Improving the analog modeling capabilities of IBIS for IBIS-AMI

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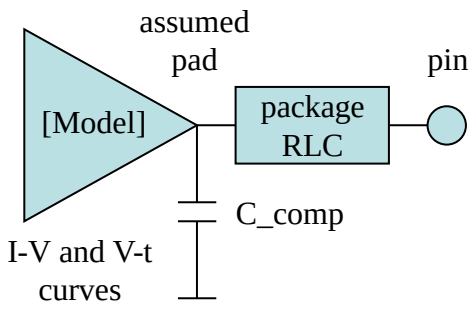
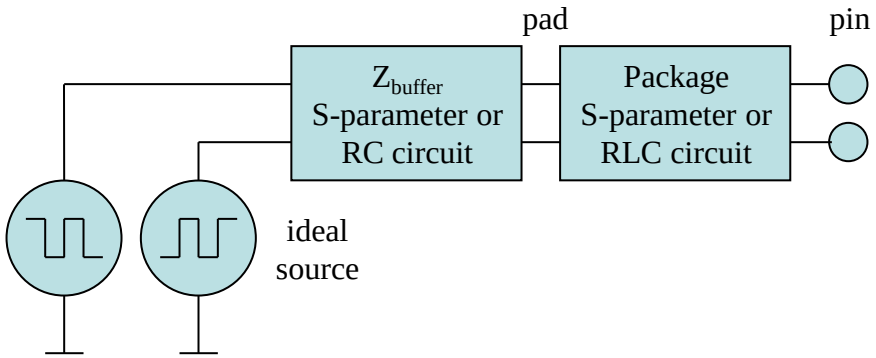
Existing and desired analog IBIS model





- **single ended or pseudo differential model**
- **non-linear buffer, frequency independent Z**
- **frequency independent package parameters**
- **skin effect, dielectric lossless not available**

- **[Model Selector] may be used for sweeping buffer impedance, amplitude and edge rate**

- **true differential model**
- **frequency dependent & lossy buffer Z (LTI only)**
- **frequency dependent & lossy package**

- **may be parameterized to sweep buffer characteristics (impedance, amplitude and edge rate)**

[External Model], [External Circuit] and [Package Model] with IBIS-ISS

- **[External Model] and [External Circuit] are basically subcircuit instances in IBIS**
  - currently limited to *-AMS and Berkeley-SPICE
  - Berkeley-SPICE is practically useless, (no parameters, W-elements, S-parameters, etc…)
- **IBIS-ISS stands for "IBIS-Interconnect-Subcircuit-Specification", a developing specification to standardize the passive modeling capabilities of HSPICE**
  - Synopsys granted permission to the IBIS Open Forum to do this
  - has subcircuit parameters, W-element, S-parameter, some controlled sources, etc…
  - has string parameters (for S-parameter file names, for example)
  - parameter assignments accept ternary operator
  - the IBIS-ISS specification is almost done, currently finishing editorial work, the goal is to make it available for IBIS 5.1
- **Why not make IBIS-ISS available for [External Model] and [External Circuit] and use them for analog AMI buffer modeling?**
  - the analog buffer models are assumed to be LTI by the AMI specification
  - this is addressed by BIRD 116 now
- **[External Model] has a few advantages over [External Circuit] for AMI purposes**
  - works together with [Model Selector]
  - supports true differential buffers [Diff Pin]
- **IBIS-ISS is also a good candidate for IBIS package modeling**

True differential models are available with [External Model]

IMPORTANT: All true differential models under [External Model] assume single-ended digital port connections (D_drive, D_enable, D_receive).

The [Diff Pin] keyword is still required within the same [Component] definition when [External Model] describes a true differential buffer. The [Model] names or [Model Selector] names referenced by the pair of pins listed in an entry of the [Diff Pin] MUST be the same.

The D_to_A or A_to_D adapters used for SPICE, Verilog-A(MS) or VHDL-A(MS) files may be set up to control or respond to true differential ports. An example is shown below.

