**BUFFER ISSUE RESOLUTION DOCUMENT (BIRD)**

**BIRD NUMBER:** 181.2

**ISSUE TITLE:** I-V Table Clarifications

**REQUESTOR:**  Mike LaBonte, Signal Integrity Software; Bob Ross, Teraspeed Labs

**DATE SUBMITTED:** August 26, 2016

**DATE REVISED:** October 13, 2016, April 14, 2017

**DATE ACCEPTED:**

**DEFINITION OF THE ISSUE:**

The IBIS I/V table keywords [Pulldown], [Pullup], [GND Clamp], [POWER Clamp] should be more clearly defined. Where it discusses reference nodes the imprecise “Vcc” is used. The Vtable equation is given for Pullup only, and should be given for all tables as well as for ECL type devices.

**SOLUTION REQUIREMENTS:**

The IBIS specification must meet these requirements:

Table : Solution Requirements

|  |  |
| --- | --- |
| Requirement | Notes |
| 1. Clearly denote both voltage measurement points in Vtable equations.
 | Must refer to nodes, not voltage levels. |
| 1. Describe reference nodes for I/V elements using consistent terminology.
 | Could use HSPICE V(node1,node2) terminology, for example. |
| 1. Provide Vtable equations for all I/V tables.
 |  |
| 1. Provide Pullup and Pulldown Vtable equations for ECL.
 | Connected to same reference node. |

**SUMMARY OF PROPOSED CHANGES:**

For review purposes, the proposed changes are summarized as follows:

Table : IBIS Keywords, Subparameters, AMI Reserved\_Parameters, and AMI functions Affected

|  |  |  |
| --- | --- | --- |
| Specification Item | New/Modified/Other | Notes |
| **[Pulldown]**, **[Pullup]**, **[GND Clamp]**, **[POWER Clamp] keywords** | Modified | No functional change, clarification only. |

**PROPOSED CHANGES:**

Replace the section starting on IBIS 6.1 page 53:

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

*Keywords:* **[Pulldown]**, **[Pullup]**, **[GND Clamp]**, **[POWER Clamp]**

*Required:* Yes, if they exist in the model

*Description:* The data points under these keywords define the I-V tables of the pulldown and pullup structures of an output buffer and the I-V tables of the clamping diodes connected to the GND and the POWER terminals, respectively. Currents are considered positive when their direction is into the component.

*Usage Rules:* In each of these sections, the first column contains the voltage value, and the three remaining columns hold the typical, minimum, and maximum current values. The four entries, Voltage, I(typ), I(min), and I(max) must be placed on a single line and must be separated by at least one white space.

All four columns are required under these keywords. However, data is only required in the typical column. If minimum and/or maximum current values are not available, the reserved word “NA” must be used. “NA” can be used for currents in the typical column, but numeric values MUST be specified for the first and last voltage points on any I-V table. Each I-V table must have at least 2, but not more than 100, rows.

*Other Notes:* The I-V table of the [Pullup] and the [POWER Clamp] structures are “Vcc relative”, meaning that the voltage values are referenced to the Vcc terminal. (Note that, under these keywords, all references to “Vcc” refer to the voltage rail defined by the [Voltage Range], [Pullup Reference], or [POWER Clamp Reference] keywords, as appropriate.) The voltages in the data tables are derived from the equation:

*Vtable = Vcc – Voutput*

Therefore, for a 5 V model, -5 V in the table actually means 5 V above Vcc, which is +10 V with respect to ground; and 10 V means 10 V below Vcc, which is -5 V with respect to ground. Vcc-relative data is necessary to model a pullup structure properly, since the output current of a pullup structure depends on the voltage between the output and Vcc terminals and not the voltage between the output and ground terminals. Note that the [GND Clamp] I-V table can include quiescent input currents, or the currents of a 3-stated output, if so desired.

When tabulating data for ECL models, the data in the [Pulldown] table is measured with the output in the “logic low” state. In other words, the data in the table represents the I-V characteristics of the output when the output is at the most negative of its two logic levels. Likewise, the data in the [Pullup] table is measured with the output in the “logic one” state and represents the I-V characteristics when the output is at the most positive logic level. Note that in BOTH of these cases, the data is referenced to the Vcc supply voltage, using the equation:

*Vtable = Vcc - Voutput*

Monotonicity Requirements:

To be monotonic, the I-V table data must meet any one of the following 8 criteria:

1- The CURRENT axis either increases or remains constant as the voltage axis is increased.

2- The CURRENT axis either increases or remains constant as the voltage axis is decreased.

3- The CURRENT axis either decreases or remains constant as the voltage axis is increased.

