**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, December 3, 2019

**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 1: 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 2: 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. |
| **[ISSO PD] and [ISSO PU] keywords** | Modified | No functional change, clarification only. |
| **[Series MOSFET] keyword** | Modified | No functional change, clarification only. |
| **Notes on Data Derivation** | Modified | No functional change, clarification only. |

**PROPOSED CHANGES:**

Proposed changes beginning on page 69 of IBIS 7.0 are shown as markup below:

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

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

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

*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 pins, respectively. Currents are considered positive when their directions are 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 whitespace character.

All four columns are required under these keywords. However, data are 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 [Pullup] 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 are 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 are referenced to the same supply voltage (i.e., Pulldown\_ref = Pullup\_ref), using the equations:

Logic high state [Pullup] table

*VtableV(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.

Data may be monotonic if currents from both the output stage and the clamp diode are added together.

It is intended that, for monotonicity checks, 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 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

|

Proposed changes beginning on page 72 of IBIS 7.0 are shown as markup below:

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

The [ISSO PD] table voltages are relative to the [Pulldown Reference] typ/min/max values (usually ground). The [ISSO PU] table voltages are relative to the [Pullup Reference] typ/min/max values (also usually the [Voltage Range] voltages). In the case of the [ISSO PU] table, the voltages follow the same Vtable = V(Pullup\_ref, Buffer\_I/O) convention as the [Pullup] table. Each of the tables are aligned with and span the typical -Vcc to Vcc voltages.

Proposed changes under Figure 15 in the [Series MOSFET] keyword section on page 82 of IBIS 7.0 are shown as markup below:

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

Either of the FETs could be removed (or have zero current contribution). Thus, this model covers all four conditions: off, single NMOS, single PMOS, and parallel NMOS/PMOS.

*Voltage = Table Voltage = Vtable = V(g,s)*

*Ids = Table Current for a given Vcc and Vds*

Internal logic that is generally referenced to the power rail is used to set the NMOS MOSFET switch to its “On” state. Internal logic, likewise referenced to ground, is used to set the PMOS device to its “On” state if the PMOS device is present. Thus, the [Voltage Range] settings provide the assumed gate voltages. If the [POWER Clamp Reference] exists, it overrides the [Voltage Range] value. The table voltage entries are actually Vgs values of the NMOS device and Vcc - Vgs values of the PMOS device, if present. The polarity conventions are identical to those used for other tables that are referenced to power rails. Thus, the voltage column can be viewed as defining the source voltage Vs points according to the convention: Vtable = V(g,s). This convention remains even without the NMOS device.

Proposed changes to Notes on Data Derivation, starting at the bottom of page 184 of IBIS 7.0 are shown as markup below:

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

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 “Pullup\_ref relative”, using the equations:

[Pullup] table

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

[POWER Clamp] table

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

In all I-V tables the full range of characterized voltages should extend below the lowest reference voltage and above the highest reference voltage by an amount equal to magnitude of the difference between those two voltages. [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.

Proposed changes to Notes on Data Derivation, starting at the bottom of page 187 of IBIS 7.0 are shown as markup below:

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

5) Series MOSFET Table Extractions:

An extraction circuit is set up according to Figure 39. The switch is configured into the “On” state. This assumes that the Vcc voltage will be applied to the gate by internal logic. Designate one terminal of the switch as the source node, and the other terminal as the drain node. The table currents designated as Ids are derived directly as a function of the Vs voltage at the source node as Vs is varied from 0 to Vcc. This voltage is entered as a Vgs value as a consequence of the relationship Vtable = V(g,s). Vds is held constant by having a fixed voltage Vds between the drain and source nodes. Note that Vds is expected to be greater than 0 V. The current flowing into the drain is tabulated in the table for the corresponding Vs points.

**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 is refactored to use text from IBIS 7.0 instead of IBIS 6.1 as the basis, with the same changes applied. It also includes changes recommended by Walter Katz, to use “terminal” in places where “pin” was inaccurate. Additional changes in other sections for consistency in how Vtable is described, recommended by Bob Ross, are included. The style of presentation is also changed, using Microsoft Word markup to show the changes instead of separate tracts of “change from” and “change to”text.