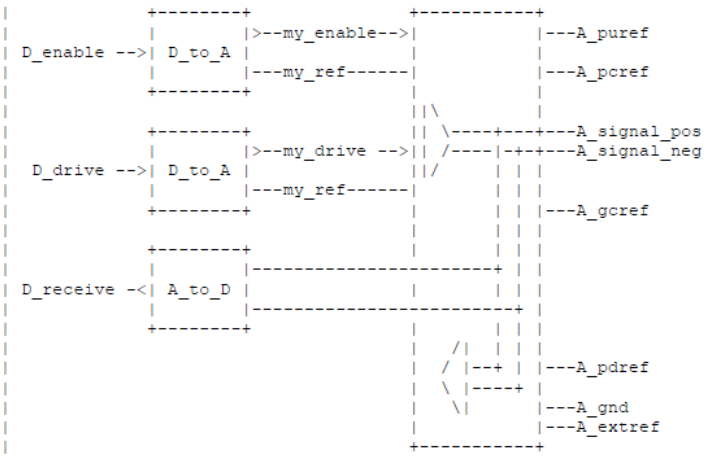
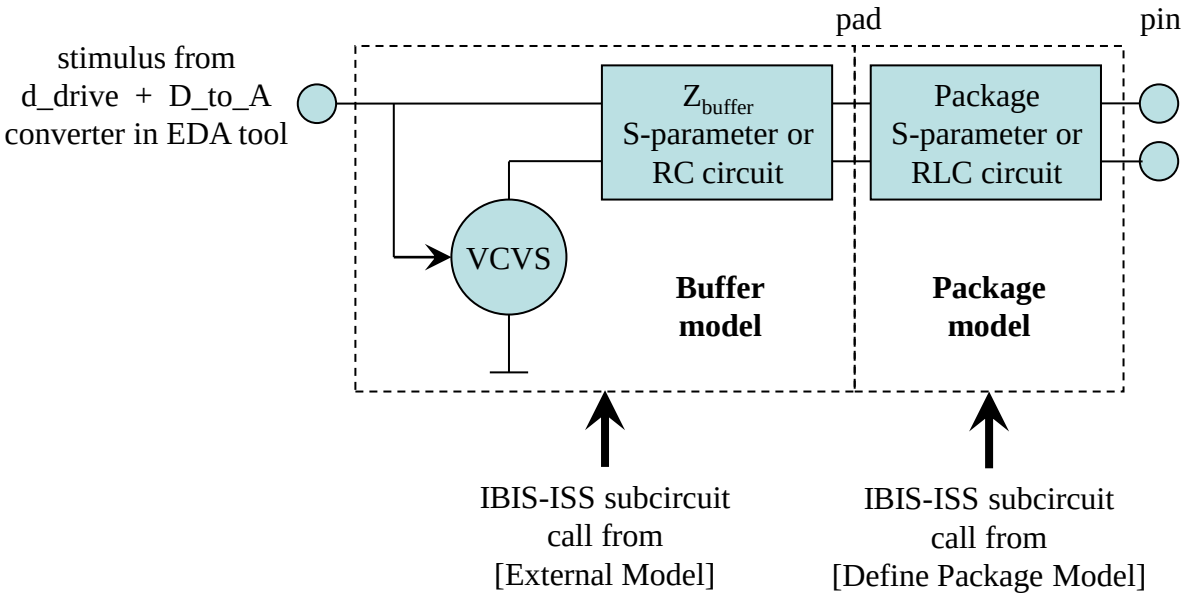


Figure 11: Example SPICE, Verilog-A(MS) or VHDL-A(MS) implementation of a true differential buffer

Analog IBIS model for AMI with [External Model]



- **Swing and edge rate of D_to_A converter can define the ideal source parameters**
  - an additional E-element is needed inside the IBIS-ISS subcircuit to generate inverted stimulus
- **Sweeps of amplitude, edge rate and impedance may be accomplished by**
  - using [Model Selector] and multiple [Model]s with hard coded D_to_A converter parameters (vlow, vhigh, trise, tfall) and S-parameter file names (or RC values) in the IBIS-ISS subcircuits, or
  - using a single [External Model] with parameterized D_to_A converters and S-parameter file names (or RC values) in the IBIS-ISS subcircuits
    - the latter are new features for IBIS which are being proposed in BIRD 117 and BIRD 118
- **The AMI Dependency Table of BIRD 119 is only a tool GUI exercise in addition to the above**
  - multi-valued AMI parameters will need a GUI anyway to let the user select “one of many”
  - the Dependency Table is just a controlling mechanism for this GUI to enforce selection rules

BIRD-s needed to make this work

- add IBIS-ISS to [External ***] “Language” subparameter
  - done (BIRD 116)

