Using IBIS in Non-ideal Power Supply Situations

- aka. Counter Proposal on BIRD 95

Author: Lance Wang, Cadence

Contributors and Reviewers from:

Cadence, NCSU, Intel, Micron, ST Microelectronics

Version 1.0

Contributors and Reviewers

- Cadence
  - Shangli Wu, C. Kumar, Jilin Tan, Ken Willis, Dragoslav Milosevic
- North Carolina State University (NCSU)
  - Ambrish Varma, Paul Franzon
- Intel
  - Arpad Muranyi, Michael Mirmak
- Micron
  - Randy Wolff
- ST Microelectronics
  - Antonio Girardi

Purpose

- IBIS needs to be used in Non-ideal power supply situations
- We need better solution than BIRD 95 since there is still a lot of concerns
  - BIRD 95 is adding VZDDQ and I/T table between Power and Ground. Link for BIRD 95:
    - http://www.vhdl.org/pub/ibis/birds/bird95.6.txt

Outline

- Scientific Approach of New Proposal
  - BIRD 95 is inside
- Static Power Supply Change Test Results
- Notes
- Next Step

General IBIS equation

General IBIS output current equation

$$-I_{out}(t) = K_u(t)I_{pu}(V_{pu}) + K_d(t)I_{pd}(V_{pd}) + I_{pc}(V_{pc}) + I_{gc}(V_{gc}) \qquad (1)$$

Where:

$I_{pu}(V_{pu})$ is the Pullup Current @ Voltage between buffer Pullup Reference and Output (die point);

$I_{pd}(V_{pd})$ is the Pulldown Current @ Voltage between buffer Pulldown Reference and Output (die point);

$I_{pc}(V_{pc})$ is the Powerclamp Current @ Voltage between Power Clamp Reference and Output (die point);

$I_{gc}(V_{gc})$ is the Groundclamp Current @ Voltage between Ground Clamp reference and Output (die point);

Based on article:

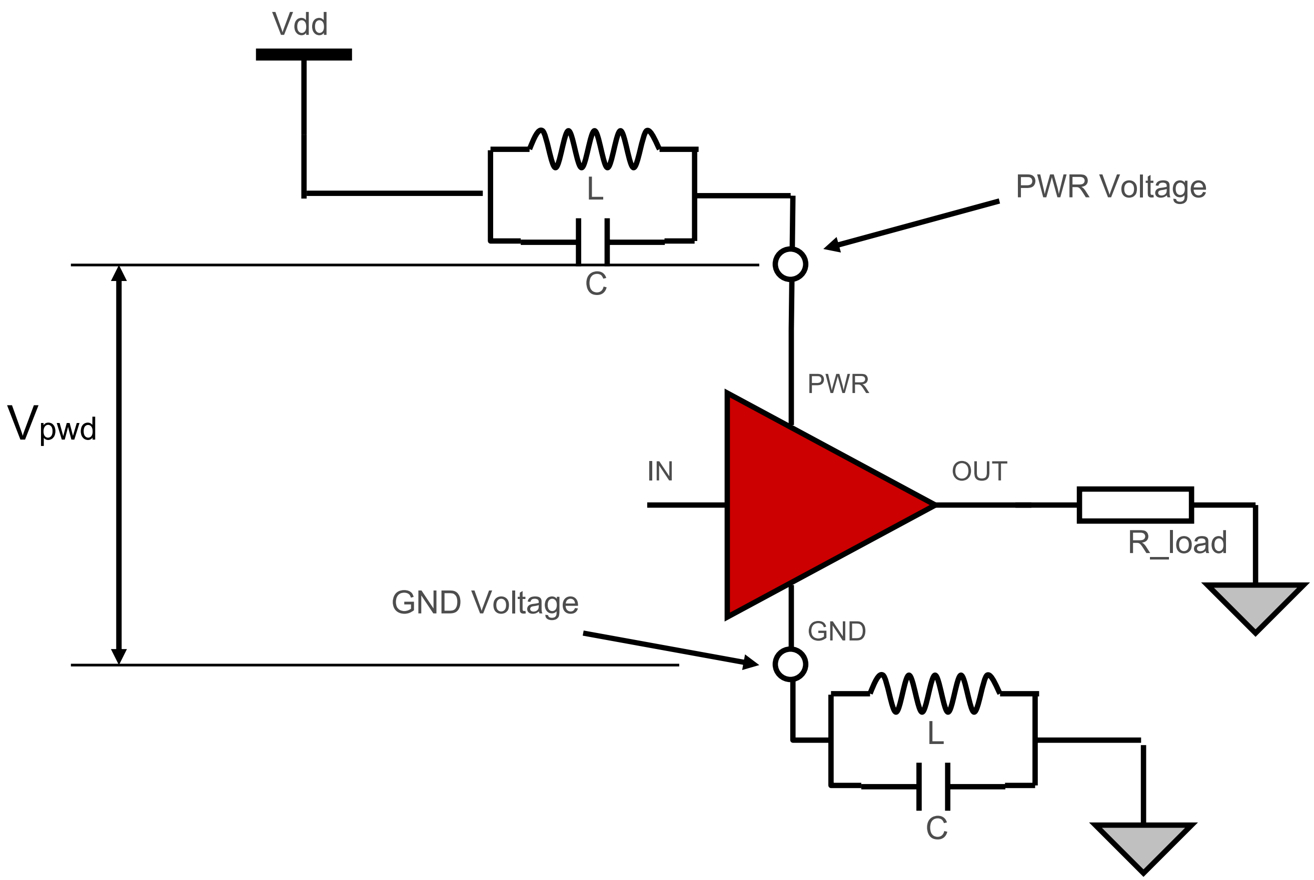
The Development of Analog SPICE Behavioral Model Based on IBIS Model

