**BUFFER ISSUE RESOLUTION DOCUMENT (BIRD)**

**BIRD NUMBER:** (for administrative use)

**ISSUE TITLE:** C\_comp Model Using IBIS-ISS or Touchstone

**REQUESTOR:**  Walter Katz, Signal Integrity Software, Inc.

Randy Wolff, Micron Technology, Inc.

**DATE SUBMITTED:** (for administrative use)

**DATE REVISED:** (for administrative use)

**DATE ACCEPTED:** (for administrative use)

**DEFINITION OF THE ISSUE:**

The current C\_comp model is either a single capacitance or optionally up to four capacitors attached to a [Model]’s power and ground reference terminals. This simple C\_comp model is not accurate enough for high speed buffers. This BIRD enhances IBIS to allow an alternative C\_comp model using an IBIS-ISS subcircuit or Touchstone file. An enhanced C\_comp model would allow modeling of effects such as frequency and voltage dependencies.

**SOLUTION REQUIREMENTS:**

The IBIS specification must meet these requirements:

Table : Solution Requirements

|  |  |
| --- | --- |
| Requirement | Notes |
| 1. Allow an IBIS-ISS subcircuit or Touchstone file to be used as a C\_comp model. |  |
| 1. Allow up to three models to be declared and define how they align with typ/min/max corners. |  |
| 1. Define the terminals of the C\_comp model including references, signal (both internal and external to allow a series resistance between buffer and pad) and a receiver terminal for probing the input buffer. | A receiver terminal would allow for modeling series element filtering between the pad and the input buffer. EDA software could support plotting of the waveform at this terminal and measurement of signal switching thresholds at this terminal. |
| 1. Support single-ended as well as pseudo/true differential models. |  |
| 1. Explain handling of the reference for Touchstone files. |  |
| 1. Define how parameters can be instantiated and passed into the IBIS-ISS subcircuits for each of the typ/min/max corners. | Parameters should be single values that can be passed into either the typ, min or max corner subcircuit. Parameters are not meant to define ranges or allow sweeps. |
| 1. Explain hierarchy of the new C\_comp model with existing keywords including [C Comp Corner] or any other C\_comp\* models. | The new C\_comp model should override other C\_comp models. May need to explain how a simulator could use traditional C\_comp\* values for K-T curve generation. Recommended use of [C Comp Corner] for this. |

**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 |
| [C\_comp Model] | New | Positioned after [C Comp Corner] |
| [C Comp Corner] | Modified | Required when using [C\_comp Model] |
| [Component] | Modified | Si\_location & Timing\_location sub-params |

**PROPOSED CHANGES:**

A new keyword [C\_comp Model] shall be positioned after [C Comp Corner]. In the tree diagram under [Model] and after [C Comp Corner], add:

│ ├── **[C\_comp Model]** Param, File\_IBIS-ISS

│ │ File\_TS, Number\_of\_terminals

The [C Comp Corner] keyword requires a modification to the “Required” description as noted below:

*Keyword:* **[C Comp Corner]**

*Required:* Yes, if the [C\_comp Model] keyword is present

The [Component] keyword requires a modification to the “Usage Rules” description as noted below:

Si\_location and Timing\_location are optional and specify where the Signal Integrity and Timing measurements are made for the component. Allowed values for either subparameter are “Buffer”, “Die”, “Pad” or “Pin”. The default location is at the “Pin”. The “Die” location is also commonly referred to as the die pad location. “Pad” is an alternative name for “Die”. The “Buffer” location refers to the Buffer\_I\* terminal(s) of a [C\_comp Model] if [C\_comp Model] is present.

After the keyword [C Comp Corner] add:

*Keyword:* **[C\_comp Model], [End C\_comp Model]**

*Required:* No

*Description:* Defines an enhanced C\_comp model referenced in an external file using either the Touchstone or IBIS-ISS languages. The [C\_comp Model] has terminals compatible with the [Model] keyword or has terminals compatible with the [Model] keyword plus additional terminals connecting between the [Model] and the pad and/or at the input buffer. Up to two [C\_comp Model]/[End C\_comp Model] sections may exist within a single [Model].