- parameterize the A/D and D/A converters of [External ***] using a new IBIS subparameter called “Converter_Parameters” under [External ***]
  - done (BIRD 117)

- allow assignments to be made in “Parameters” list under [External ***] from parameters in the .ami file which is defined in the [Algorithmic Model] keyword
  - done (BIRD 118)

- may need a BIRD to create one or more reserved analog port names for the output of Rx to be able to make it available for AMI usage
  - this depends on the meaning of the triangle symbols in the circuit diagrams of the analog buffer models of BIRD 119
  - http://www.eda.org/ibis/birds/bird119/bird119.pdf (pg. 7, 9)

- Dependency Tables are only a GUI implementation exercise

- make IBIS-ISS available for accurate package modeling in IBIS while keeping the flexibility already present through the [Alternate Package Models] and [Model Selector] keywords
  - done (BIRD 125)

Illustrating BIRD 119 RC Tx model with [External Model] & IBIS-ISS

```
|------------------------------------------------------------------
| Example of an analog AMI Tx model using [External Model] and
| an IBIS-ISS circuit:
|------------------------------------------------------------------
|
[Model] ISS_Diff_Tx
Model_type Output_diff
Rref_diff = 100
|
| Other model subparameters are optional
|
| typ min max
[Voltage Range] 1.0  NA  NA
|
[Ramp]
dV/dt_r  0.2/0.08n  0.2/0.08n  0.2/0.08n
dV/dt_f  0.2/0.08n  0.2/0.08n  0.2/0.08n
|
|
[External Model]
Language ISS
|
| Corner corner_name file_name circuit_name (.subckt name)
Corner    Typ         AMIdriver.cir   AMI_RCdrv
|
| List of parameters
Parameters  Voh_H  Voh_L = AMIfile(Voh)
Parameters  Vol_H  Vol_L = AMIfile(Vol)
Parameters  Rs_H  Rs_L   = AMIfile(Rs)
Parameters  Rt_H  Rt_L  Rd
Parameters  Cc_H  Cc_L   = AMIfile(Cc)
Parameters  Cd  Vt
|
| List of converter parameters
Converter_Parameters  Vlo = -0.5
Converter_Parameters  Vhi =  0.5
Converter_Parameters  Tfa =  AMIfile(Trf)
Converter_Parameters  Tri =  AMIfile(Trf)
|
| Ports List of port names (in same order as in SPICE)
Ports  A_signal_pos  A_signal_neg  my_drive
Ports  A_puref  A_pdref  my_ref
|
| D_to_A d_port port1 port2 vlow vhigh trise tfall corner_name
D_to_A  D_drive  my_drive  my_ref  Vlo  Vhi  Tfa  Tri  Typ
|
[End External Model]
|
[Algorithmic Model]
Executable  Windows_VisualStudio_32  MentorTx.dll  MentorTx.ami
[End Algorithmic Model]
```

The MentorTx.ami file must contain:

```
(Voh (Usage Info)(Value 0.9)(Type Float)
   (Description "Output open circuit high voltage")
)
(Vol (Usage Info)(Value 0.0)(Type Float)
   (Description "Output open circuit low voltage")
)
(Trf (Usage Info)(Value 40e-12)(Type Float)
   (Description "20%-80% output rise time")
)
(Rs (Usage Info)(Value 47.75)(Type Float)
   (Description "Single-ended output resistance")
)
(Cc (Usage Info)(Value 0.5e-12)(Type Float)(Default 0.5e-12)
   (Description "Output Capacitance")
)
```

```
*******************************************************************************
.SUBCKT  AMI_RCdrv  A_signal_pos  A_signal_neg  my_drive  A_puref  A_pdref  my_ref
+ Voh_H = 1
+ Voh_L = 1
+ Vol_H = 0
+ Vol_L = 0
+ Rs_H  = 1
+ Rs_L  = 1
+ Rt_H  = 1e+6
+ Rt_L  = 1e+6
+ Rd    = 1e+6
+ Cc_H  = 0
+ Cc_L  = 0
+ Cd    = 0
+ Vt    = 0

Evtt     my_vtt      A_pdref  VCVS  A_puref  A_pdref  'Vt'
Edc_H    dc_H        A_pdref  VCVS  A_puref  A_pdref  '(Voh_H+Vol_H)/2'
Egain_H  my_drive_H  dc_H     VCVS  my_drive  my_ref   '(Voh_H-Vol_H)'
Edc_L    dc_L        A_pdref  VCVS  A_puref  A_pdref  '(Voh_L+Vol_L)/2'
Egain_L  my_drive_L  dc_L     VCVS  my_drive  my_ref   '(Vol_L-Voh_L)'

Rs_H  my_drive_H    A_signal_pos  R=Rs_H
Rs_L  my_drive_L    A_signal_neg  R=Rs_L
Rd    A_signal_pos  A_signal_neg  R=Rd
Rt_H  A_signal_pos  my_vtt        R=Rt_H
Rt_L  A_signal_neg  my_vtt        R=Rt_L
Cd    A_signal_pos  A_signal_neg  C=Cd
Cc_H  A_signal_pos  my_ref        C=Cc_H
Cc_L  A_signal_neg  my_ref        C=Cc_L

*******************************************************************************
.ends
```

