Combined I-V Table Checks (BUG140)

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Bob Ross
Teraspeed Consulting Group
bob@teraspeed.com

Yingxin Sun, Joy Li
Cadence Design Systems
sunyx@cadence.com
joyli@cadence.com
BUGI40 Issue

• Unexpected Non-Monotonic Warnings for Combined I-V Tables (derived from monotonic data)

• Combined I-V table checks:
  – [Pulldown] + [Gnd Clamp] + [Power Clamp]
  – [Pullup] + [Gnd Clamp] + [Power Clamp]

• Ibischk5 parser is de facto standard for IBIS model correctness (and ibischk5 is embedded in tools)
• Some companies require 0 Errors, 0 Warnings
• IBIS Quality Spec, recommends 0 Errors and 0 Warnings
• Warning messages create support issue for model authors or automatic modeling utility
Facts

- No specification REQUIREMENT that individual or combined I-V tables be monotonic.
- No stated method to sum mismatched voltage points (piecewise linear interpolation is allowed and used).
- Specification recommends individual I-V table parser checking.
- Combined checks added with BUG94 (BUG92 dealt with submodels): http://www.eda.org/ibis/bugs/ibischk/.
- Non-monotonicity often occurs outside of normal simulation region – in clamping region and not a problem.
- Ibischk5 parser is operating correctly.
Observations

• Non-monotonic behavior can occur
  – Combined I-V table slope is small
  – I-V table points are misaligned due to
    • Offset V intervals due to Gnd, Vdd and delta V
    • Different reference voltages (min/max)
    • Extraction with piecewise linear interpolation calculations (if not done right)
    • I-V tables have different V resolution
  – Combination of above cases
Example: x Step 2, Offset by 1

(\textbf{Red: Interpolated Value})

<table>
<thead>
<tr>
<th>x</th>
<th>y_1</th>
<th>y_2</th>
<th>(y_1 - y_2 = 0?)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
<td>5</td>
<td>-1</td>
</tr>
<tr>
<td>3</td>
<td>10</td>
<td>9</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>16</td>
<td>17</td>
<td>-1</td>
</tr>
<tr>
<td>5</td>
<td>26</td>
<td>25</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>36</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Non-monotonic due to piecewise linear interpolation on both columns
### Step 0.02, Offset by 0.01

**(Red: Interpolated Value)**

<table>
<thead>
<tr>
<th>x</th>
<th>y1</th>
<th>y2</th>
<th>y1−y2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(x^2)</td>
<td>(x^2)</td>
<td></td>
</tr>
<tr>
<td>0.00</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0001</td>
</tr>
<tr>
<td>0.01</td>
<td>0.0002</td>
<td>0.0001</td>
<td>0.0001</td>
</tr>
<tr>
<td>0.02</td>
<td>0.0004</td>
<td>0.0005</td>
<td>−0.0001</td>
</tr>
<tr>
<td>0.03</td>
<td>0.0010</td>
<td>0.0009</td>
<td>0.0001</td>
</tr>
<tr>
<td>0.04</td>
<td>0.0016</td>
<td>0.0017</td>
<td>−0.0001</td>
</tr>
<tr>
<td>0.05</td>
<td>0.0026</td>
<td>0.0025</td>
<td>0.0001</td>
</tr>
<tr>
<td>0.06</td>
<td>0.0036</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Still non-monotonic with higher resolution data.
### x Steps 0.02 and 0.01, 0.00 Offset

**Red**: Interpolated Value

<table>
<thead>
<tr>
<th>x</th>
<th>y₁</th>
<th>y₂</th>
<th>y₁−y₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.000</td>
<td>0.00000</td>
<td>0.00000</td>
<td>0.00000</td>
</tr>
<tr>
<td>0.001</td>
<td>0.00002</td>
<td>0.00001</td>
<td>0.00001</td>
</tr>
<tr>
<td>0.002</td>
<td>0.00004</td>
<td>0.00004</td>
<td>0.00000</td>
</tr>
<tr>
<td>0.003</td>
<td>0.00010</td>
<td>0.00009</td>
<td>0.00001</td>
</tr>
<tr>
<td>0.004</td>
<td>0.00016</td>
<td>0.00016</td>
<td>0.00000</td>
</tr>
<tr>
<td>0.005</td>
<td>0.00026</td>
<td>0.00025</td>
<td>0.00001</td>
</tr>
<tr>
<td>0.006</td>
<td>0.00036</td>
<td>0.00036</td>
<td>0.00000</td>
</tr>
</tbody>
</table>

Different resolution data causes non-monotonic combination.
Real Data from BUG140 and Cadence Presentation

• “Golden Parser Non-monotonic Warning’s Investigation” by Yingxin Sun and Joy Li, Cadence Design Systems, November 9, 2012: http://tinyurl.com/byqu7yn

• Presented at IBIS Quality Committee November 27, 2012

• BUG140: http://www.eda.org/ibis/bugs/ibischk/

• (In all test cases, the [Gnd Clamp] data is 0.0 in the region of interest)
Checking bug140a.ibs

IBISCHK5 V5.1.2

Checking bug140a.ibs for IBIS 3.2 Compatibility...

