

How to Make Good EMD Models

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General Overview

- The **IBIS v7.1 specification** introduced a major improvement for multi-die package and multi-chip module modeling
- The new capability is known as **Electrical Module Description (EMD)** modeling which was proposed in **BIRD202.3**
 - <https://www.ibis.org/birds/bird202.3.docx>
 - EMD is functionally very similar to EBD in the IBIS specification, with significant improvements
 - **Supports SPICE subcircuits and Touchstone files** (with or without coupling)
 - **Supports signal only, power delivery only, or combined signal and power delivery modeling**
- EMD can be used to model the “package” of stacked-die or multi-chip devices as well as the PCB of DIMM modules and other plug-in boards
- EMD models can be nested (i.e., reference other EMD models)
 - Up to six levels of hierarchy for nested .emd files are supported

The anatomy of EMD files

- The header section
 - [IBIS Ver], [File Name], [File Rev], [Date] , [Source], [Disclaimer], [Copyright], [Notes]
- [Begin EMD] / [End EMD]
 - [Manufacturer], [Description], [Number Of EMD Pins], [EMD Pin List], [EMD Parts], [EMD Designator List], [Designator Pin List], [Voltage List], [EMD Group]
- [EMD Set] / [End EMD Set]
 - [Manufacturer], [Description]
 - [EMD Model]

EMD Model

- Contains a pointer to a Touchstone or IBIS-ISS (SPICE subcircuit) file
- Contains as many “terminal lines” as the number of ports (+1) or subcircuit terminals
- Unused ports for Touchstone files are supported with three pre-defined automatic termination options
- The terminal lines define the type of the port or terminal (signal or power rail) and what they are connected to (EMD pin or Designator pin)
- These connection definitions can use signal names or bus label names to make connections to groups of pins

What do we need to make an EMD file?

- One or more Touchstone or IBIS-ISS (SPICE subcircuit) files
 - These files contain the interconnect models which connect the EMD pins with the “Designator Pins”, i.e., the pins of the IBIS files
 - They may contain signals only, power delivery network (PDN) only, or both
- One or more IBIS files
 - These files contain the buffer models
 - They may be bare-die models (e.g., for MCMs) or packaged models (e.g., for DIMMs)
- Pin list and signal names for the EMD model
 - These are the pins which connect the EMD model with the outside world
 - These pin names and signal names should match the corresponding names in the data sheet
 - The EMD signal names do not need to match with the signal names inside the IBIS file
- Information about what the Touchstone ports or SPICE terminals are connected to
 - Connections can only be made to EMD pins or Designator pins

Notes on power aware modeling

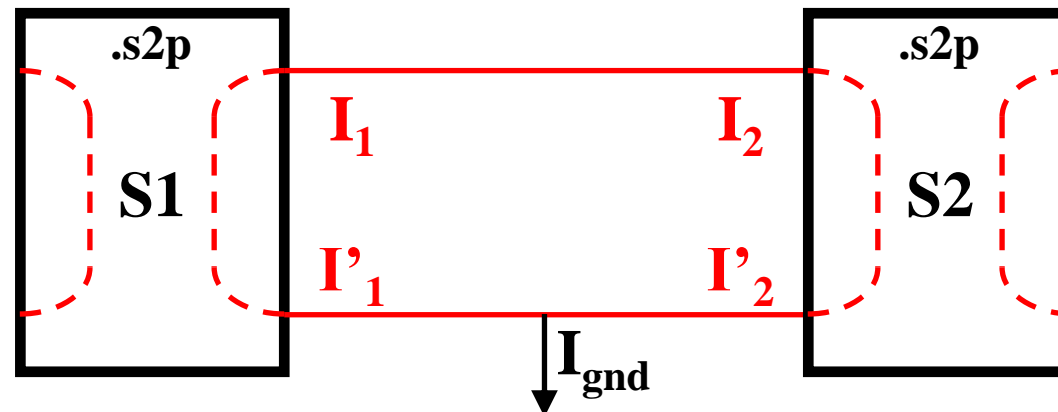
- A power-aware IBIS model must contain the following keywords
 - [ISSO PU], [ISSO PD], [Composite Current] (in the scope of a [Model] keyword)
 - [Pin Mapping] (in the scope of a [Component] keyword)
- If the EMD file contains non-power-aware IBIS model(s)
 - It is useless to include PDN models in the EMD file
 - It is not prohibited, but doesn't do any good
 - Simulators will most likely power the buffer models with ideal sources
- If the EMD file contains power-aware IBIS model(s)
 - All **power and ground** pins should be included in [EMD Pin List]
 - All **power and ground** pins should be included in [Designator Pin List]
 - Connectivity between **all power and ground** pins should be defined in [EMD Model]
 - This may be done using individual pin names, signal names, or bus label names
 - Try **not** to use A_gnd (the IBIS equivalent of the SPICE node 0) for ground connections

