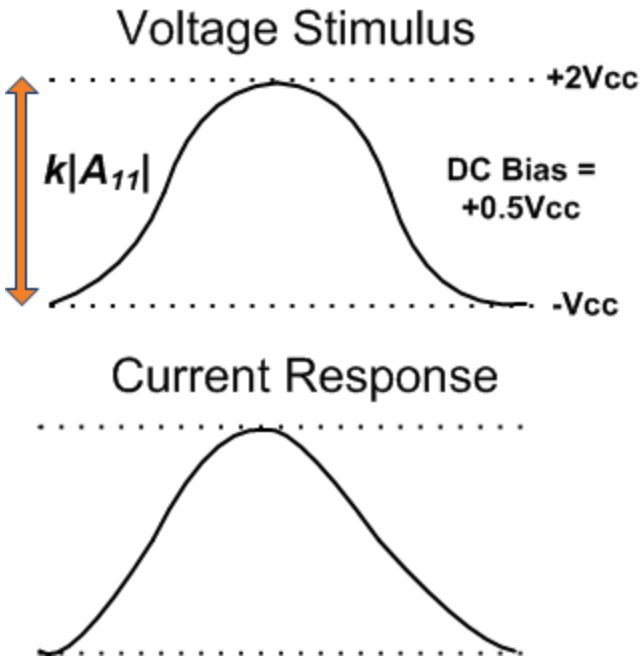
$$V_a = A_a + B_a$$

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

x2ibis Flowchart

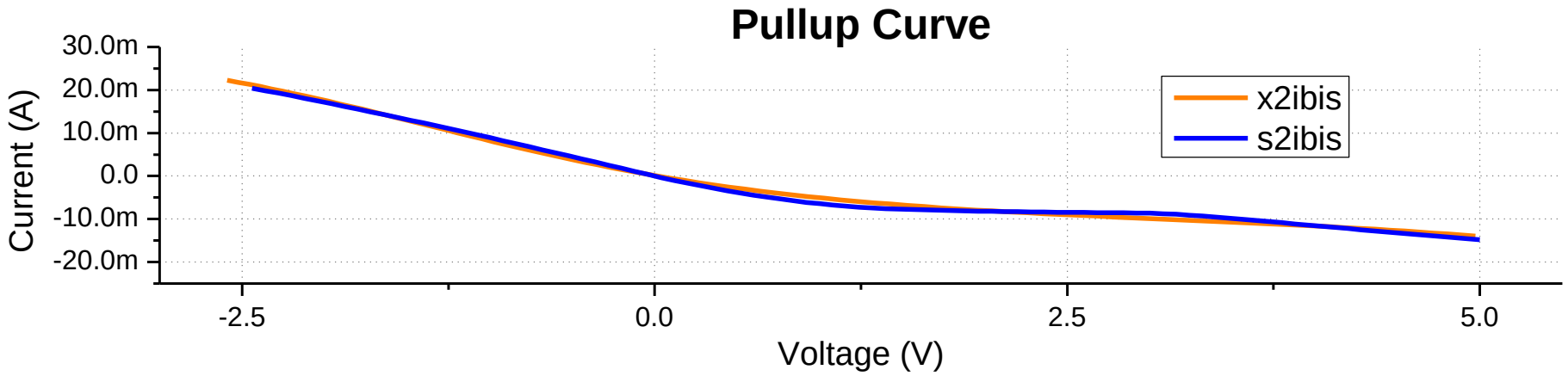


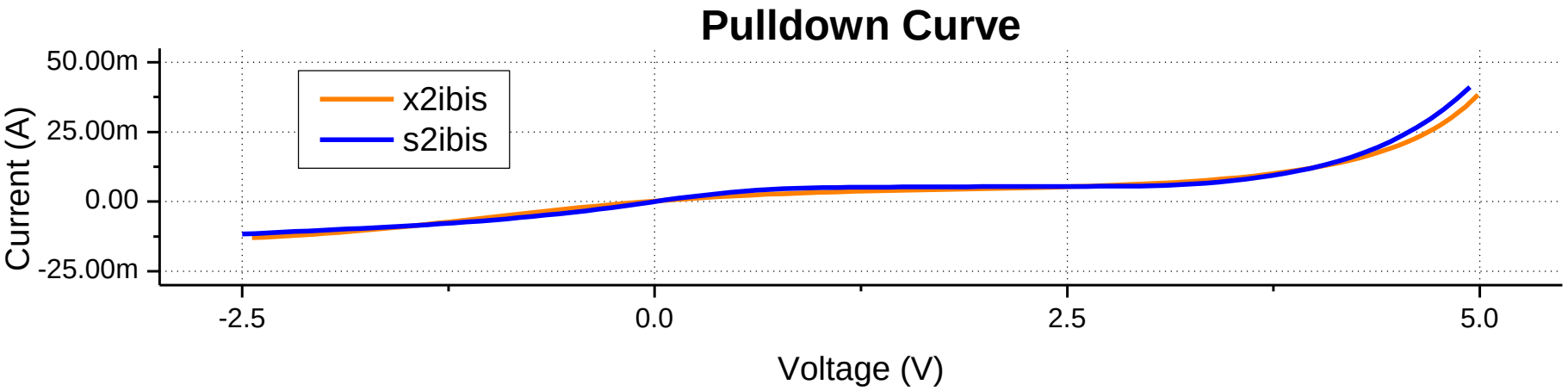
I-V Curve Calculation from X-Parameter Measurement