Ying Wang Han Ngee Tan
School of EEE, Nanyang Technological University, Singapore 639798
E-mail: p143278083@ntu.edu.sg

http://ieeexplore.ieee.org/iel4/6127/16377/00757386.pdf?arnumber=757386

Limitation of general IBIS equation

- Can not handle power/ground bounce for SSN
- Can not handle gate-modulation



Equations for new proposal

Add power/ground voltage dependences to original IBIS equation

$$-I_{out}(t)=K_u(t)I_{pu}(V_{pu}, V_{pwdp}) + K_d(t)I_{pd}(V_{pd}, V_{pwdp}) + I_{pc}(V_{pc},V_{pwdc}) + I_{gc}(V_{gc}, V_{pwdc}) \qquad (2)$$

Where:

$I_{pu}(V_{pu}, V_{pwdp})$ is the Pullup Current @ Voltage between buffer Pullup Reference and Output (die point) and voltage between Pullup and Pulldown references ;

$I_{pd}(V_{pd}, V_{pwdp})$ is the Pulldown Current @ Voltage between buffer Pulldown Reference and Output (die point) and voltage between Pullup and Pulldown references ;

$I_{pc}(V_{pc}, V_{pwdc})$ is the Powerclamp Current @ Voltage between Power Clamp Reference and Output (die point) and voltage between Power and Ground Clamp references ;

$I_{gc}(V_{gc}, V_{pwdc})$ is the Groundclamp Current @ Voltage between Ground Clamp reference and Output (die point) and voltage between Power and Ground Clamp references ;

$V_{pu}=V_{cc} - V_{out}$, $V_{pd}=V_{out} – V_{cc}$, $V_{pc}=V_{pc} – V_{out}$, $V_{gc}=V_{out} – V_{gc}$.

Equations for new proposal (cont.)

Assume power/ground bounces are small enough to use first order Taylor expansion

$$I_{pu}(V_{pu},V_{pwdp}) \approx I_{pu}(V_{pu},V_{pwdp0}) + \frac{\partial I_{pu}}{\partial V_{pwdp}}|_{V_{pwdp0}} *(V_{pwdp} - V_{pwdp0})$$

$$I_{pd}(V_{pd},V_{pwdp}) \approx I_{pd}(V_{pd},V_{pwdp0}) + \frac{\partial I_{pd}}{\partial V_{pwdp}}|_{V_{pwdp0}} *(V_{pwdp} - V_{pwdp0})$$

$$I_{pc}(V_{pc},V_{pwdc}) \approx I_{pc}(V_{pc},V_{pwdc0}) + \frac{\partial I_{pc}}{\partial V_{pwdc}}|_{V_{pwdc0}} *(V_{pwdc} - V_{pwdc0})$$

$$I_{gc}(V_{gc},V_{pwdc}) \approx I_{gc}(V_{gc},V_{pwdc0}) + \frac{\partial I_{gc}}{\partial V_{pwdc}}|_{V_{pwdc0}} *(V_{pwdc} - V_{pwdc0})$$

Where V_{pwdp0} is Ideal Pullup/Pulldown Power Supply
V_{pwdc0} is Ideal Clamp Power Supply

Equations for new proposal (cont.)