The Touchstone reference terminal problem

Consider two cascaded 2-port Touchstone models

- $I_1 = I_2$
- From “port regularity” $I'_1 = I_1$ and $I'_2 = I_2$
- Consequently $I'_1 = I'_2$, and
- $I_{\text{gnd}} = 0$
- Hence adding a connection to ground doesn't change the port voltages and currents, it may only affect their absolute potential

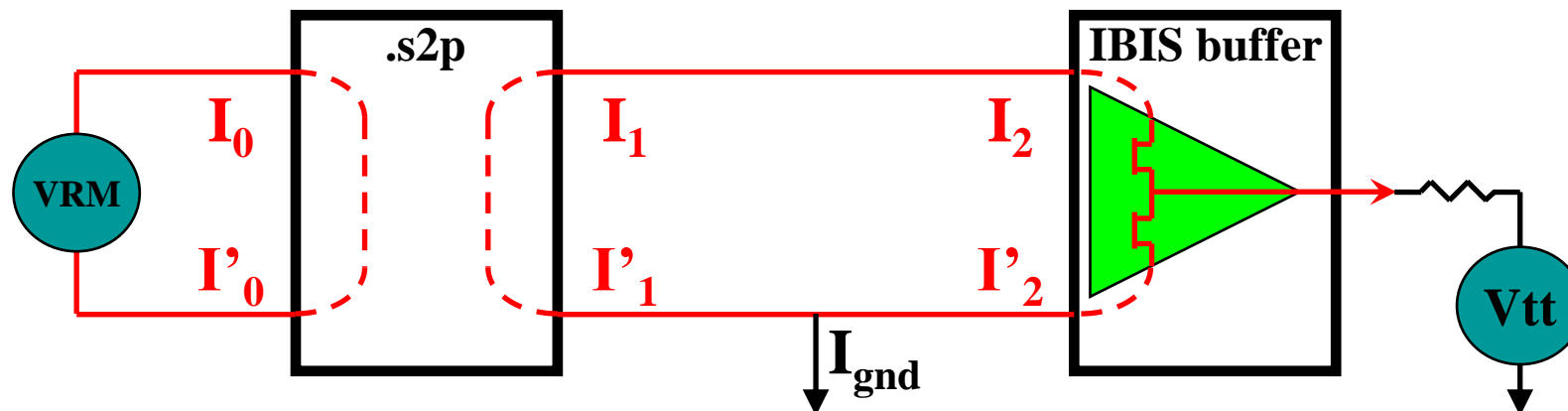
<https://www.ibis.org/summits/feb18/dmitriev-zdorov.pdf> (slide 8)



The Touchstone reference terminal problem (cont'd)