Illustrating BIRD 119 S-parameter Tx model with [External Model] & IBIS-ISS

```
|-----------------------------------------------------------------
| Example of an analog AMI Tx model using [External Model] and
| an IBIS-ISS S-parameter:
|-----------------------------------------------------------------
|
[Model] ISS_Diff_Tx
Model_type Output_diff
Rref_diff = 100
|
| Other model subparameters are optional
|
| typ min max
[Voltage Range] 1.0  NA  NA
|
[Ramp]
dV/dt_r  0.2/0.08n  0.2/0.08n  0.2/0.08n
dV/dt_f  0.2/0.08n  0.2/0.08n  0.2/0.08n
|
|
[External Model]
Language ISS
|
| Corner corner_name file_name circuit_name (.subckt name)
Corner    Typ         AMIdriver.cir   AMI_Sdrv
|
| List of parameters
Parameters  TSFile = AMIfile(Tstonefile)
Parameters  Voh_H  Voh_L = AMIfile(Voh)
Parameters  Vol_H  Vol_L = AMIfile(Vol)
|
| List of converter parameters
Converter_Parameters  Vlo = -0.5
Converter_Parameters  Vhi =  0.5
Converter_Parameters  Tfa =  AMIfile(Trf)
Converter_Parameters  Tri =  AMIfile(Trf)
|
| Ports List of port names (in same order as in SPICE)
Ports  A_signal_pos  A_signal_neg  my_drive
Ports  A_puref  A_pdref  my_ref
|
| D_to_A d_port port1 port2 vlow vhigh trise tfall corner_name
D_to_A  D_drive  my_drive  my_ref  Vlo  Vhi  Tfa  Tri  Typ
|
[End External Model]
|
[Algorithmic Model]
Executable  Windows_VisualStudio_32  MentorTx.dll  MentorTx.ami
[End Algorithmic Model]
```

The MentorTx.ami file must contain:

```
(Tstonefile (Usage Info)(Type String)
   (Corner "NC.s4p" "WC.s4p" "BC.s4p")
   (Description "Driver on-die S-parameter file")
)
(Voh (Usage Info)(Value 0.9)(Type Float)
   (Description "Output open circuit high voltage")
)
(Vol (Usage Info)(Value 0.0)(Type Float)
   (Description "Output open circuit low voltage")
)
(Trf (Usage Info)(Value 40e-12)(Type Float)
   (Description "20%-80% output rise time")
)
```

```
*******************************************************************************
.SUBCKT  AMI_Sdrv  A_signal_pos  A_signal_neg  my_drive  A_puref  A_pdref  my_ref
+ TSFile="TouchstoneFileName.s4p"
+ Voh_H = 1
+ Voh_L = 1
+ Vol_H = 0
+ Vol_L = 0

Edc_H    dc_H        A_pdref  VCVS  A_puref  A_pdref  '(Voh_H+Vol_H)/2'
Egain_H  my_drive_H  dc_H     VCVS  my_drive  my_ref  '(Voh_H-Vol_H)'
Edc_L    dc_L        A_pdref  VCVS  A_puref  A_pdref  '(Voh_L+Vol_L)/2'
Egain_L  my_drive_L  dc_L     VCVS  my_drive  my_ref  '(Vol_L-Voh_L)'

Sdriver  my_drive_H  A_signal_pos  my_drive_L  A_signal_neg
+ MNAME=TSFile
+ [FBASE = base_frequency] [FMAX=maximum_frequency]

*******************************************************************************
.ends
```

