Modeling on-die terminations in IBIS (without double counting)

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Outline

• Summary of advanced buffer features
• General guidelines for making models for buffers with advanced features
• Static parallel termination
  • Algorithms to avoid double counting
• Switched parallel termination
Advanced buffer modeling

• **Pullup or pulldown “resistors”**
  • they prevent 3-stated buses from floating around the threshold voltages
  • usually in the kΩ range (I_{sat} in μA range)
  • usually implemented as a transistor turned on constantly

• **Integrated terminators**
  • static transmission line termination (low impedance)
  • dynamic implementations designed to save power

• **Bus hold circuits (may be dynamic)**
  • similar to pu/pd resistor idea, but usually has a lower impedance
  • could be time, edge or level dependent if dynamic

• **Dynamic clamping mechanisms**
  • strong clamps turn on momentarily to prevent excessive overshoot

• **Staged buffers**
  • mostly used in slew rate controlled drivers

• **Kicker circuits**
  • transition boosters and then turn off

• **Anything else you can invent goes here...**
Modeling static advanced features

- Anything that is ON constantly should be modeled using the [Power Clamp] or [GND Clamp] I-V curves
  - pullup or pulldown “resistors”
  - static integrated terminators
  - static clamps, ESD circuits
  - static bus hold circuits
- Make sure you are using the appropriate rail for correct power and GND bounce simulation purposes
  - use [Power Clamp] for pullup resistor
  - [GND Clamp] for pulldown resistor, etc.
- Some additional post processing may be required to avoid double counting
Modeling dynamic advanced features

• Use IBIS version 3.2 features
  • keywords: [Driver Schedule], [Add Submodel], [Submodel], [Submodel Spec]
  • subparameters: Dynamic_clamp, Bus_hold

• Detailed knowledge of circuit behavior is required

• Familiarity with buffer’s SPICE netlist required

• May have to dissect or modify SPICE netlist to generate necessary data in separate steps

• It may not be possible to make such models from simple and/or direct lab measurements
Block diagram of a CMOS IBIS model

- Power/GND clamp IV curves are always ON
  - Use these for everything that is static
    - Parasitic diodes
    - ESD circuits
    - On-die terminations, etc…
- Pullup/Pulldown IV curves are switched ON/OFF by the Ramps/Vt curves
  - Use these for everything that is switched or dynamic
    - Drivers, “kickers”
    - Dynamic clamps
    - Dynamic on-die terminations, etc…
On-die terminations

• **Series termination**
  • does not require any special work because it is described by the shape of the I-V curve

• **Parallel termination**
  • if the parallel termination is on all the time, use the method described for pullup/pulldown resistors

• **Switched parallel termination**
  • the parallel termination device is turned off while the opposite half of the buffer is driving
  • make a normal complementary model for the driver portion of the buffer
  • make a difference I-V curve for the terminator device and use the [Add Submodel] keyword in **non-driving** mode with the [Submodel] keyword’s **dynamic_clamp** in static mode (without a pulse)
Pullup resistor example

I-V curves of a 3-stated buffer with pullup R

POWER clamps (Vcc relative)

POWER clamps (GND relative)

GND clamps (GND relative)

GND clamps (Vcc relative)

\{ typ. \\ min. \\ max. \}
Zooming in on I-V curves

The I-V curve of the resistor shows up in both POWER and GND clamp data.
Algorithm in pictures

POWER clamps
(Vcc relative)

GND clamps
(GND relative)

Must be shifted to 0 amps to avoid double counting
Algorithm in words

- Sweep device from $-V_{cc}$ to $2*V_{cc}$ twice: GND and $V_{cc}$ relative

- Cut clamp curve which will include the resistor at $V_{cc}$
  - This can be automated by detecting which group of IV curves goes through the origin

- Cut other clamp curve at 0V

- Normalize (shift) the clamp curve which will not include the resistor to zero current at 0V

- Extrapolate both clamp curves horizontally to $2*V_{cc}$
Pullup and pulldown resistor example

- Looking into the output pad we see $R_{\text{thevenin}}$
- It is not possible to separate $R_{\text{thevenin}}$ into $R_{pu}$ and $R_{pd}$ from a single measurement at the pad
- The algorithm described on the following pages is only a crude approximation, but it may be better than leaving everything in one IV curve
  - Useful for POWER and GND bounce simulations
IV curves of pu and pd R example

I-V curves of a 3-stated buffer with both pu and pd R
Algorithm in pictures

![Graph showing I-V curve simulations with various labels like I_GNDCLAMP and I_POWERCLAMP.]
Algorithm in words

• Sweep device from $-V_{cc}$ to $2*V_{cc}$ twice: GND and $V_{cc}$ relative
• Cut clamp curves where they reach zero current going left to right
• Extrapolate all clamp curves horizontally to $2*V_{cc}$
Switched parallel termination example

- This buffer is a normal CMOS driver, but its pullup is ON in receive mode acting as a parallel terminator

<table>
<thead>
<tr>
<th>Submodel name</th>
<th>Mode</th>
<th>ParTerm</th>
<th>Non-Driving</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Voltage</th>
<th>I(typ)</th>
<th>I(min)</th>
<th>I(max)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-1.79999995E+0</td>
<td>14.23263550E-3</td>
<td>17.10075140E-3</td>
<td>12.31312752E-3</td>
</tr>
</tbody>
</table>

The I-V curve table of the [Pullup] is repeated here, because the terminator is actually the pullup left on in receive mode.