Substitute into equation (2)

$$-I_{out}(t) = K_u(t) I_{pu}(V_{pu}, V_{pwdp0}) + K_d(t) I_{pd}(V_{pd}, V_{pwdp0}) + I_{pc}(V_{pc}, V_{pwdc0}) + I_{gc}(V_{gc}, V_{pwdc0})$$
$$+ (K_u(t) Y_{pu} + K_d(t) Y_{pd})(V_{pwdp}(t) - V_{pwdp0}) + (Y_{pc} + Y_{gc})(V_{pwdc}(t) - V_{pwdc0}) \qquad (3)$$

where

$$Y_{pu} = \frac{\partial I_{pu}}{\partial V_{pwdp}} \Big|_{V_{pwdp0}}$$

$$Y_{pd} = \frac{\partial I_{pd}}{\partial V_{pwdp}} \Big|_{V_{pwdp0}}$$

$$Y_{pc} = \frac{\partial I_{pc}}{\partial V_{pwdc}} \Big|_{V_{pwdc0}}$$

$$Y_{gc} = \frac{\partial I_{gc}}{\partial V_{pwdc}} \Big|_{V_{pwdc0}}$$

Equations for new proposal (cont.)

Re-arrange equation (3) to

$$-I_{out}(t) = -I_{out}(t,V_{out})|_{V_{pwdp0},V_{pwdc0}} + (K_u(t)Y_{pu} + K_d(t)Y_{pd})*V_{pwdp}(t) + (Y_{pc} + Y_{gc})*V_{pwdc}(t) - I_{offset}(t) \quad (4)$$

where

$$-I_{out}(t,V_{out})|_{V_{pwdp0},V_{pwdc0}} = K_u(t)I_{pu}(V_{pu},V_{pwdp0}) + K_d(t)I_{pd}(V_{pd},V_{pwdp0})$$

$$+ I_{pc}(V_{pc},V_{pwdc0}) + I_{gc}(V_{gc},V_{pwdc0})$$

$$I_{offset}(t) = (K_u(t)*Y_{pu} + K_d(t)*Y_{pd})*V_{pwdp0} + (Y_{pc} + Y_{gc})*V_{pwdc0}$$

Equations for new proposal (cont.)

Equation (4) could easily include gate modulation effect

$$-I_{out}(t) = -I_{out}(t,V_{out})|_{V_{pwdp0},V_{pwdc0}} + (K'_u(t)Y_{pu} + K'_d(t)Y_{pd})*V_{pwdp}(t) + (Y_{pc} + Y_{gc})*V_{pwdc}(t) - I'_{offset}(t) \quad (6)$$

where

$$-I_{out}(t,V_{out})|_{V_{pwdp0},V_{pwdc0}} = K'_u(t)I_{pu}(V_{pu},V_{pwdp0}) + K'_d(t)I_{pd}(V_{pu},V_{pwdp0})$$

$$+I_{pc}(V_{pc},V_{pwdc0}) + I_{gc}(V_{gc},V_{pwdc0})$$

$$I'_{offset}(t) = (K'_u(t)*Y_{pu} + K'_d(t)*Y_{pd})*V_{pwdp0} + (Y_{pc} + Y_{gc})*V_{pwdc0}$$

$$K'_u(t) = K_u(t)*K_{ssn-pullup}$$

$$K'_d(t) = K_d(t)*K_{ssn-pulldown}$$

Where Kssn-pullup/Kssn-pulldown are coefficients for Gate modulation

Equations for new proposal (cont.)