4- The CURRENT axis either decreases or remains constant as the voltage axis is decreased.

5- The VOLTAGE axis either increases or remains constant as the current axis is increased.

6- The VOLTAGE axis either increases or remains constant as the current axis is decreased.

7- The VOLTAGE axis either decreases or remains constant as the current axis is increased.

8- The VOLTAGE axis either decreases or remains constant as the current axis is decreased.

An IBIS syntax checking program shall test for non-monotonic data and provide a maximum of one warning per I-V table if non-monotonic data is found. For example:

“Warning: Line 300, Pulldown I-V table for model DC040403 is non-monotonic! Most EDA tools will filter this data to remove the non-monotonic data.”

It is also recognized that the data may be monotonic if currents from both the output stage and the clamp diode are added together as most EDA tools do. To limit the complexity of the IBIS syntax checking programs, such programs will conduct monotonicity testing only on one I-V table at a time.

It is intended that the [POWER Clamp] and [GND Clamp] tables are summed together and then added to the appropriate [Pullup] or [Pulldown] table when a buffer is driving high or low, respectively.

From this assumption and the nature of 3-statable buffers, it follows that the data in the clamping table sections are handled as constantly present tables and the [Pullup] and [Pulldown] tables are used only when needed in the simulation.

The clamp tables of an Input or I/O buffer can be measured directly with a curve tracer, with the I/O buffer 3-stated. However, sweeping enabled buffers results in tables that are the sum of the clamping tables and the output structures. Based on the assumption outlined above, the [Pullup] and [Pulldown] tables of an IBIS model must represent the difference of the 3-stated and the enabled buffer’s tables. (Note that the resulting difference table can demonstrate a non-monotonic shape.) This requirement enables the EDA tool to sum the tables, without the danger of double counting, and arrive at an accurate model in both the 3-stated and enabled conditions.

Since in the case of a non 3-statable buffer, this difference table cannot be generated through lab measurements (because the clamping tables cannot be measured alone), the [Pullup] and [Pulldown] tables of an IBIS model can contain the sum of the clamping characteristics and the output structure. In this case, the clamping tables must contain all zeroes, or the keywords must be omitted.

*Example:*

[Pulldown]

| Voltage I(typ) I(min) I(max)

|

 -5.0V -40.0m -34.0m -45.0m

 -4.0V -39.0m -33.0m -43.0m

| .

 0.0V 0.0m 0.0m 0.0m

| .

 5.0V 40.0m 34.0m 45.0m

 10.0V 45.0m 40.0m 49.0m

|

[Pullup] | Note: Vtable = Vcc - Voutput

|

| Voltage I(typ) I(min) I(max)

|

 -5.0V 32.0m 30.0m 35.0m

 -4.0V 31.0m 29.0m 33.0m

| .

 0.0V 0.0m 0.0m 0.0m

| .

 5.0V -32.0m -30.0m -35.0m

 10.0V -38.0m -35.0m -40.0m

|

[GND Clamp]

|

| Voltage I(typ) I(min) I(max)

|

 -5.0V -3900.0m -3800.0m -4000.0m

 -0.7V -80.0m -75.0m -85.0m

 -0.6V -22.0m -20.0m -25.0m

 -0.5V -2.4m -2.0m -2.9m

 -0.4V 0.0m 0.0m 0.0m

 5.0V 0.0m 0.0m 0.0m

|

[POWER Clamp] | Note: Vtable = Vcc - Voutput

|

| Voltage I(typ) I(min) I(max)

|

 -5.0V 4450.0m NA NA

 -0.7V 95.0m NA NA

 -0.6V 23.0m NA NA

 -0.5V 2.4m NA NA

 -0.4V 0.0m NA NA

 0.0V 0.0m NA NA

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with new text:

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

*Keywords:* **[Pulldown]**, **[Pullup]**, **[GND Clamp]**, **[POWER Clamp]**

*Required:* Yes, if they exist in the model

*Description:* The data points under these keywords define the I-V tables of the pulldown and pullup structures of an output buffer and the I-V tables of the clamping diodes connected to the GND and the POWER terminals, respectively. Currents are considered positive when their direction is into the I-V table representation of a device through the Buffer\_I/O terminal (a name used for terminals that are not connected to supplies in a [Model] and for any Model\_type).

*Usage Rules:* In each of these sections, the first column contains the voltage value, and the three remaining columns hold the typical, minimum, and maximum current values. The four entries, Voltage, I(typ), I(min), and I(max) must be placed on a single line and must be separated by at least one white space.