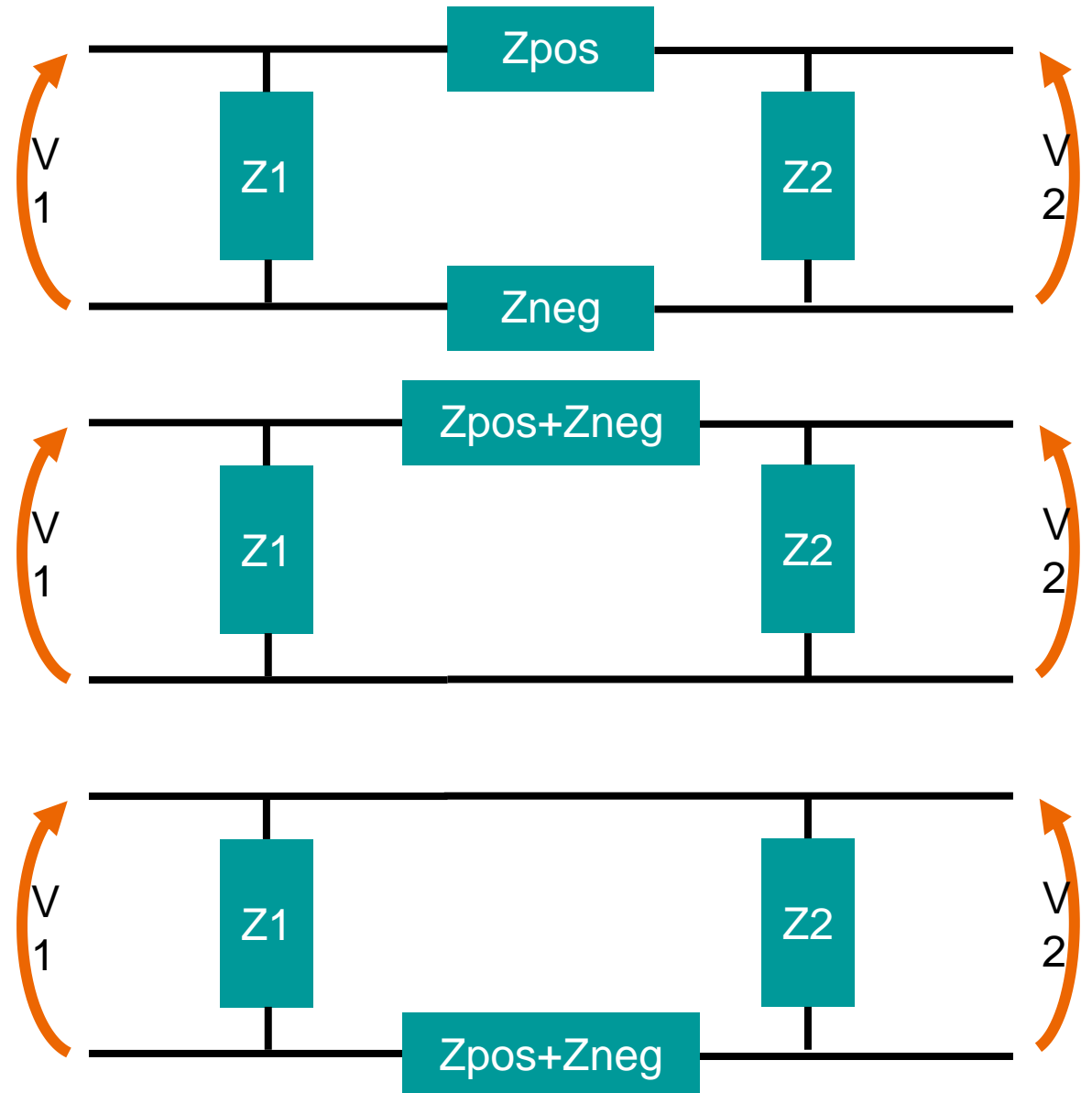
Now consider a simple 2-port Touchstone PDN model for a motherboard (.s2p)

- One of the ports is connected to the voltage regulator (VRM)
- The other port is connected to the integrated circuit (IBIS buffer)
- The S-parameter model describes the full PDN loop, i.e., includes the power and ground planes
- Since the IBIS buffer is a 3-terminal device, $I'_2 \neq I_2$, consequently $I_{\text{gnd}} \neq 0$
 - When the buffer is driving 'high': $I_{\text{gnd}} = I'_1 = I_1 = I_2 = I_{\text{Vtt}}$ and $I'_2 = 0$
 - When the buffer is driving 'low': $I'_1 = I_1 = I_2 = 0$ and $I'_2 = I_{\text{gnd}} = I_{\text{Vtt}}$
- This violates the fundamentals of S-parameters
- The PDN model will have no effect on the signal when driving low and will have “double” the effect when driving high (because it includes both the power **and** ground planes)



Double-counted path

- When “Ground” net is used as the negative terminal, its effect on the circuit is pushed to the positive terminal
- S matrices are the same in these 3 cases
- Impedance, and hence voltage, between negative terminals of the 2 ports is not equal
- Impedance between positive terminals of the 2 ports is not equal



More on referencing in EMD files

- When using power-aware IBIS model(s) with one or more PDN models, **all** of the power and ground pins of the IBIS model(s) must be properly connected
- It is also important to include **all** of the power and ground pins of the EMD model in the [EMD Pin List] keyword and connect them to the corresponding ports of the PDN model(s)
- How should the S-parameter reference terminals be connected?
- Note: The EMD specification only supports a single reference terminal (N+1) for Touchstone models

S-parameter examples

- The next two examples illustrate common mistakes which result in bad EMD files
- The 3rd example illustrates an acceptable (but not the best) way to define ground connections
- The 4th example illustrates the best way to define the ground connections

- Note: In these examples the S-parameter model does not include explicit ports for the ground plane(s) of the PCB

- The 5th example might be the most ideal method because it has explicit ports for the ground net