- 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).

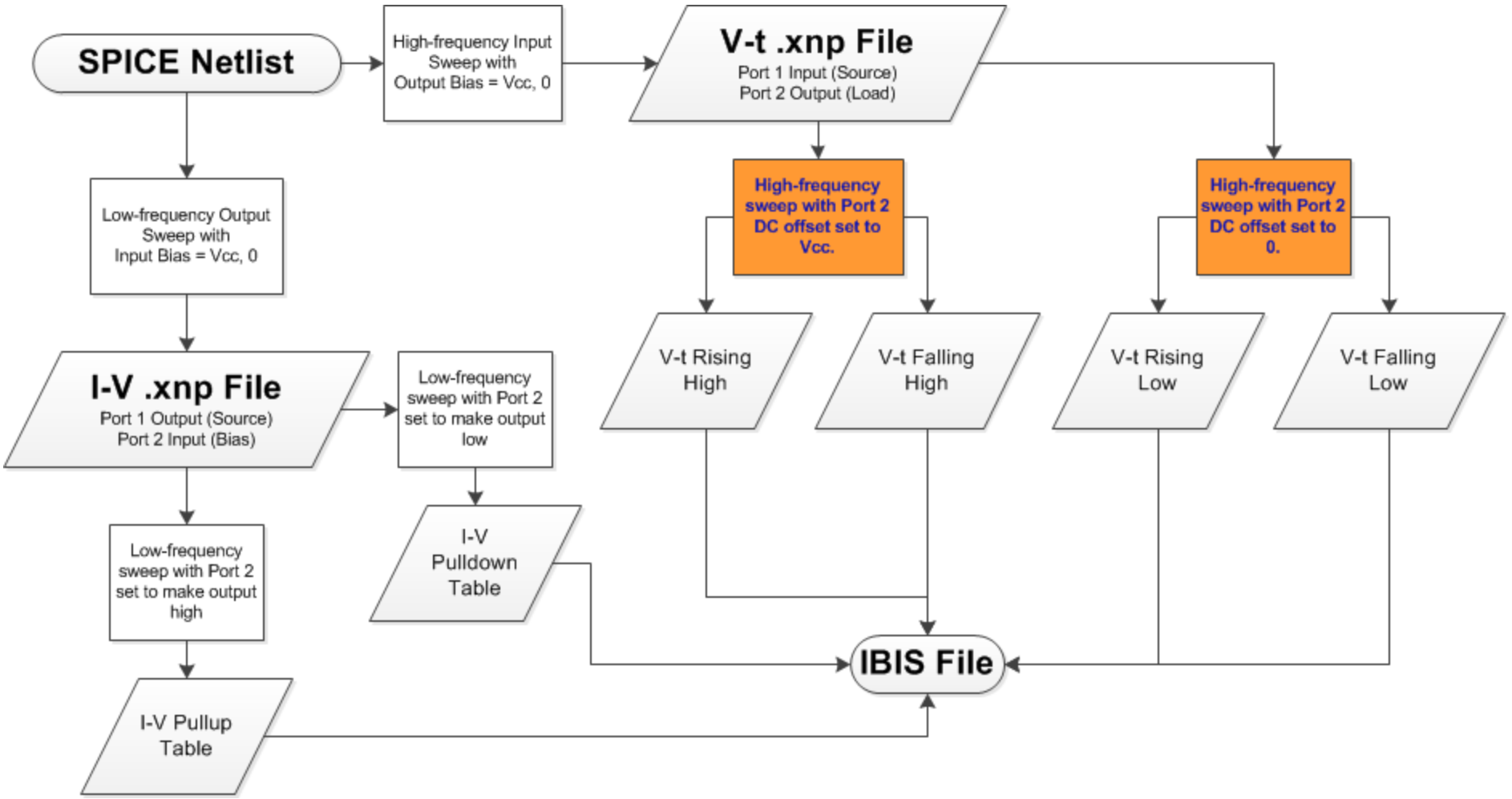
I-V Curve Generation Results



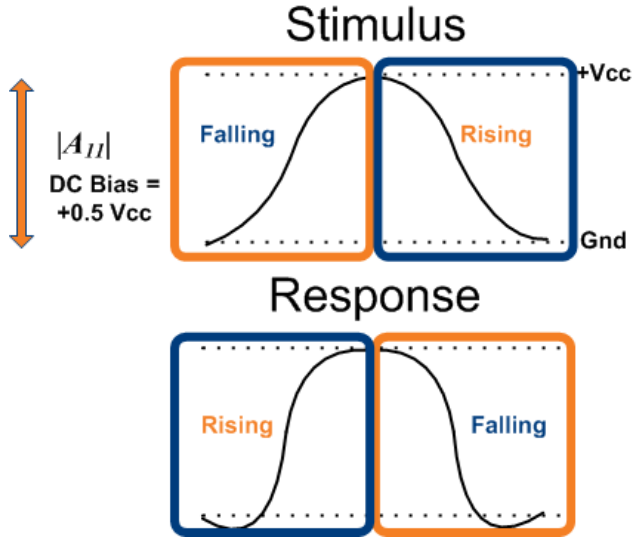