All four columns are required under these keywords. However, data is only required in the typical column. If minimum and/or maximum current values are not available, the reserved word “NA” must be used. “NA” can be used for currents in the typical column, but numeric values MUST be specified for the first and last voltage points on any I-V table. Each I-V table must have at least 2, but not more than 100, rows.

*Other Notes:* The I-V table of the [Pullup] and the [POWER Clamp] structures are “Pullup\_ref relative”, meaning that the voltage values are referenced to the Pullup\_ref terminal. (Note that, under these keywords, all references to “Pullup\_ref” refer to the voltage rail defined by the [Voltage Range], [Pullup Reference], or [POWER Clamp Reference] keywords, as appropriate.) The voltages in the Voltage column of the data tables are derived from the equation:

*Vtable = V(Pullup\_ref, Buffer\_I/O)*

The I-V table of the [POWER Clamp] structures is “Power\_clamp\_ref relative”, meaning that the voltage values are referenced to the Power\_clamp\_ref terminal. (Note that, under these keywords, all references to “Power\_clamp\_ref” refer to the voltage rail defined by the [Voltage Range], or [POWER Clamp Reference] keywords, as appropriate.) The voltages in the Voltage column of the data tables are derived from the equation:

*Vtable* = *V(Power\_clamp\_ref, Buffer\_I/O)*

The I-V table of the [Pulldown] structures is “Pulldown\_ref relative”, meaning that the voltage values are referenced to the Pulldown\_ref terminal. (Note that, under these keywords, all references to “Pulldown\_ref” refer to the voltage rail by default GND if not defined or defined by the [Pulldown Reference] keyword.) The voltages in the Voltage column of the data tables are derived from the equation:

*Vtable* = *V(Buffer\_I/O, Pulldown\_ref)*

The I-V table of the [GND Clamp] structures is “Gnd\_clamp\_ref relative”, meaning that the voltage values are referenced to the Gnd\_clamp\_ref terminal. (Note that, under these keywords, all references to “Gnd\_clamp\_ref” refer to the voltage rail by default GND if not defined or defined by the [GND Clamp Reference] keyword.) The voltages in the Voltage column of the data tables are derived from the equation:

*Vtable* = *V(Buffer\_I/O, Gnd\_clamp\_ref)*

Therefore, for a 5 V model (Vcc=[Voltage Range]=[Pullup Reference]=[POWER Clamp Reference]=5.0V, [Pulldown Reference]=[GND Clamp Reference]=0.0V), -5 V in the table actually means 5 V above Vcc, which is +10 V with respect to ground; and 10 V means 10 V below Vcc, which is -5 V with respect to ground. Vcc-relative data is necessary to model a pullup structure properly, since the output current of a pullup structure depends on the voltage between the output and Vcc terminals and not the voltage between the output and ground terminals. Note that the [GND Clamp] I-V table can include quiescent input currents, or the currents of a 3-stated output, if so desired.

When tabulating data for ECL models, the data in the [Pulldown] table is measured with the output in the “logic low” state. In other words, the data in the table represents the I-V characteristics of the output when the output is at the most negative of its two logic levels. Likewise, the data in the [Pullup] table is measured with the output in the “logic one” state and represents the I-V characteristics when the output is at the most positive logic level. Note that in BOTH of these cases, the data is referenced to the same supply voltage (i.e., Pulldown\_ref = Pullup\_ref), using the equations:

Logic high state [Pullup] table

*Vtable* = *V(Pullup\_ref, Buffer\_I/O)*

Logic low state [Pulldown] table

*Vtable* = *V(Pulldown\_ref, Buffer\_I/O)*

Monotonicity Requirements

To be monotonic, the I-V table data must meet any one of the following 8 criteria:

1- The CURRENT value either increases or remains constant as the voltage value is increased.

2- The CURRENT value either increases or remains constant as the voltage value is decreased.

3- The CURRENT value either decreases or remains constant as the voltage value is increased.

4- The CURRENT value either decreases or remains constant as the voltage value is decreased.

5- The VOLTAGE value either increases or remains constant as the current value is increased.

6- The VOLTAGE value either increases or remains constant as the current value is decreased.

7- The VOLTAGE value either decreases or remains constant as the current value is increased.

8- The VOLTAGE value either decreases or remains constant as the current value is decreased.

It is also recognized that the data may be monotonic if currents from both the output stage and the clamp diode are added together.

It is intended that the [POWER Clamp] and [GND Clamp] tables are summed together and their combined currents are added to the currents of the [Pullup] and [Pulldown] tables (which can be controlled separately from the clamp currents) when a buffer is driving high or low.

From this assumption and the nature of 3-statable buffers, it follows that the data in the clamping table sections are handled as constantly present tables and the [Pullup] and [Pulldown] tables are used only when needed in the simulation.