Example 1 - Missing ground pin connections on both sides of the Touchstone model wrong

```
! PORT 1      (PIN U1.R94, A0, S)
! PORT 2      (PIN U2.R94, A0, S)
! PORT 3      (PIN U3.R94, A0, S)
! PORT 4      (PIN U4.L94, A0, S)
! PORT 5      (PIN U5.L94, A0, S)
! PORT 6      (PIN BGA.K2, A0, S)

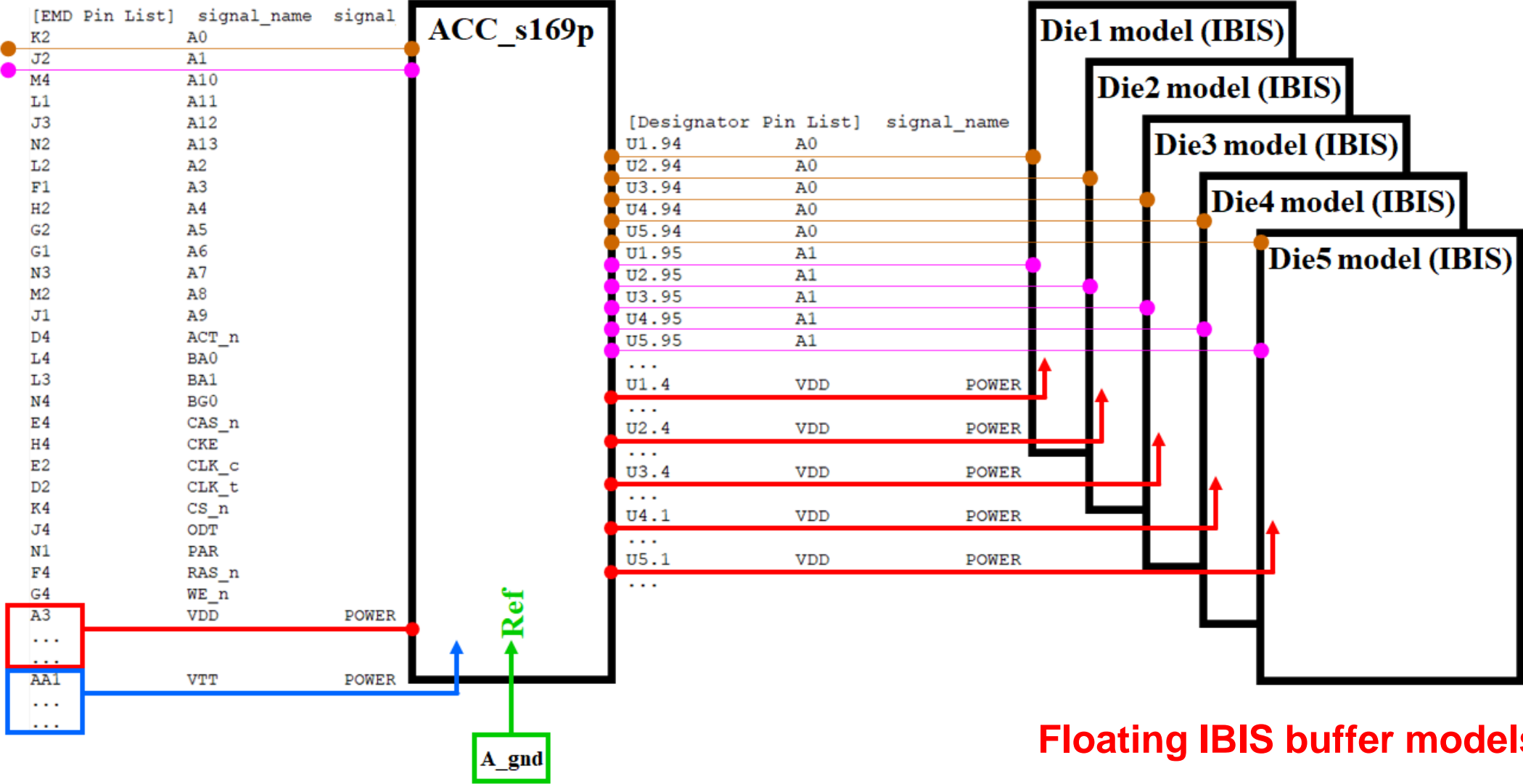
! PORT 7      (PIN U1.R95, A1, S)
! PORT 8      (PIN U2.R95, A1, S)
! PORT 9      (PIN U3.R95, A1, S)
! PORT 10     (PIN U4.L95, A1, S)
! PORT 11     (PIN U5.L95, A1, S)
! PORT 12     (PIN BGA.J2, A1, S)

! PORT 163    (GROUP:VDD.U1, VDD, P)
! PORT 164    (GROUP:VDD.U2, VDD, P)
! PORT 165    (GROUP:VDD.U3, VDD, P)
! PORT 166    (GROUP:VDD.U4, VDD, P)
! PORT 167    (GROUP:VDD.U5, VDD, P)
! PORT 168    (GROUP:VDD.BGA, VDD, P)
! PORT 169    (GROUP:VTT.BGA, VTT, P)

! GROUP PORT 163 NAME:VDD.U1, U1.L4, U1.L8, U1.L17, U1.L20, U1.L33, U1.L36, U1.L40, U1.L45, U1.L49, U1.L52, ...
! GROUP PORT 164 NAME:VDD.U2, U2.L4, U2.L8, U2.L17, U2.L20, U2.L33, U2.L36, U2.L40, U2.L45, U2.L49, U2.L52, ...
! GROUP PORT 165 NAME:VDD.U3, U3.L4, U3.L8, U3.L17, U3.L20, U3.L33, U3.L36, U3.L40, U3.L45, U3.L49, U3.L52, ...
! GROUP PORT 166 NAME:VDD.U4, U4.L1, U4.L13, U4.L16, U4.L25, U4.L30, U4.L48, U4.R4, U4.R8, U4.R17, U4.R20, ...
! GROUP PORT 167 NAME:VDD.U5, U5.L1, U5.L13, U5.L16, U5.L25, U5.L30, U5.L48, U5.R4, U5.R8, U5.R17, U5.R20, ...
! GROUP PORT 168 NAME:VDD.BGA, BGA.A3, BGA.A4, BGA.A7, BGA.AB5, BGA.AB9, BGA.AB11, BGA.AB13, BGA.AC7, BGA.B1, BGA.B5, ...
! GROUP PORT 169 NAME:VTT.BGA, BGA.AA1, BGA.AA2, BGA.AA3, BGA.AA4, BGA.AB1, BGA.AB2, BGA.AB3, BGA.AB4, BGA.AC2, BGA.AC3, ...
```