Illustrating BIRD 119 RC Rx model with [External Model] & IBIS-ISS

```
|------------------------------------------------------------------
| Example of an analog AMI Rx model using [External Model] and
| an IBIS-ISS circuit:
|------------------------------------------------------------------
|
[Model] ISS_Diff_Rx
Model_type Input_diff
|
| Other model subparameters are optional
|
| typ min max
[Voltage Range] 1.0  NA  NA
|
|
[External Model]
Language ISS
|
| Corner corner_name file_name circuit_name (.subckt name)
Corner    Typ         AMIreceiver.cir   AMI_RCrcv
|
| List of parameters
Parameters  Voh_H  Voh_L = AMIfile(Voh)
Parameters  Vol_H  Vol_L = AMIfile(Vol)
Parameters  Rt_H  Rt_L   = AMIfile(Rt)
Parameters  Rd           = AMIfile(Rd)
Parameters  Cc_H  Cc_L   = AMIfile(Cc)
Parameters  Cd  Vt
|
| List of converter parameters
Converter_Parameters  Vlo = -0.05
Converter_Parameters  Vhi =  0.05
|
| Ports List of port names (in same order as in SPICE)
Ports  A_signal_pos  A_signal_neg  my_rcv_H  my_rcv_L  my_rcv_D
Ports  A_puref  A_pdref  my_ref
|
| D_to_A d_port port1 port2 vlow vhigh corner_name
A_to_D  D_receive  my_rcv_H  my_rcv_L  Vlo  Vhi  Typ
|A_to_D  D_receive  A_signal_pos  A_signal_neg  Vlo  Vhi  Typ
|
[End External Model]
|
[Algorithmic Model]
Executable  Windows_VisualStudio_32  MentorTx.dll  MentorRx.ami
[End Algorithmic Model]
```

The MentorRx.ami file must contain:

```
(Voh (Usage Info)(Value 0.9)(Type Float)
   (Description "Output open circuit high voltage")
)
(Vol (Usage Info)(Value 0.0)(Type Float)
   (Description "Output open circuit low voltage")
)
(Trf (Usage Info)(Value 40e-12)(Type Float)
   (Description "20%-80% output rise time")
)
(Rt (Usage Info)(Value 47.75)(Type Float)
   (Description "Single-ended termination resistance")
)
(Rd (Usage Info)(Value 99.75)(Type Float)
   (Description "Differential termination resistance")
)
(Cc (Usage Info)(Value 0.5e-12)(Type Float)(Default 0.5e-12)
   (Description "Input Capacitance")
)
```

```
*******************************************************************************
.SUBCKT  AMI_RCrcv  A_signal_pos  A_signal_neg  my_rcv_H  my_rcv_L  my_rcv_D
+  A_puref  A_pdref  my_ref
+ Voh_H = 1
+ Voh_L = 1
+ Vol_H = 0
+ Vol_L = 0
+ Rt_H  = 1e+6
+ Rt_L  = 1e+6
+ Rd    = 1e+6
+ Cc_H  = 0
+ Cc_L  = 0
+ Cd    = 0
+ Vt    = 0

Cc_H  A_signal_pos  my_ref        C=Cc_H
Cc_L  A_signal_neg  my_ref        C=Cc_L
Cd    A_signal_pos  A_signal_neg  C=Cd
Rt_H  A_signal_pos  my_vtt        R=Rt_H
Rt_L  A_signal_neg  my_vtt        R=Rt_L
Rd    A_signal_pos  A_signal_neg  R=Rd

Evtt     my_vtt  A_pdref  VCVS  A_puref  A_pdref  'Vt'
Egain_H  my_rcv_H  my_ref    VCVS  A_signal_pos  A_pdref  '(Voh_H-Vol_H)'
Egain_L  my_rcv_L  my_ref    VCVS  A_signal_neg  A_pdref  '(Vol_L-Voh_L)'
Egain_D  my_rcv_D  my_rcv_H  VCVS  A_signal_neg  A_pdref  '(Vol_L-Voh_L)'

*******************************************************************************
.ends
```