The clamp tables of an Input or I/O buffer can be measured directly with a curve tracer, with the I/O buffer 3-stated. However, sweeping enabled buffers results in tables that are the sum of the clamping tables and the output structures. Based on the assumption outlined above, the [Pullup] and [Pulldown] tables of an IBIS model must represent the difference of the 3-stated and the enabled buffer’s tables. (Note that the resulting difference table can demonstrate a non-monotonic shape.) This requirement enables the EDA tool to sum the tables, without the danger of double counting, and arrive at an accurate model in both the 3-stated and enabled conditions.

Since in the case of a non 3-statable buffer, this difference table cannot be generated through lab measurements (because the clamping tables cannot be measured alone), the [Pullup] and [Pulldown] tables of an IBIS model can contain the sum of the clamping characteristics and the output structure. In this case, the clamping tables must contain all zeroes, or the keywords must be omitted.

*Examples:*

| Partial CMOS Example:

[Pulldown] | Note: Vtable = V(Buffer\_I/O, Pulldown\_ref)

|

| Voltage I(typ) I(min) I(max)

|

 -5.0V -40.0m -34.0m -45.0m

 -4.0V -39.0m -33.0m -43.0m

| .

 0.0V 0.0m 0.0m 0.0m

| .

 5.0V 40.0m 34.0m 45.0m

 10.0V 45.0m 40.0m 49.0m

|

[Pullup] | Note: Vtable = V(Pullup\_ref, Buffer\_I/O)

|

| Voltage I(typ) I(min) I(max)

|

 -5.0V 32.0m 30.0m 35.0m

 -4.0V 31.0m 29.0m 33.0m

| .

 0.0V 0.0m 0.0m 0.0m

| .

 5.0V -32.0m -30.0m -35.0m

 10.0V -38.0m -35.0m -40.0m

|

[GND Clamp] | Note: Vtable = V(Buffer\_I/O, Gnd\_clamp\_ref)

|

| Voltage I(typ) I(min) I(max)

|

 -5.0V -3900.0m -3800.0m -4000.0m

 -0.7V -80.0m -75.0m -85.0m

 -0.6V -22.0m -20.0m -25.0m

 -0.5V -2.4m -2.0m -2.9m

 -0.4V 0.0m 0.0m 0.0m

 5.0V 0.0m 0.0m 0.0m

|

[POWER Clamp] | Note: Vtable = V(Power\_clamp\_ref, Buffer\_I/O)

|

| Voltage I(typ) I(min) I(max)

|

 -5.0V 4450.0m NA NA

 -0.7V 95.0m NA NA

 -0.6V 23.0m NA NA

 -0.5V 2.4m NA NA

 -0.4V 0.0m NA NA

 0.0V 0.0m NA NA

| Partial ECL Example ([Pullup] and [Pulldown] tables only)

| NOTE, the I-V table polarity conventions are the same

[Pulldown] | Note: Vtable = V(Pulldown\_ref, Buffer\_I/O)

|

| Voltage I(typ) I(min) I(max)

|

 3.0 -0.1784 NA NA

 2.8 -0.1542 NA NA

 2.6 -0.1283 NA NA

 2.4 -0.09974 NA NA

 2.2 -0.06772 NA NA

 2 -0.03161 NA NA

 1.8 -0.001643 NA NA

 1.7 -4.412e-05 NA NA

 1.6 -9.504e-07 NA NA

 1.5 0.0 NA NA

 0 0.0 NA NA

 -2.0 0.0 NA NA

|

[Pullup] | Note: Vtable = V(Pullup\_ref, Buffer\_I/O)

|

| Voltage I(typ) I(min) I(max)

|

 3.0 -0.2515 NA NA

 2.8 -0.2339 NA NA

 2.6 -0.2163 NA NA

 2.4 -0.1987 NA NA

 2.2 -0.1809 NA NA

 2 -0.1629 NA NA

 1.8 -0.1444 NA NA

 1.6 -0.1246 NA NA

 1.4 -0.09973 NA NA

 1.2 -0.06941 NA NA

 1 -0.03504 NA NA

 0.8 -0.003236 NA NA

 0.7 -0.0001101 NA NA

 0.6 -2.396e-06 NA NA

 0.5 0 NA NA

 0.0 0 NA NA

 -2.0 0.0 NA NA

|

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Replace section 9 NOTES ON DATA DERIVATION METHOD, item 2, starting on page 165 of IBIS 6.1:

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2) Voltage Ranges:

Points for each table must span the voltages listed in Table 16.