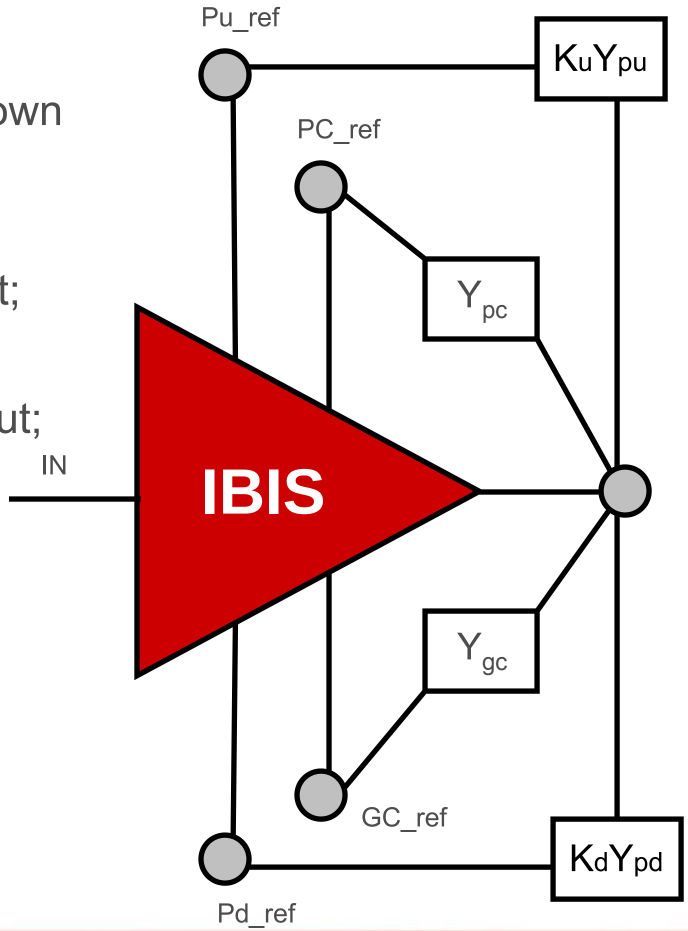
Implementation

Y_{pu} should connected between Pullup Reference and Output;

Y_{pd} should connected between Pulldown Reference and Output;

Y_{pc} should connected between PowerClamp Reference and Output;

Y_{gc} should connected between GroundClamp Reference and Output;



Equations for new proposal (cont.)

- Transconductance extraction
  - Y_{pu}
    - Average slope table of I_{out}/V_{pwdp} curve between V_{pwdp0} +/- ΔV_p
  - Y_{pd}
    - Average slope table of I_{out}/V_{pwdp} curve V_{pwdp0} +/- ΔV_p
  - Y_{pc}
    - Average slope table of I_{pc}/V_{pwdc} curve between V_{pwdc0} +/- ΔV_c
  - Y_{gc}
    - Average slope table of I_{gc}/V_{pwdc} curve between V_{pwdc0} +/- ΔV_c

Where $\Delta V_p = (V_{pwdp} - V_{pwdp0}) * 0.05$, $\Delta V_c = (V_{pwdc} - V_{pwdc0}) * 0.05$

BIRD 95 is inside

Further simplification equation (4) to BIRD 95 approach

$$-I_{out}(t) \approx -I_{out}(t,V_{out})|_{V_{pwdp0},V_{pwdc0}} + Y_{vddq} * V_{pwdp}(t) - I'_{offset}(t) \qquad (5)$$

$$where$$

$$-I_{out}(t,V_{out})|_{V_{pwdp0},V_{pwdc0}} = K_u(t) I_{pu}(V_{pu},V_{pwdp0}) + K_d(t) I_{pd}(V_{pd},V_{pwdp0})$$

$$+ I_{pc}(V_{pc},V_{pwdc0}) + I_{gc}(V_{gc},V_{pwdc0})$$

$$I'_{offset}(t) = (K_u(t) * Y_{pu}) * V_{pwdp0} + Y_{pc} * V_{pwdc0}$$

$$Y_{vddq} = (K_u(t) * Y_{pu} + Y_{pc})$$

Assumptions for this simplification:

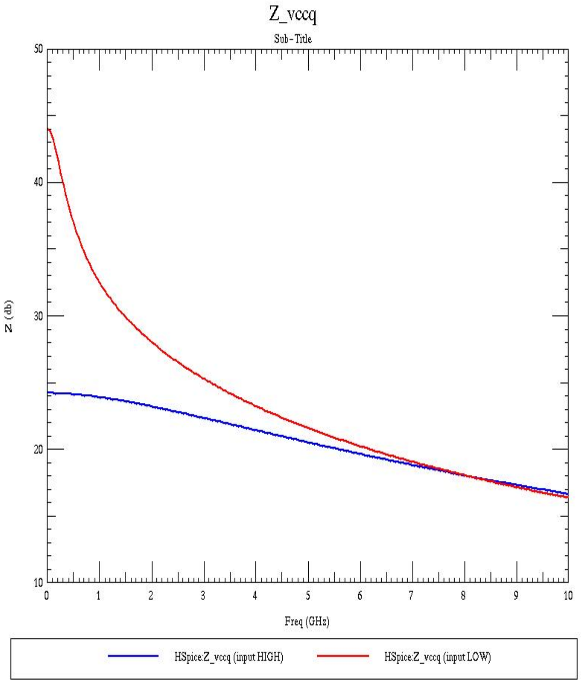
1. No ground bounce ($V_{gnd}(t)=V_{gnd0}=0$)
2. All additional offset current go to ground instead of $I_{out.}$ (This could be applied only for Pre-drive stage or Open terminations.)
3. Transconductance Yvddq could be connected ONLY between power and ground if condition 2 is valid