*Sub-Params:* Mode, Param, File\_IBIS-ISS, File\_TS, Number\_of\_Terminals

*Usage Rules:* If [C\_comp Model] is present, it overrides [C Comp Corner] or any other C\_comp\* representations. If [C\_comp Model] is present, [C Comp Corner] is required. EDA software may use the [C Comp Corner] values for V-T curve shaping during simulation.

*Other Notes:*

Interconnect Models allow for on-die interconnect circuits between the buffer I/O terminal and the die pad. A C\_comp Model may also contain series elements modeling on-die interconnect between the buffer I/O terminal and the die pad. Use of a C\_comp Model with series elements in the signal path shall assume that V-T curves are measured at the Buffer\_I/O terminal of the [Model]. If there is no on-die interconnect model, then this is the “pad” in legacy IBIS models. The effect of series elements in a C\_comp Model may need to be de-embedded from I-V table data in the [Model].

The following subparameters are defined:

Mode

Param

File\_IBIS-ISS

File\_TS

Number\_of\_terminals = <value>

In addition to these subparameters, the [C\_comp Model]/[End C\_comp Model] section may contain lines describing terminals and their connections. No specific subparameter name, token, or other string is used to identify terminal lines.

Unless noted below, no C\_comp Model subparameter requires the presence of any other subparameter.

Mode rules:

The subparameter Mode is required and may be either Driving, Non-Driving, or All. If the top-level model type is one of the I/O or 3-state models, Mode may be Driving, Non-Driving, or All, and up to two C\_comp Models may be defined, one for Driving mode and one for Non-driving mode. For example, if the C\_comp Model mode is Non-Driving, then the C\_comp Model is used only in the high-Z state of a 3-state model.

The Mode cannot not conflict with the top-level model type. For example, if the top-level model type is Open or Output, Mode cannot be set to Non-Driving. Similarly, if the top-level model type is Input, Mode cannot be set to Driving.

The C\_comp Model mode can be set to All to cover all permitted modes for any top-level model type including, for example, Input, Output, and I/O.

*Example:*

Mode Driving

Param rules:

The subparameter Param is optional and only legal with the File\_IBIS-ISS subparameter documented below. Param is illegal with the File\_TS subparameter documented below. Param shall be followed by several arguments: an unquoted string argument giving the name of the parameter to be passed into the IBIS-ISS subcircuit, a reserved word for the parameter format, and other arguments based on the parameter format to be passed into the IBIS-ISS subcircuit. Valid entries for format are:

Value –A single numerical value or string value.

Corner – Three numerical values or three string values (surrounded by double quotes) located in the typ, min and max columns. A typ value is required. Either or both the min and max entries may be NA, in which cases the typ entry is used. The typ, min and max parameters are associated with the corner\_name Typ, Min and Max files and their corresponding circuit\_names respectively.

Several Param lines are permitted as long as each of the parameter names is unique within the [C\_comp Model]/[End C\_comp Model] section. The Param values shall all be numerical or all string values (or NA).

The numerical value rules follow the scaling conventions in Section 3.2, “SYNTAX RULES”. The EDA tool is responsible for translating IBIS specified parameters into IBIS-ISS parameters. For example, 1 megaohm, would be represented as 1M in Param value according to the Section 3 rules, but would be converted by the EDA tool to case-insensitive 1meg (1X is not recommended) or 1E6 for IBIS-ISS use. Quoted string parameters in IBIS are converted to the string parameter syntax in IBIS-ISS subcitcuits. For example, the Param value “typ.s1p” would be converted to str(‘typ.s1p’) in IBIS-ISS subcircuits.

*Examples:*

| Param param\_name format typ min max

Param R\_esr Corner 4.0 6.0 2.0

Param C\_123 Value 425f

Param ts\_file Corner “typ.s1p” “min.s1p” “max.s1p”

File\_IBIS-ISS rules:

Either File\_IBIS-ISS or File\_TS is required for a [C\_comp Model]/[End C\_comp Model] section*.* The File\_IBIS-ISS subparameter is followed by three unquoted string arguments consisting of corner\_name, file\_reference, and circuit\_name (.subckt name) for an IBIS-ISS file. The IBIS-ISS file under file\_reference shall be located in the same directory as the referencing .ibs file or in a specified directory under the referencing file as determined by the directory path (i.e., a file reference containing a relative path to a directory below that of the referencing .ibs file is permitted). The corner\_name shall be Typ, Min or Max. File\_IBIS-ISS for the Typ corner\_name is required, and File\_IBIS-ISS for the Min and Max corner\_names are optional. If present, each File\_IBIS-ISS shall have a unique corner\_name. If File\_IBIS-ISS for either the Min or Max corner\_name is missing, the File\_IBIS-ISS for the Typ corner\_name shall be used to describe the missing corner\_name file reference. The Min and Max file\_names should represent minimum (slow) and maximum (fast) model conditions respectively.