Table 16 – Voltage Ranges

| **Table** | **Low Voltage** | **High Voltage** |
| --- | --- | --- |
| [Pulldown] | GND – POWER | POWER + POWER |
| [Pullup] | GND – POWER | POWER + POWER |
| [GND Clamp] | GND – POWER | GND + POWER |
| [POWER Clamp] | POWER | POWER + POWER |
| [Series Current] | GND – POWER | GND + POWER |
| [Series MOSFET] | GND | GND + POWER |

As described in the [Pulldown Reference] keyword section, the I-V tables of the [Pullup] and the [POWER Clamp] structures are “Vcc relative”, using the equation:

*Vtable = Vcc - Voutput*

For example, a model with a 5 V power supply voltage should be characterized between (0 - 5) = -5 V and (5 + 5) = 10 V; and a model with a 3.3 V power supply should be characterized between (0 - 3.3) = -3.3 V and (3.3 + 3.3) = 6.6 V for the [Pulldown] table.

When tabulating output data for ECL type models, the voltage points must span the range of Vcc to Vcc - 2.2 V. This range applies to both the [Pullup] and [Pulldown] tables. Note that this range applies ONLY when characterizing an ECL output.

These voltage ranges must be spanned by the IBIS data. Data derived from lab measurements may not be able to span these ranges as such and so may need to be extrapolated to cover the full range. This data must not be left for the EDA tool to provide.

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with new text:

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

2) Voltage Ranges:

Voltage values in the first column of each I-V table must span the ranges shown in Table 16 where:

*Vpower\_ref = [Pulldown Reference] or [GND Clamp Reference] or 0*

*Vpower\_supply = [Pullup Reference] or [Power Clamp Reference] or [Voltage Range]*

Table 16 – Voltage Ranges

| **Table** | **Low Voltage** | **High Voltage** |
| --- | --- | --- |
| [Pulldown] | Vpower\_ref – Vpower\_supply | Vpower\_supply + Vpower\_supply |
| [Pullup] | Vpower\_ref – Vpower\_supply | Vpower\_supply + Vpower\_supply |
| [GND Clamp] | Vpower\_ref – Vpower\_supply | Vpower\_ref + Vpower\_supply |
| [POWER Clamp] | Vpower\_supply | Vpower\_supply + Vpower\_supply |
| [Series Current] | Vpower\_ref – Vpower\_supply | Vpower\_ref + Vpower\_supply |
| [Series MOSFET] | Vpower\_ref | Vpower\_ref + Vpower\_supply |

As described in the section for the [Pulldown], [Pullup], [GND Clamp], and [POWER Clamp] keywords, the I-V tables of the [Pullup] and the [POWER Clamp] structures are “Vcc relative”. For example, the table voltage for [Pullup] is described by the equation:

*Vtable = V(Pullup\_ref, Buffer\_I/O)*

For example, a model with a 5 V power supply voltage should be characterized between (0 - 5) = -5 V and (5 + 5) = 10 V; and a model with a 3.3 V power supply should be characterized between (0 - 3.3) = -3.3 V and (3.3 + 3.3) = 6.6 V for the [Pulldown] table.

When tabulating output data for ECL type models, the voltage points must span the range of Vcc to Vcc - 2.2 V. This range applies to both the [Pullup] and [Pulldown] tables. Note that this range applies ONLY when characterizing an ECL output.

These voltage ranges must be spanned by the IBIS data. Data derived from lab measurements may not be able to span these ranges as such and so may need to be extrapolated to cover the full range. This data must not be left for the EDA tool to provide.

**BACKGROUND INFORMATION/HISTORY:**

These changes were initially discussed in IBIS Editorial Task Group meetings on April 01 and 22, and July 15, 2016. The BIRD draft was reviewed by the IBIS Advanced Technology Modeling Task Group August 09, 2016 and by the IBIS Editorial Task Group August 19, 2016.

BIRD181.1 Changes were in response to comments at the IBIS Teleconference meeting on September 23, 2016 by Radek Biernacki and others.

Also, per Quality Task Group discussion on October 11, 2016, the ibischk message description was significantly edited because the IBIS Specification might suggest briefly parser messages, but not get into their detail. The message verbiage is different than as stated. All the monotonic messages have been reclassified as NOTEs messages per BUG140; Individual I-V tables and summed I-V tables are checked. Also, it is legal to have monotonic I-V tables. So the details in these paragraphs are no longer correct and relevant and appropriate for the IBIS Specification.

BIRD181.2 includes changes to the NOTES ON DATA DERIVATION section suggested by Bob Ross in BIRD181.1 Terminology Issues rev 5, presented March 21, 2017.