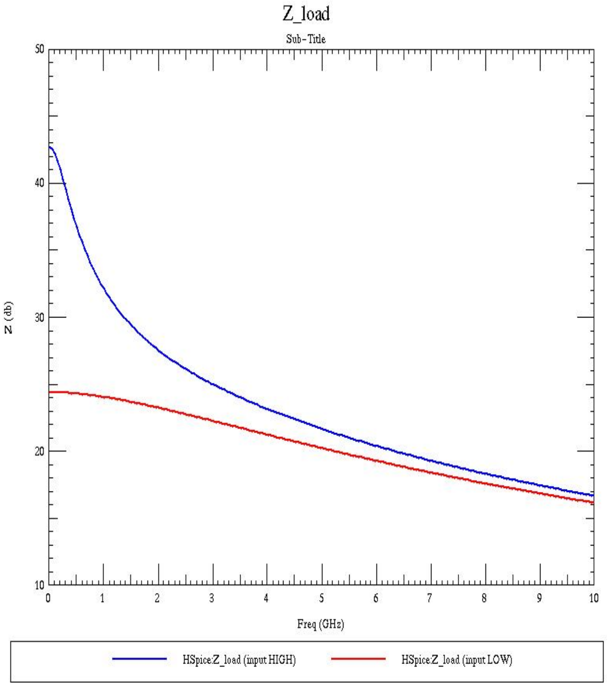
Equations for new proposal (cont.)

- Further more
  - We added Y based on DC portion of Power Supply Changes
  - We need to add Y_{AC} based on AC portion of Power Supply Changes
  - Y_{AC} could be voltage controlled capacitance based on our current study result
  - Study is continued for this new proposal
  - More info links
    - http://www.vhdl.org/pub/ibis/futures/bird95-cap.ppt
    - http://www.vhdl.org/pub/ibis/futures/ST_Vgs_Presentation.pdf

Equations for new proposal (cont.)

- Test Results of Dynamic Output Impedances
  - Input State Dependent Impedance measured between Power and Output (Z_vccq), Ground and Output (Z_load)