Parameter assignment mechanism and Dependency Table

- **The "Parameters" and/or "Converter_Parameters" subparameters in the IBIS [Model] may be linked with parameters in the .ami file that is defined under the [Algorithmic Model] keyword inside the same [Model]**
  - syntax: `Parameters ParamName = AMIfile(AMIparamName)`
    `Converter_Parameters ParamName = AMIfile(AMIparamName)`
    where "`AMIfile()`" is a reserved word to indicate the linkage to the .ami file specified under the [Algorithmic Model] keyword
    and "`AMIparamName`" inside the parentheses must match a parameter name inside the .ami file that is specified under the [Algorithmic Model] keyword
- **Multiple `ParamName`-s are allowed on the same line if they are assigned the value from the same AMI parameter**
- **The assignment is not required; if the assignment is not present, the default values on the ISS subcircuit definition line will be in effect**
- **If the AMI parameter is a single valued parameter, the assignment can be made directly without using a tool GUI**
- **If the AMI parameter is multi-valued parameter, either the default value should be used in the assignment, or the EDA tool should provide a GUI for the user to make the selection**
- **Since the AMI Dependency Table is essentially a selection constraint for the allowable assignments, it should be implemented in the parameter editor GUI of the EDA tool, so that the user's selections are governed by the content of the Dependency Table**

Package modeling with IBIS-ISS (a simple example)

```
|-------------------------------------------------------------
| Example of an IBIS model using an IBIS-ISS package model
|-------------------------------------------------------------
|
[Pin] signal_name  model_name
  1   Channel_1P   ISS_Diff_Tx
  2   Channel_1N   ISS_Diff_Tx
  3   Channel_2P   ISS_Diff_Tx
  4   Channel_2N   ISS_Diff_Tx
|
[Package Model]  A_4_pin_pkg_model
|
|…
|…
```

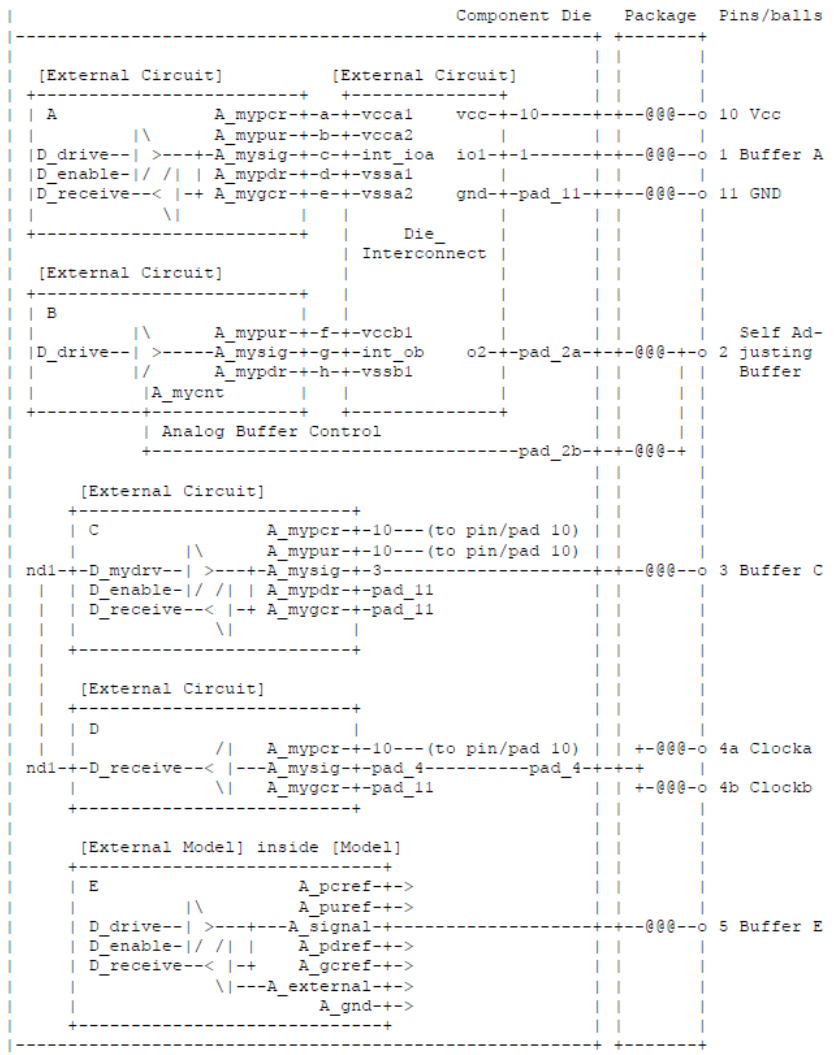
```
|-------------------------------------------------------------
| This example implements a package model using an IBIS-ISS
| subcircuit.
|-------------------------------------------------------------
|
[Define Package Model]  A_4_pin_pkg_model
[Manufacturer]          Noname Company, Inc.
[OEM]                   Another Noname Package Company, Inc.
[Description]           4-pin illustration package model
[Number Of Pins]  4
|
[Pin Numbers]
  1   DiePort = IDiePort_1
  2   DiePort = IDiePort_2
  3   DiePort = IDiePort_3
  4   DiePort = IDiePort_4
|
[Package Circuit]
Language IBIS-ISS
|
| Corner corner_name file_name circuit_name (.subckt name)
Corner  Typ  PackageModel.spi  S_pkg
|
| Parameters List of parameters
Parameters  TSFile = "My_TstoneFile.s8p"
|
| Ports are in same order as defined in SPICE
Ports  1           2           3           4
Ports  IDiePort_4  IDiePort_3  IDiePort_2  IDiePort_1
|
[End Package Circuit]
[End Package Model]
```

```
**************************************************************
.SUBCKT  S_pkg  P1  P2  P3  P4  P5  P6  P7  P8
+ TSFile="TouchstoneFileName.s8p"

Sdriver  P1  P2  P3  P4  P5  P6  P7  P8
+ MNAME=TSFile
+ [FBASE = base_frequency] [FMAX=maximum_frequency]

**************************************************************
.ends
```