Example 1 - Missing ground pin connections on both sides of the Touchstone model wrong



Example 2 - Missing ground pin connections on the IBIS side wrong

```
! PORT 1 (PIN U1.R94, A0, S)
! PORT 2 (PIN U2.R94, A0, S)
! PORT 3 (PIN U3.R94, A0, S)
! PORT 4 (PIN U4.L94, A0, S)
! PORT 5 (PIN U5.L94, A0, S)
! PORT 6 (PIN BGA.K2, A0, S) - (GROUP:GND.BGA, GND, P)

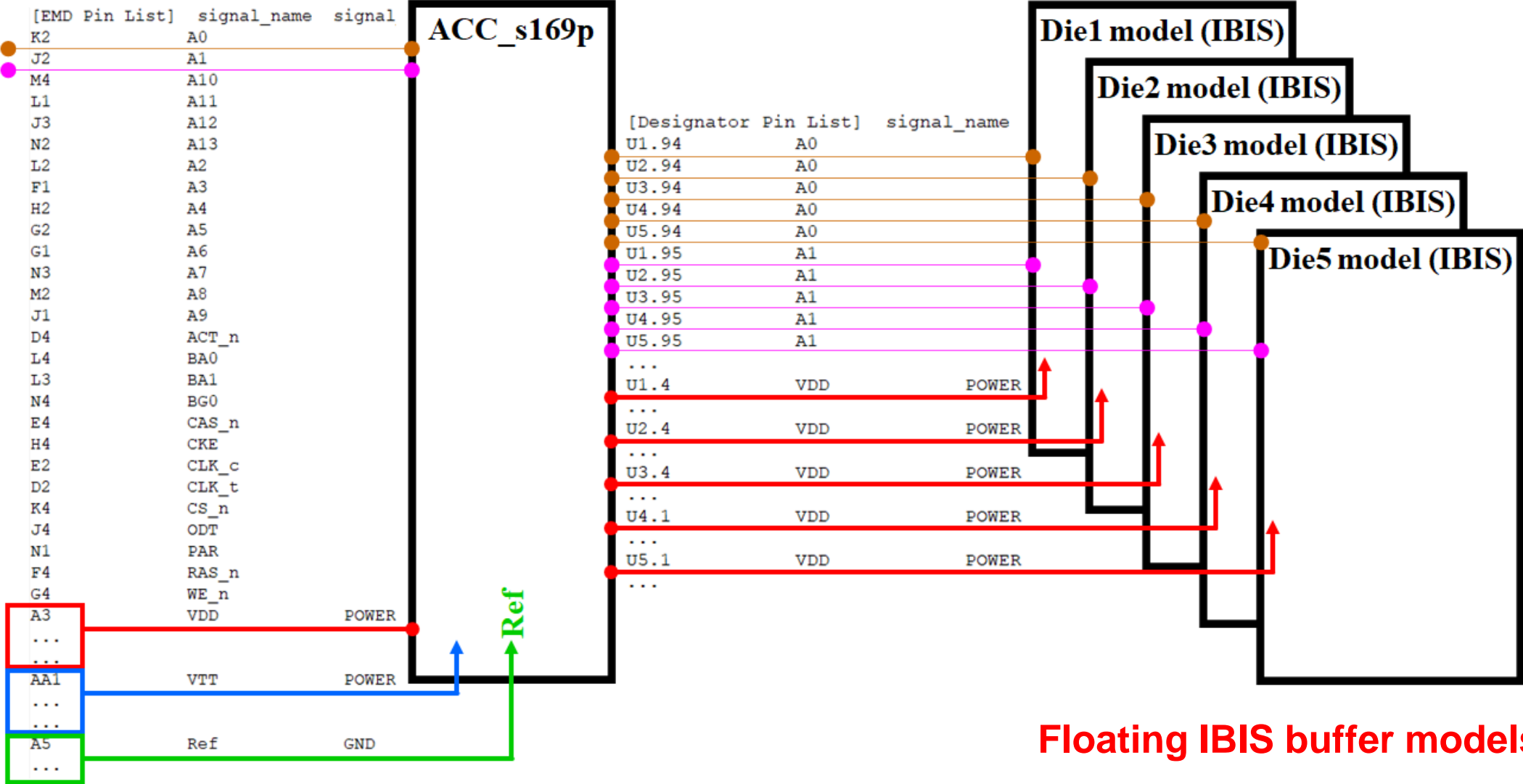
! PORT 7 (PIN U1.R95, A1, S)
! PORT 8 (PIN U2.R95, A1, S)
! PORT 9 (PIN U3.R95, A1, S)
! PORT 10 (PIN U4.L95, A1, S)
! PORT 11 (PIN U5.L95, A1, S)
! PORT 12 (PIN BGA.J2, A1, S) - (GROUP:GND.BGA, GND, P)

! PORT 163 (GROUP:VDD.U1, VDD, P)
! PORT 164 (GROUP:VDD.U2, VDD, P)
! PORT 165 (GROUP:VDD.U3, VDD, P)
! PORT 166 (GROUP:VDD.U4, VDD, P)
! PORT 167 (GROUP:VDD.U5, VDD, P)
! PORT 168 (GROUP:VDD.BGA, VDD, P) - (GROUP:GND.BGA, GND, P)
! PORT 169 (GROUP:VTT.BGA, VTT, P) - (GROUP:GND.BGA, GND, P)

! GROUP PORT 6 NAME:GND.BGA, BGA.A5, BGA.A9, BGA.A11, BGA.A14, BGA.AA5, BGA.AA13, BGA.AC5, BGA.AC9, BGA.AC11, BGA.AC14, BGA.B2, BGA.C1, BGA.C4, ...
! GROUP PORT 12 NAME:GND.BGA, BGA.A5, BGA.A9, BGA.A11, BGA.A14, BGA.AA5, BGA.AA13, BGA.AC5, BGA.AC9, BGA.AC11, BGA.AC14, BGA.B2, BGA.C1, BGA.C4, ...