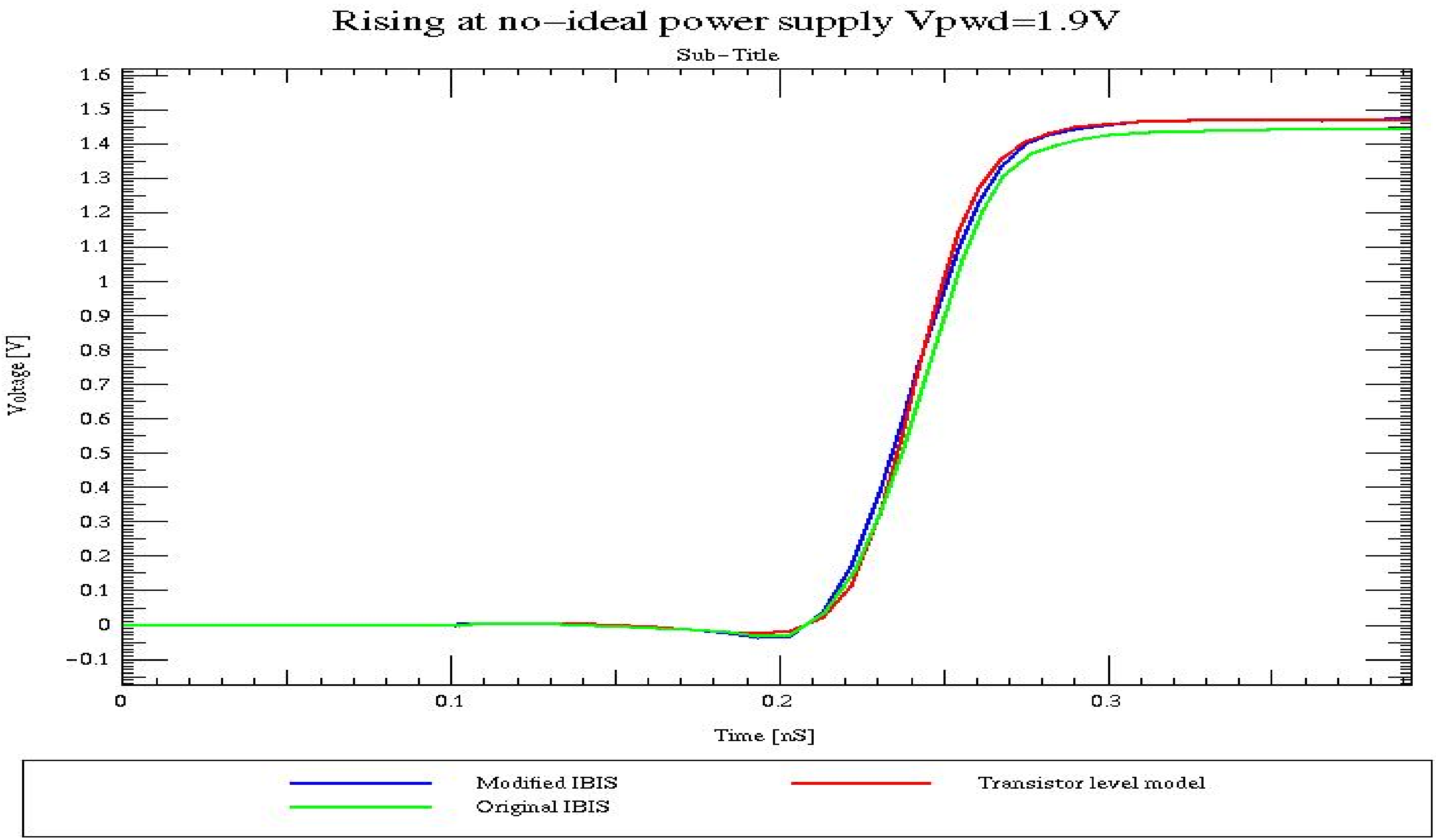


cadence

Static Power Supply Change Test Results

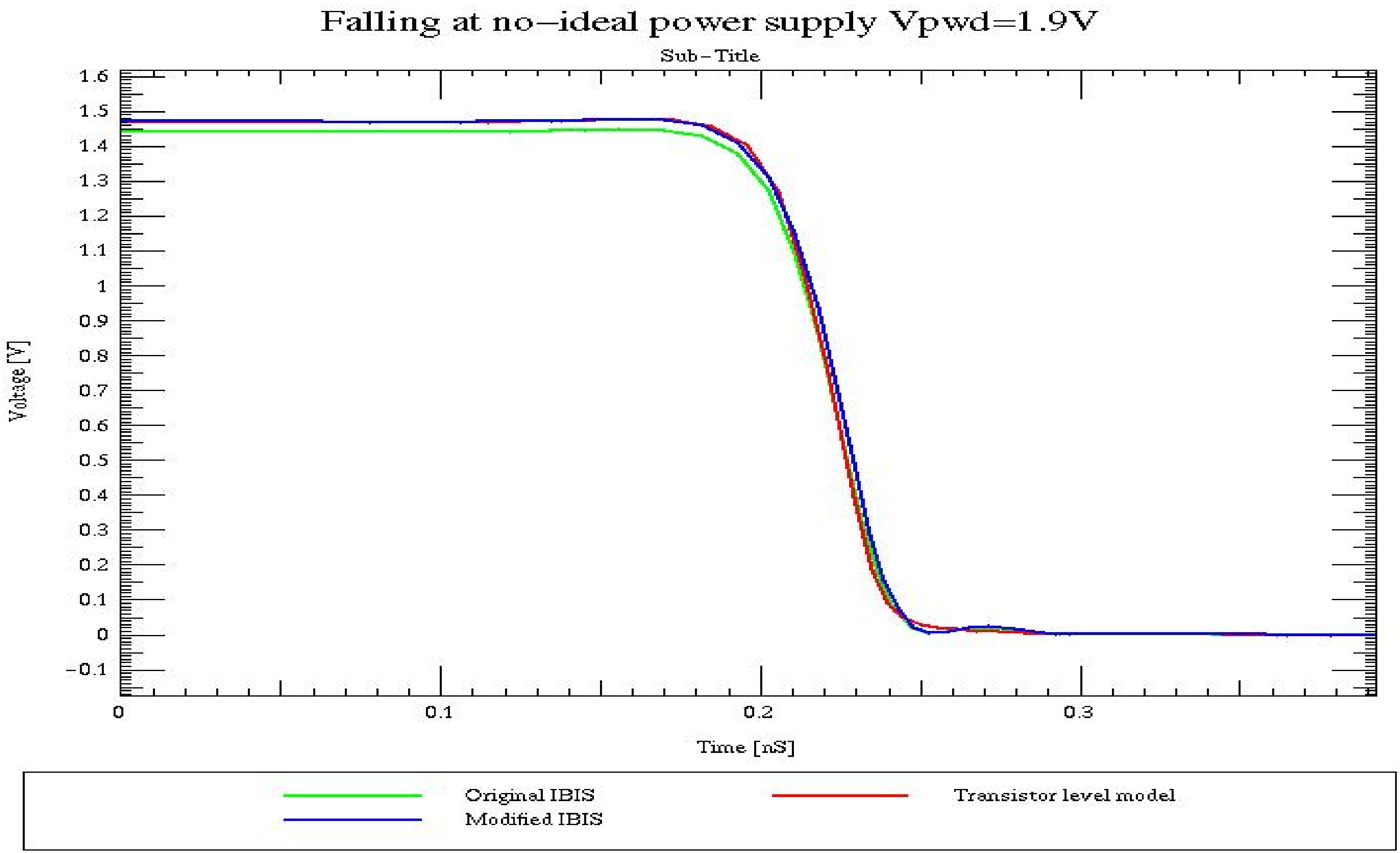
- Case1: Rising and Falling @ V_{pwd} = 1.9V
- Case2: Rising and Falling @ V_{pwd} = 1.7V
- Using IBIS model with I/V and V/T table characterized @ V_{pwd}=1.8V