IBIS v5.0 Specification - pg. 136, Fig. 12



Package modeling with IBIS-ISS (IBIS pg. 136, Fig. 12 implementation)

```
|------------------------------------------------------------
| Example of an IBIS model using an IBIS-ISS package model.
| This example implements a package call for the drawing in
| Fig. 12 on pg. 136 of the IBIS v5.0 specification.
|------------------------------------------------------------
|
[Pin] signal_name  model_name
 10   Vcc          POWER
  1   A0           CIRCUITCALL
 11   GND          GND
  2   CAS0         CIRCUITCALL
  3   A1           CIRCUITCALL
  4a  Clk_A        CIRCUITCALL
  4b  Clk_B        CIRCUITCALL
  5   A2           Buffer_E
|
[Node Declarations]
| Die nodes:
a  b  c  d  e  f  g  h  nd1    | List of die nodes
|
| Die pads:
pad_2a  pad_2b  pad_4  pad_11  | List of die pads
|
[End Node Declarations]
|
[Package Model]  QS-SMT-cer-8-pin-pkgs
|
|…
|…
```

```
**************************************************************
.SUBCKT  S_pkg  P1  P2   P3   P4   P5   P6   P7   P8
+               P9  P10  P11  P12  P13  P14  P15  P16
+ TSFile="TouchstoneFileName.s16p"

Sdriver  P1  P2   P3   P4   P5   P6   P7   P8
+        P9  P10  P11  P12  P13  P14  P15  P16
+ MNAME=TSFile
+ [FBASE = base_frequency] [FMAX=maximum_frequency]

**************************************************************
.ends
```

```
|------------------------------------------------------------
| This example implements a package model using an IBIS-ISS
| subcircuit for the drawing in Fig. 12 on pg. 136 of the
| IBIS v5.0 specification.
|------------------------------------------------------------
|
[Define Package Model]  QS-SMT-cer-8-pin-pkgs
[Manufacturer]          Quality Semiconductors Ltd.
[OEM]                   Acme Package Co.
[Description]           8-Pin ceramic SMT package
[Number Of Pins]  8
|
[Pin Numbers]
 10   DiePort = IDiePort_10
  1   DiePort = IDiePort_1
 11   DiePort = pad_11
  2   DiePort = pad_2a
  2   DiePort = pad_2b
  3   DiePort = IDiePort_3
  4a  DiePort = pad_4
  4b  DiePort = pad_4
  5   DiePort = IDiePort_5
|
[Package Circuit]
Language IBIS-ISS
|
| Corner corner_name file_name circuit_name (.subckt name)
Corner  Typ  PackageModel.spi  S_pkg
|
| Parameters List of parameters
Parameters  TSFile = "My_TstoneFile.s16p"
|
| Ports are in same order as defined in SPICE
Ports  10  1  11  2  3  4a  4b  5
Ports  IDiePort_5  pad_4  IDiePort_3  pad_2b
Ports  pad_2a      pad_11  IDiePort_1  IDiePort_10
|
[End Package Circuit]
[End Package Model]
```