! GROUP PORT 163 NAME:VDD.U1, U1.L4, U1.L8, U1.L17, U1.L20, U1.L33, U1.L36, U1.L40, U1.L45, U1.L49, U1.L52, U1.L57, U1.L62, ...
! GROUP PORT 164 NAME:VDD.U2, U2.L4, U2.L8, U2.L17, U2.L20, U2.L33, U2.L36, U2.L40, U2.L45, U2.L49, U2.L52, U2.L57, U2.L62, ...
! GROUP PORT 165 NAME:VDD.U3, U3.L4, U3.L8, U3.L17, U3.L20, U3.L33, U3.L36, U3.L40, U3.L45, U3.L49, U3.L52, U3.L57, U3.L62, ...
! GROUP PORT 166 NAME:VDD.U4, U4.L1, U4.L13, U4.L16, U4.L25, U4.L30, U4.L48, U4.R4, U4.R8, U4.R17, U4.R20, U4.R33, U4.R36, ...
! GROUP PORT 167 NAME:VDD.U5, U5.L1, U5.L13, U5.L16, U5.L25, U5.L30, U5.L48, U5.R4, U5.R8, U5.R17, U5.R20, U5.R33, U5.R36, ...
! GROUP PORT 168 NAME:VDD.BGA, BGA.A3, BGA.A4, BGA.A7, BGA.AB5, BGA.AB9, BGA.AB11, BGA.AB13, BGA.AC7, BGA.B1, BGA.B5, BGA.B9, BGA.B11, ...
! GROUP PORT 168 NAME:GND.BGA, BGA.A5, BGA.A9, BGA.A11, BGA.A14, BGA.AA5, BGA.AA13, BGA.AC5, BGA.AC9, BGA.AC11, BGA.AC14, BGA.B2, BGA.C1, ...
! GROUP PORT 169 NAME:VTT.BGA, BGA.AA1, BGA.AA2, BGA.AA3, BGA.AA4, BGA.AB1, BGA.AB2, BGA.AB3, BGA.AB4, BGA.AC2, BGA.AC3, BGA.AC4
! GROUP PORT 169 NAME:GND.BGA, BGA.A5, BGA.A9, BGA.A11, BGA.A14, BGA.AA5, BGA.AA13, BGA.AC5, GA.AC9, BGA.AC11, BGA.AC14, BGA.B2, BGA.C1, ...
```

