Extracting On-Die Terminators

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Process Motivation

• Issues with “Clip and Extend” recommendations
• “Black box” rules from experiences since 1992 (Zeelan with Quad format)
  – Decompose model consistent with the internal architecture
    • Example: Output and clamps isolated by curvature changes (Nasef, October 1999 IBIS Summit)
  – Extrapolate for continuous slope
    • Outputs above and on-die extractions here
    • Known SPICE MOSFET level slope discontinuity issues
• Extrapolation recommended in IBIS Cookbook
Creating Clamp Tables

• Goal: Mimic physical device 3-terminal simulation
  – [Gnd Clamp Ref] Vg, [Power Clamp Ref] Vp anchors
    • ESD or substrate “diodes”
    • On-Die Terminator (ODT) “resistance” structure
  – Best currents thru Vp and Vg for rail analysis
  – I/O node correct with Vg and Vp changes

• Default algorithm covers most practical cases
  – Based on deviation from Thevenin resistor ODT
  – “pullup” and “pulldown” ODTs are subsets
  – **DEC: Deviate Extrapolate Calculate**
Example: 50 Ω, 1.2 V ODT

$V_p = 1.8$ V

75 Ω

1.2 V

150 Ω

$V_g = 0$ V

50 Ω Total I-V curve with 0.6 V

“stick” diodes anchored to each rail
Clip and Extend

\[ V_p = 1.8 \text{ V} \]

\[ 75 \text{ \Omega} \]

\[ 1.2 \text{ V} \]

\[ 150 \text{ \Omega} \]

\[ V_g = 0 \text{ V} \]

50 \text{ \Omega} Total I-V curve with 0.6 V “stick” diodes anchored to each rail
I(V) Blocks and Simulations

Resistor Network

Vg = 0 V

- 8 ma, 225 Ω
- 75 Ω
- ~1.2 V
- 0 ma, 50 Ω
- 150 Ω

Vp = 1.8 V

- 25 Ω, 50 Ω or Open
- 50 Ω or Open
- ~1.2 V or Unknown
- 50 Ω or Open
- 1.2 V

Clip and Extend Model

Vg = 0 V

- 0 ma, Open, less/equal 100 Ω
- 0.6 V
- 50 Ω or Open
- 0 ma, 25 Ω, 50 Ω or Open
- 1.2 V
Problems with Clip and Extend

• Wrong circuit impacting IBIS 3.2 and beyond
  – DC currents different (with, without I/O node circuit)
  – AC Thevenin impedances different and open
  – Higher frequency effects from non-linear elements
  – Driver at I/O node sees different impedance

• Tool dependencies including
  – Slope discontinuities issues
  – Open 0 ma discontinuities with potential simulation ambiguities and failures (Errors)
  – Unpredictable performance even with validation

• Avoid “Clip and Extend”, use DEC
• Be wary of any truncation recommendation
DEC (from Resistors) Algorithm

- Draw box bounded by \((V_g, I_g)\) and \((V_p, I_p)\) and draw the zero current axis
- Draw the three lower-left to upper right diagonals, where the upper region is for the [Gnd Clamp], and the lower region is for the [Power Clamp]
- **Deviate**: Proportionally allocate “Total I-V” delta deviation to [Gnd Clamp] and [Power Clamp] diagonals
- **Extrapolate** [Gnd Clamp] data ABOVE \(V_p\)
- **Extrapolate** [Power Clamp] data BELOW \(V_g\)
- **Calculate** [Gnd Clamp] data BELOW \(V_g\) (Total - PC)
- **Calculate** [Power Clamp] data ABOVE \(V_p\) (Total - GC)
- (Backup slides for some computational details)
Diagonals and Resistors

Calculate

Extrapolate

Total I-V

[Gnd Clamp] Resistor

[Power Clamp] Resistor

0 ma

Vp

Vg
DEC Algorithm

\[ \text{delta} \frac{l_p}{l_p + l_g} \]

\[ \text{delta} \frac{l_g}{l_p + l_g} \]

[Power Clamp]

[Gnd Clamp]