*Examples:*

| file\_type corner\_name file\_reference circuit\_name (.subckt name)

File\_IBIS-ISS Typ c\_comp.iss c\_comp\_typ

File\_IBIS-ISS Min c\_comp.iss c\_comp\_min | same file as Typ

File\_IBIS-ISS Max c\_comp\_max.iss c\_comp\_max | in separate file

File\_TS rules:

Either File\_TS or File\_IBIS-ISS is required for a [C\_comp Model]/[End C\_comp Model] section. File\_TS is followed by three unquoted string arguments for typ, min, and max Touchstone file references. The typ entry is required and shall point to a Touchstone file representing typical conditions and located in the same directory as the referencing .ibs file or in a specified directory under the referencing file as determined by the directory path (i.e., a file reference containing a relative path to a directory below that of the referencing .ibs file is permitted). The min and max entries may point to the same file or other files representing minimum (slow) and maximum (fast) models or contain NA. If the entry is NA, the typical file entry shall be used.

*Examples:*

| file\_type typ min max

File\_TS c\_comp\_typ.s5p c\_comp\_min.s5p c\_comp\_max.s5p

| file\_type typ min max

File\_TS c\_comp\_typ.s4p c\_comp\_min.s4p NA

Number\_of\_terminals rules:

The Number\_of\_terminals subparameter is required and defines the number of Terminals associated with the C\_comp Model. The subparameter name shall be followed by a single integer argument equal to or greater than two on the same line. This value will also match the number of terminals used in an associated IBIS-ISS subcircuit, or the number of ports plus 1 (N+1) used in a corresponding Touchstone file. The argument shall be separated from the subparameter name by the “=” character. The subparameter name, “=” character, and argument may optionally be separated by whitespace. Only one Number\_of\_terminals subparameter may appear for a given [C\_comp Model] keyword. The Number\_of\_terminals subparameter shall appear before any terminal lines and after all other subparameters for a given C\_comp Model.

Terminal line rules:

Terminal lines shall appear after the Number\_of\_terminals subparameter and before the [End C\_comp Model] keyword. No token or reserved word identifies terminal lines. Each terminal line contains information on a terminal of an IBIS-ISS subcircuit (or Touchstone file). Two or more terminal lines may appear under a given [C\_comp Model] keyword. At least one signal and one reference terminal line is required.

Terminal lines are of the following form, with each identifier separated by whitespace:

<Terminal\_number> <Terminal\_type>

Terminal\_number

Terminal\_number is an identifier for a specific terminal. Terminal\_number shall be a positive non-zero integer less than or equal to the value of the Number\_of\_terminals argument. The same Terminal\_number shall not appear more than once for a given C\_comp Model. All terminals found in the associated IBIS-ISS subcircuit, or ports plus the reference port found in the associated Touchstone file, shall be defined for a given C\_comp Model. No terminals shall be left undefined.

The Terminal\_number entry shall match the IBIS\_ISS terminal (node) position or the Touchstone file terminal (line) position, plus an undeclared reference line. The Terminal\_number entries may be listed in any order as long as there are no duplicate entries.

Terminal\_type  
Terminal\_type shall be one of the following: Buf\_I/O, Buf\_O, Buf\_I/O\_pos, Buf\_O\_pos, Buf\_I/O\_neg, Buf\_O\_neg, Buf\_I, Buf\_I\_pos, Buf\_I\_neg, Pullup\_ref, Pulldown\_ref, Power\_clamp\_ref, Gnd\_clamp\_ref or Ext\_ref. Terminal\_type entries are described in Table 1.