Example 2 - Missing ground pin connections on the IBIS side wrong



Floating IBIS buffer models!

Example 3 - Missing ground pins on the EMD side with grounded IBIS side (better)

```
! PORT 1 (PIN U1.R94, A0, S) - (GROUP:GND.U1, GND, P)
! PORT 2 (PIN U2.R94, A0, S) - (GROUP:GND.U2, GND, P)
! PORT 3 (PIN U3.R94, A0, S) - (GROUP:GND.U3, GND, P)
! PORT 4 (PIN U4.L94, A0, S) - (GROUP:GND.U4, GND, P)
! PORT 5 (PIN U5.L94, A0, S) - (GROUP:GND.U5, GND, P)
! PORT 6 (PIN BGA.K2, A0, S)

! PORT 7 (PIN U1.R95, A1, S) - (GROUP:GND.U1, GND, P)
! PORT 8 (PIN U2.R95, A1, S) - (GROUP:GND.U2, GND, P)
! PORT 9 (PIN U3.R95, A1, S) - (GROUP:GND.U3, GND, P)
! PORT 10 (PIN U4.L95, A1, S) - (GROUP:GND.U4, GND, P)
! PORT 11 (PIN U5.L95, A1, S) - (GROUP:GND.U5, GND, P)
! PORT 12 (PIN BGA.J2, A1, S)

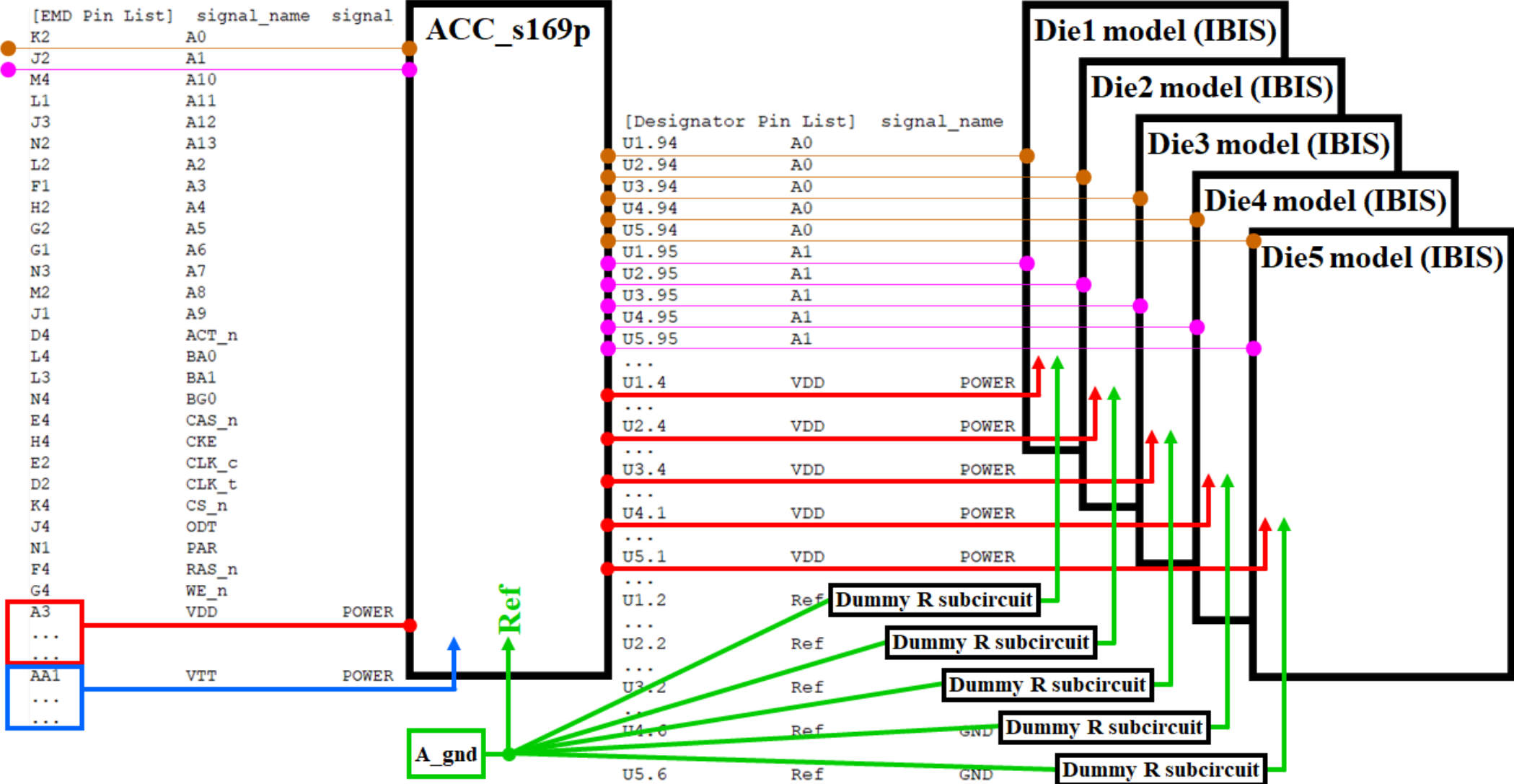
! PORT 163 (GROUP:VDD.U1, VDD, P) - (GROUP:GND.U1, GND, P)
! PORT 164 (GROUP:VDD.U2, VDD, P) - (GROUP:GND.U2, GND, P)
! PORT 165 (GROUP:VDD.U3, VDD, P) - (GROUP:GND.U3, GND, P)
! PORT 166 (GROUP:VDD.U4, VDD, P) - (GROUP:GND.U4, GND, P)
! PORT 167 (GROUP:VDD.U5, VDD, P) - (GROUP:GND.U5, GND, P)
! PORT 168 (GROUP:VDD.BGA, VDD, P)
! PORT 169 (GROUP:VTT.BGA, VTT, P)