Total I-V

Calculate

Extrapolate

\[ l_p \]

\[ 0 \text{ ma} \]

\[ V_g \]

\[ V_p \]
ODT Example (delta=0)
DEC Observations

• Emulates ODT circuit for Vg and Vp changes
  – At I/O node, Thevenin 1.2 V shifts correctly, and source impedance = 50 Ω
  – Vp to Vg rail-to-rail impedance = 225 Ω
  – Diodes correctly anchored to Vg and Vp

• Supports single resistor ODT subsets
  – “pullup” ODT
  – “pulldown” ODT

• Backup slides for a suggested computation details
  – Typ-min-max data alignment
  – Vcc relative [Power Clamp] calculation

• Shape anchoring and internal reference overrides next
Anchor Shape to [Power Clamp]

[Power Clamp]

Total I-V

[Gnd Clamp]

Calculate

Extrapolate

$\delta$

$I_g$

$V_g$

$V_p$

$I_p$

0 ma
Real “50 Ω” ODT Choices

Clip and Extend

Default DEC

[Gnd Clamp] Shape

[Power Clamp] Shape
Total I-V as [Gnd Clamp]

Calculate

Extrapolate

[Ig]

[Vg]

[Power Clamp]

[0 ma]

[delta]
Application

• Total I-V in [Gnd Clamp] table tracks Vg changes
• For legacy IBIS “clip” ranges
  – [Gnd Clamp]: -Vcc to Vcc
  – [Power Clamp]: Vcc to 2*Vcc
• TTL Input: 2.1 V ”diode” anchored to Vg per IBIS
• Current could have been anchored to Vp (default)
• Both anchors partially applicable
50 Ω, 1.2 V Anchored to Vg
Total I-V as [Power Clamp]

Calculate Ig

Extrapolate

Calculate Ip

Extrapolate

0 ma

delta
50 Ω, -0.6 V Anchored to Vp
Real “50 Ω” ODT Choices

- Clip and Extend: 52.8 Ω
- Default DEC: 94.2 Ω and 120 Ω

I-V in [Gnd Clamp]

I-V in [Power Clamp]
Shape between $V_g$ and $V_p$

- In general, Total I-V shape between $V_g$ and $V_p$ remains reasonable for $V_g$ and $V_p$ modulation
- DEC method applies for other reference shapes and other overrides
- Such as linear resistor partitioned into quadratic components next
**Quadratic Clamps**

- Linear Thevenin terminator with “quadratic” resistors
  - [Gnd clamp] chosen with slope = 0 at Vp
  - Use same Extrapolate and Calculate rules
Conclusions

• Many choices exist to partition an I-V table into clamp tables
• DEC algorithm based on ODT resistor deviation covers practical cases
• Overrides shown, based on additional knowledge (could be expanded)
• DEC favored over “Clip and Extend” for accuracy, robustness, and portability
Backup – Suggested Calculations

- Uses both a Vg (Gnd) referenced Total I-V and a Vp (typ, min, max Vcc) referenced Total I-V
  - Typ, Min, Max for each case
    - From –Vcc to 2*Vcc
    - Same sample points aligned for typ, min, max data
  - [Gnd Clamp] uses Vg referenced data
  - [Power Clamp] uses Vp referenced data
  - (One Total I-V table could be calculated from the other over a larger sweep range to get aligned data)

- DEC – Extrapolate 0 to –Vcc, Calculate, do simple extrapolation above Vcc to 2*Vcc
[Gnd Clamp] Calculation

\( \text{delta} \times \frac{I_p}{(I_p + I_g)} \)

\([\text{Gnd Clamp} - \text{Relative}] \)

Calculate: \( I_g \)

Extrapolate: \( I_p \)

Total I-V (Gnd_Relative)

Extrapolate

\( \text{PC} = \text{Total} - \text{GC} \) (a few points to extrapolate)

0 V

Vcc (typ, min, max)
[Power Clamp] Calculation

GC = Total – PC (a few points to extrapolate)

\[ \text{delta} = \frac{\text{delta} \times I_g}{I_p + I_g} \]

Calculate

Extrapolate

0 V

Vcc (typ, min, max)

0 ma
Comments

• Extrapolations below 0 V
  – Based on extrapolating a few calculated points
  – All data points at Total I-V voltages

• Extrapolate above Vcc (typ, min, max)
  – The typ and min columns need entries or NA’s to Vcc (max)
  – Extrapolate columns to 2*Vcc
    • Fill in remaining values
    • Optionally, one value at 2*Vcc