Static Power Supply Changed to 1.9V

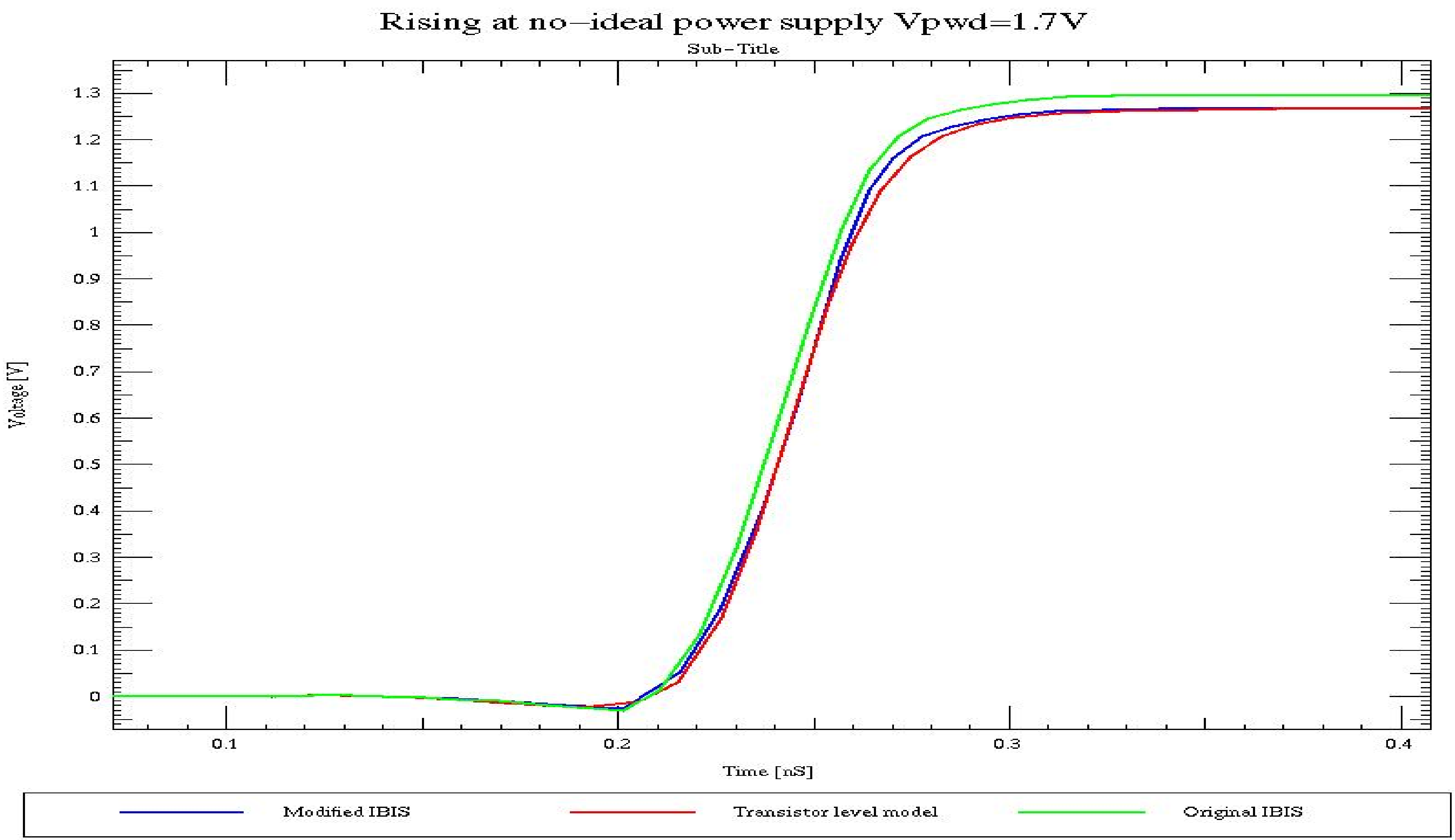


cadence

Static Power Supply Changed to 1.9V

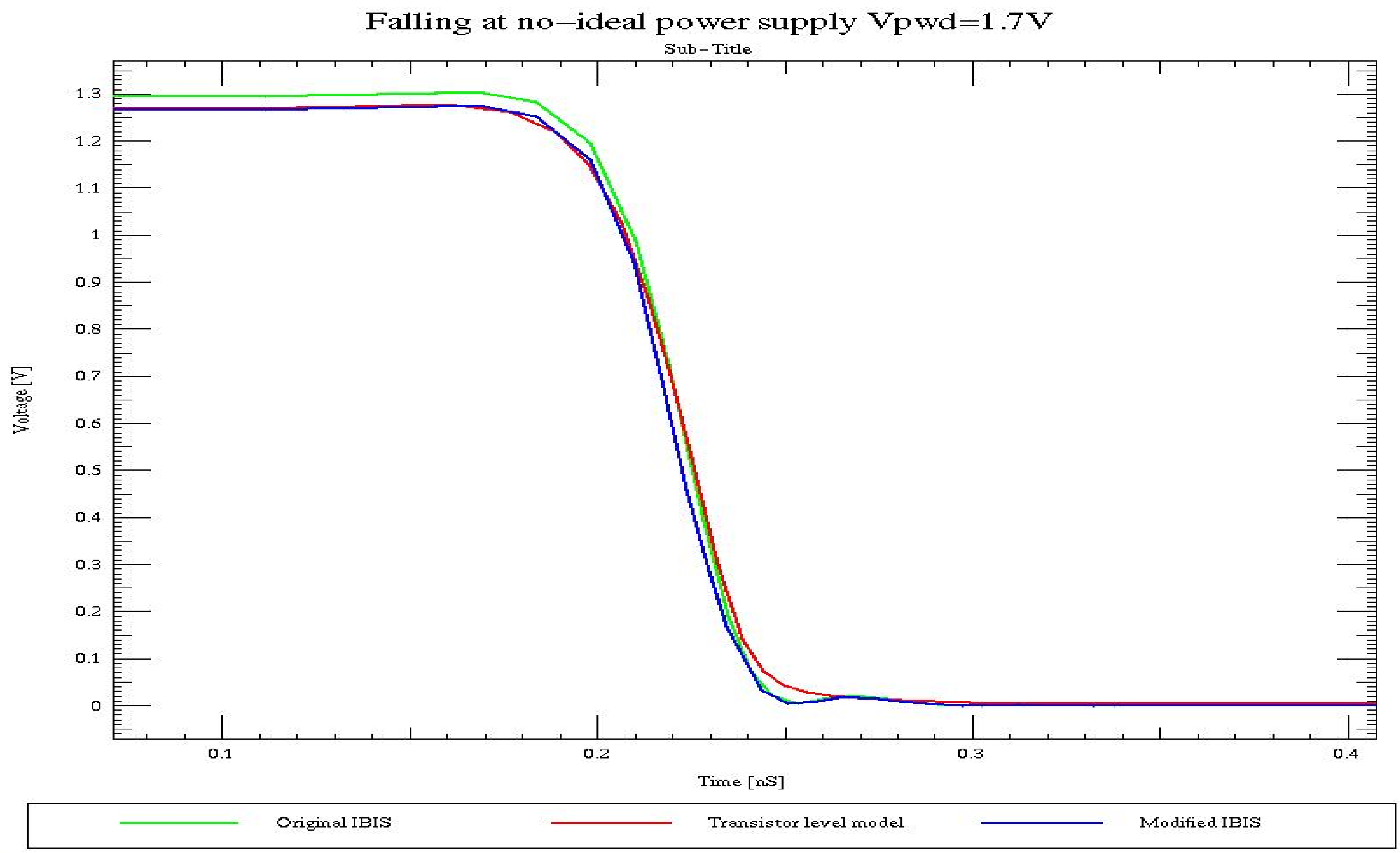


Static Power Supply Changed to 1.7V



cadence

Static Power Supply Changed to 1.7V



Notes

- Theoretically, this proposal contains the goals both BIRD 98/97 and BIRD 95 try to achieve
  - Showed the limitations of BIRD 95
- Using IBIS in non-ideal power supply network could be solved in one proposal. It could be better to be solved as a big picture view

Next Steps

- Continue to study and develop Y_{AC}
- Test them
- Discuss it in IBIS committee
- Propose new BIRD or add-on to BIRD 98/97 when it is properly

Welcome any comments and inputs for the technical discussions!

Thanks!

Thanks all efforts from the contributors and reviewers.
And
The contributions from all the members in IBIS are needed!