NOTE (line 39) - Pulldown Typical data is non-monotonic
NOTE (line 42) - Pulldown Minimum data is non-monotonic
NOTE (line 42) - Pulldown Maximum data is non-monotonic
NOTE (line 135) - Pullup Typical data is non-monotonic
NOTE (line 137) - Pullup Maximum data is non-monotonic
NOTE (line 138) - Pullup Minimum data is non-monotonic
WARNING - Combined Pulldown for Model: iobuf Maximum data is non-monotonic

Errors : 0
Warnings: 1

File Passed
bug140a.ibs Maximum Data (Vdd = 1.3 V)

Power Clamp

1.8 V

1.8 V

Pulldown
Example 1 (Cont. 2)

Pulldown curve
Interpolation is lower than actual

Zoom-in view: Error introduced by piecewise linear interpolation

Clamp curve (gnd referenced)
Interpolation is higher than actual
Example 1 (Cont.3)

Zoom-in view: Errors introduced in the combined pulldown curve
Checking bug140b.ibs

IBISCHK5 V5.1.2

Checking bug140b.ibs for IBIS 4.2 Compatibility...

NOTE (line 40) - Pulldown Minimum data is non-monotonic
NOTE (line 51) - Pulldown Maximum data is non-monotonic
NOTE (line 52) - Pulldown Typical data is non-monotonic
NOTE (line 135) - Pullup Typical data is non-monotonic
NOTE (line 146) - Pullup Maximum data is non-monotonic
NOTE (line 202) - Pullup Minimum data is non-monotonic
WARNING - Combined Pulldown for Model: model_with_warning Typical data is non-monotonic
WARNING - Combined Pulldown for Model: model_with_warning Maximum data is non-monotonic

Errors : 0
Warnings: 2

File Passed
bug140b.ibs Typical Data (Vdd = 1.5V)

- Power Clamp
- 1.95 V
- Pulldown
- 1.95 V
- Different delta V density
Combined Pulldown Data with Aligned Vdd (Different Delta V’s)

<table>
<thead>
<tr>
<th>Value</th>
<th>Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.850</td>
<td>2.395370e-002</td>
</tr>
<tr>
<td>1.880</td>
<td>2.397163e-002</td>
</tr>
<tr>
<td>1.900</td>
<td>2.401136e-002</td>
</tr>
<tr>
<td>1.920</td>
<td>2.401229e-002</td>
</tr>
<tr>
<td>1.950</td>
<td>2.411007e-002</td>
</tr>
<tr>
<td>1.960</td>
<td>2.411006e-002</td>
</tr>
<tr>
<td>2.000</td>
<td>2.432631e-002</td>
</tr>
<tr>
<td>2.040</td>
<td>2.472520e-002</td>
</tr>
<tr>
<td>2.050</td>
<td>2.489275e-002</td>
</tr>
<tr>
<td>2.080</td>
<td>2.539300e-002</td>
</tr>
</tbody>
</table>

10 nA (0.000041%) non-monotonicity
Checking bug140b.ibs

IBISCHK5 V5.1.2

Checking bug140b.ibs for IBIS 4.2 Compatibility...

NOTE (line 40) - Pulldown Minimum data is non-monotonic
NOTE (line 51) - Pulldown Maximum data is non-monotonic
NOTE (line 52) - Pulldown Typical data is non-monotonic
NOTE (line 135) - Pullup Typical data is non-monotonic
NOTE (line 146) - Pullup Maximum data is non-monotonic
NOTE (line 202) - Pullup Minimum data is non-monotonic
WARNING - Combined Pulldown for Model: model_with_warning Typical data is non-monotonic
WARNING - Combined Pulldown for Model: model_with_warning Maximum data is non-monotonic

Errors : 0
Warnings: 2

File Passed
bug140b.ibs Maximum Data (Vdd = 1.58 V)

Power Clamp

1.95 V Pulldown

1.95 V
Example 2 (Cont. 2)

Current (A)

- Pulldown curve
- Clamp curve (gnd referenced)

Error introduced by piecewise linear interpolation
Example 2 (Cont.3)

Current (A)

Voltage (V)

Non-monotonic part

Errors introduced in the combined pulldown curve (close look)
BUG140 Resolution

• Change WARNING to NOTE
  – Valid solution for user
  – Avoids tool and model developer support issues

• Add “based on piecewise linear interpolation” to message

• No practical fix
  – Still issues with higher resolution or choosing percentage threshold
  – Piecewise linear interpolation is legal, and spline fitting would just hide information