**Table 1 – Terminal\_type Definitions**

|  |  |
| --- | --- |
| **Terminal\_type** | **Definition** |
| Buffer\_I/O | Connects to the [Model]’s signal terminal. This is the location that is either at the die pad, or there may optionally be on-die interconnect between this terminal and the die pad. |
| Buffer\_O | Internal node connecting between a [Model] and the Buffer\_I/O terminal when there is a series component to the C\_comp Model. |
| Buffer\_I/O\_pos | Connects to the positive (non-inverting) side of a differential [Model]’s signal terminal. This is the location that is either at the die pad, or there may optionally be on-die interconnect between this terminal and the die pad. |
| Buffer\_O\_pos | Internal node connecting between a [Model] and the Buffer\_I/O\_pos terminal when there is a series component to the differential C\_comp Model. |
| Buffer\_I/O\_neg | Connects to the complementary (inverting) side of a differential [Model]’s signal terminal. This is the location that is either at the die pad, or there may optionally be on-die interconnect between this terminal and the die pad. |
| Buffer\_O\_neg | Internal node connecting between a [Model] and the Buffer\_I/O\_neg terminal when there is a series component to the differential C\_comp Model. |
| Buffer\_I | Available when there is a series element between the Buffer\_I/O terminal and the input buffer, where Signal Integrity and/or Timing measurements could be made for the component. This location may be referenced as a Si\_location and/or Timing\_location by [Component]. |
| Buffer\_I\_pos | Available when there is a series element between the Buf\_I/O\_pos terminal and the differential input buffer, where Signal Integrity and/or Timing measurements could be made for the component. This location may be referenced as a Si\_location and/or Timing\_location by [Component]. |
| Buffer\_I\_neg | Available when there is a series element between the Buffer\_I/O\_neg terminal and the differential input buffer, where Signal Integrity and/or Timing measurements could be made for the component. This location may be referenced as a Si\_location and/or Timing\_location by [Component]. |
| Pullup\_ref | Connects to the [Model]’s pullup reference. |
| Pulldown\_ref | Connects to the [Model]’s pulldown reference. |
| Power\_clamp\_ref | Connects to the [Model]’s power clamp reference. |
| Gnd\_clamp\_ref | Connects to the [Model]’s ground clamp reference. |
| Ext\_ref | Connects to the [Model]’s external reference. |

A C\_comp Model can either replace C\_comp by connecting a single terminal of the C\_comp Model at the same location that the [Model]’s C\_comp connects (see Figure X), or it can replace C\_comp with a model containing series elements (see Figure Y). In the case of a model including series elements, the C\_comp Model will require a terminal at the output of the buffer (Buffer\_I/O) and a terminal at an internal buffer node (Buffer\_O).

**[C\_comp Model]**

**Buffer Terminal**

**Buffer\_I/O**

**Power\_clamp\_ref**

**Gnd\_clamp\_ref**

**[Model]**

**V-T Waveform Measurement Point**

**Buffer**

**(I-V & K-T)**

**Pullup\_ref**

**Pulldown\_ref**

**Buffer\_I/O**

**Pullup\_ref**

**Pulldown\_ref**

**Power\_clamp\_ref**

**Gnd\_clamp\_ref**

**Figure X**

Some Input and/or I/O buffers contain series elements between the die pad and the input buffer circuit that may provide isolation or filtering. If it is desired to view the analog input waveform at the input buffer, the C\_comp Model can contain the terminal Buffer\_I as seen in Figure Y. Buffer\_I may be referenced as a Si\_location and/or Timing\_location by [Component]. The terminal Buffer\_I is analogous to the terminal my\_receive of an [External Model] as seen in Figure 24. If the buffer is differential, then terminals Buffer\_\*\_pos and Buffer\_\*\_neg can be used as seen in Figure Z.