x2ibis and s2ibis have excellent match

x2ibis Flowchart

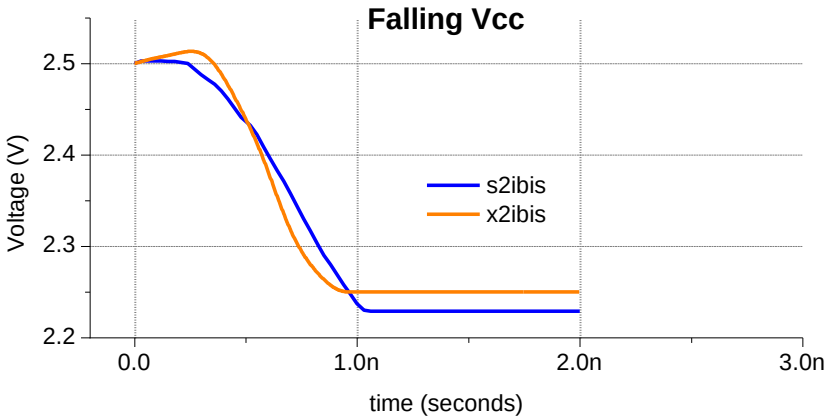


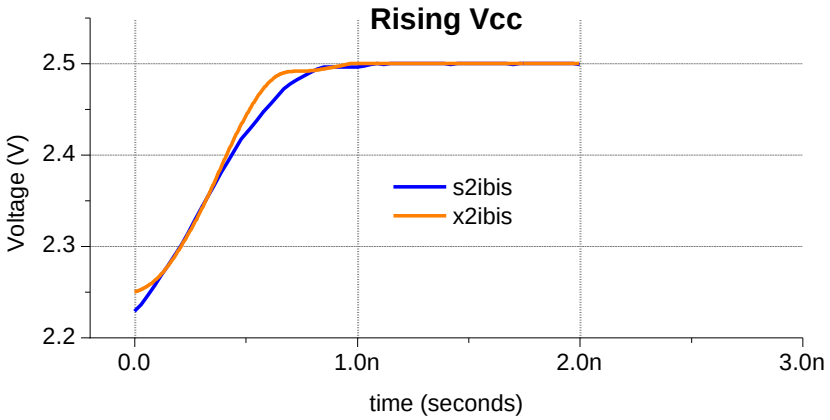
V-t Curve Calculation from X-Parameter Measurement

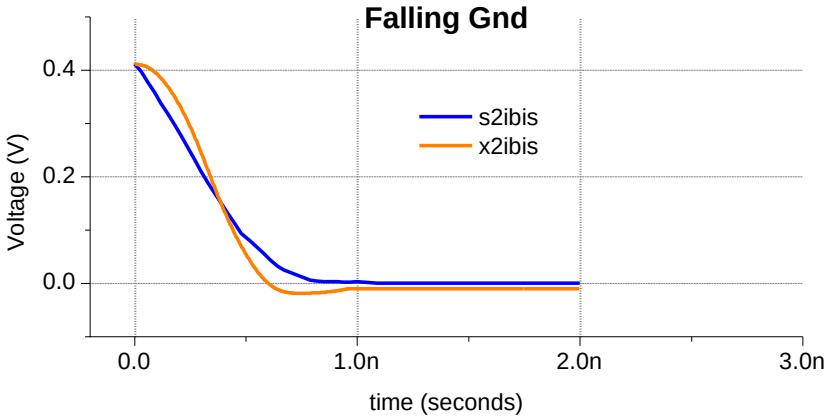


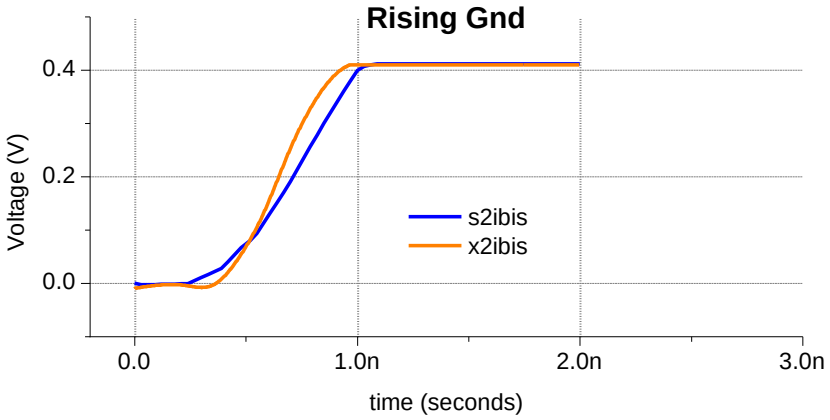
- Approximate a step function with a sinusoid.
- Generate V-t rising and falling curves from the corresponding portions of the response to the stimulus.
- Normalize beginning and end points to match I-V data.

V-t Curve Generation Results





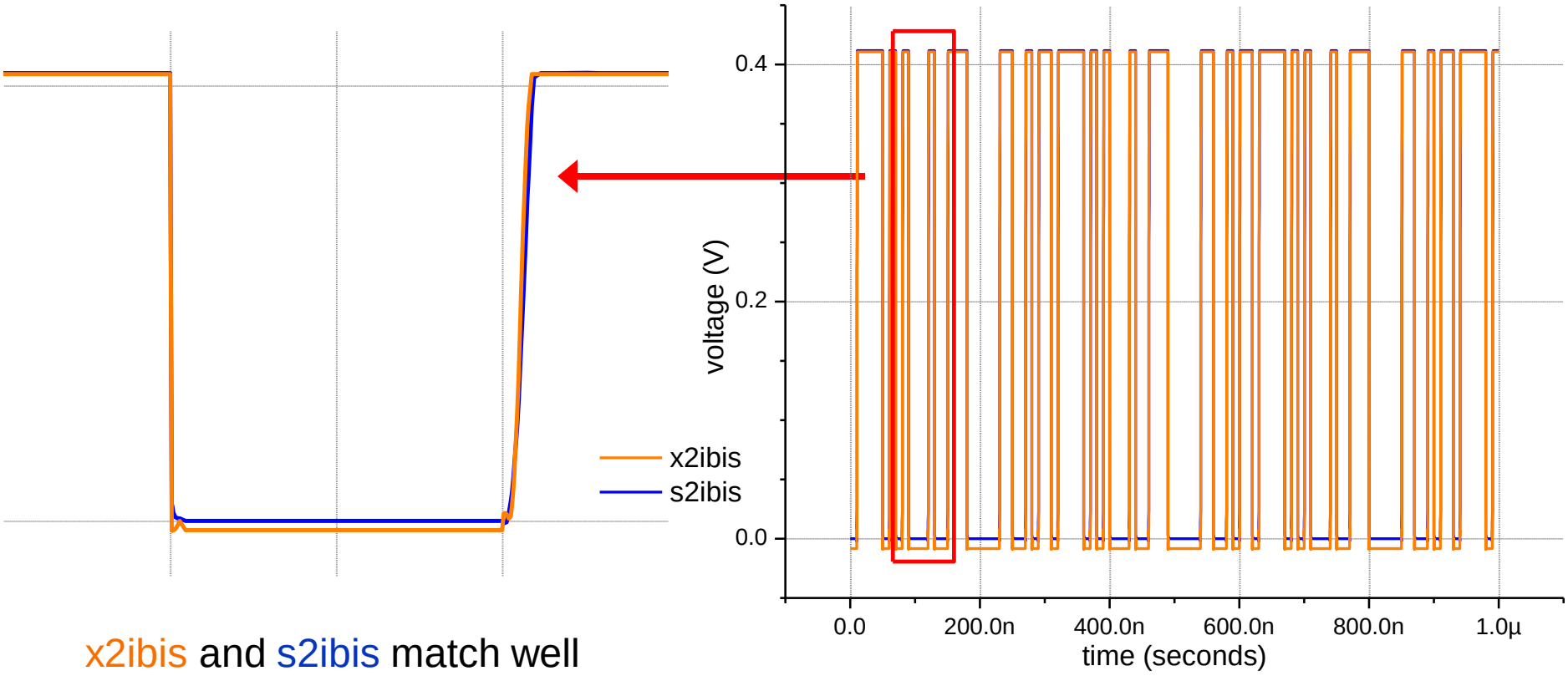




x2ibis and s2ibis have reasonable match

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

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