**[C\_comp Model]**

**Buffer Terminal**

**Buffer\_O**

**Power\_clamp\_ref**

**Gnd\_clamp\_ref**

**[Model]**

**V-T Waveform Measurement Point**

**Buffer**

**(I-V & K-T)**

**Pullup\_ref**

**Pulldown\_ref**

**Buffer\_I/O**

**Pullup\_ref**

**Pulldown\_ref**

**Power\_clamp\_ref**

**Gnd\_clamp\_ref**

**Buffer\_I**

**Buffer\_I**

**Buffer\_I/O**

**Figure Y**

**[C\_comp Model]**

**Buffer Terminal**

**Buffer\_O\_pos**

**Power\_clamp\_ref**

**Gnd\_clamp\_ref**

**[Model]**

**Buffer**

**(I-V & K-T)**

**Pullup\_ref**

**Pulldown\_ref**

**Buffer\_I/O\_pos**

**Pullup\_ref**

**Pulldown\_ref**

**Power\_clamp\_ref**

**Gnd\_clamp\_ref**

**Buffer\_I\_pos**

**Buffer\_I\_pos**

**Buffer\_I/O\_pos**

**Buffer\_I\_neg**

+

-

**Buffer Terminal**

**Buffer\_I/O\_neg**

**Buffer\_I/O\_neg**

**Buffer\_O\_neg**

**Buffer**

**(I-V & K-T)**

**Buffer\_I\_neg**

Inverted Buffer associated through [Diff Pin]

**Figure Z**

*Other Notes:*

Touchstone Files

For a C\_comp Model using File\_TS with N ports, N equals the number of ports present in the data of the associated Touchstone 1.x file, or the value associated with the [Number of Ports] keyword in the associated Touchstone 2 file. The Number\_of\_terminals entry in the C\_comp Model shall be an integer equal to N+1. Terminal rules are described below:

* The EDA tool shall use the terminal “N+1” entry as the reference node for each of the N ports. For a C\_comp Model with N ports, the terminals and ports are associated as follows:
  + Terminal              Port
  + 1                              1
  + 2                              2
  + …
  + N                             N
  + N+1 reference
* Terminal N+1 shall be connected to a buffer terminal which is in turn connected to a pin with a signal\_name of POWER or GND.

*Examples:*

[C\_comp Model]

File\_IBIS-ISS Typ A.iss A

Mode Non-Driving

Param C Corner 1pF 2pF 0.5pF

Number\_of\_Terminals 2

1 Buffer\_I/O

2 Gnd\_clamp\_ref

[End C\_comp Model]

[C\_comp Model]

File\_TS C\_typ.s2p C\_min.s2p C\_max.s2p

Mode Driving

Number\_of\_Terminals 3

1 Buffer\_O

2 Buffer\_I/O

3 Pulldown\_ref

[End C\_comp Model]

[C\_comp Model]

File\_IBIS-ISS Typ B.iss B

Mode All

Number\_of\_Terminals 7

1 Buffer\_O

2 Buffer\_I/O

3 Pullup\_ref

4 Pulldown\_ref

5 Power\_clamp\_ref

6 Gnd\_clamp\_ref

7 Buffer\_I

[End C\_comp Model]

[C\_comp Model]

File\_TS C\_typ.s4p NA NA

Mode Driving

Number\_of\_Terminals 5

1 Buffer\_O\_pos

2 Buffer\_O\_neg

3 Buffer\_I/O\_pos

4 Buffer\_I/O\_neg

5 Pulldown\_ref

[End C\_comp Model]

The following section should be appended to the end of the IBIS document.

**RULES OF PRECEDENCE**

The EDA tool shall either use C\_comp\* or [C\_comp Model], but not both. The user and EDA tool may assume that [C\_comp Model] is more accurate than C\_comp\*. EDA software may use the [C Comp Corner] values for V-T curve shaping during simulation.

**BACKGROUND INFORMATION/HISTORY:**

Several drafts of the BIRD document were shared with the IBIS ATM task group in late 2014 and early 2015. Draft 6 from April 7, 2015 is found here: <http://www.ibis.org/macromodel_wip/archive/20150407/randywolff/C_comp%20Model%20Using%20IBIS-ISS%20BIRD%20draft%206/>. Draft 6 was used as a starting point for this BIRD with the document updated for the new BIRD template.

Notes on a discussion of the requirements section were captured in the IBIS ATM meeting minutes of May 31, 2016, <http://www.ibis.org/macromodel_wip/minutes/20160531/>.

Notes on the addition of the Mode subparameter were captured in the IBIS ATM meeting minutes of August 15, 2017, <http://www.ibis.org/macromodel_wip/minutes/20170815/>.