! GROUP PORT 1 NAME:GND.U1, U1.L2, U1.L11, U1.L15, U1.L23, U1.L38, U1.L42, U1.L43, U1.L47, U1.L50, U1.L54, U1.L55, U1.L59, U1.L60, U1.L64, U1.L66, U1.L69, U1.L72, U1.L90, U1.L106, ...
! GROUP PORT 2 NAME:GND.U2, U2.L2, U2.L11, U2.L15, U2.L23, U2.L38, U2.L42, U2.L43, U2.L47, U2.L50, U2.L54, U2.L55, U2.L59, U2.L60, U2.L64, U2.L66, U2.L69, U2.L72, U2.L90, U2.L106, ...
! GROUP PORT 3 NAME:GND.U3, U3.L2, U3.L11, U3.L15, U3.L23, U3.L38, U3.L42, U3.L43, U3.L47, U3.L50, U3.L54, U3.L55, U3.L59, U3.L60, U3.L64, U3.L66, U3.L69, U3.L72, U3.L90, U3.L106, ...
! GROUP PORT 4 NAME:GND.U4, U4.L6, U4.L10, U4.L18, U4.L22, U4.L27, U4.L28, U4.L32, U4.L34, U4.R2, U4.R11, U4.R15, U4.R23, U4.R38, U4.R42, U4.R43, U4.R47, U4.R50, U4.R54, U4.R55, ...
! GROUP PORT 5 NAME:GND.U5, U5.L6, U5.L10, U5.L18, U5.L22, U5.L27, U5.L28, U5.L32, U5.L34, U5.R2, U5.R11, U5.R15, U5.R23, U5.R38, U5.R42, U5.R43, U5.R47, U5.R50, U5.R54, U5.R55, ...

! GROUP PORT 7 NAME:GND.U1, U1.L2, U1.L11, U1.L15, U1.L23, U1.L38, U1.L42, U1.L43, U1.L47, U1.L50, U1.L54, U1.L55, U1.L59, U1.L60, U1.L64, U1.L66, U1.L69, U1.L72, U1.L90, U1.L106, ...
! GROUP PORT 8 NAME:GND.U2, U2.L2, U2.L11, U2.L15, U2.L23, U2.L38, U2.L42, U2.L43, U2.L47, U2.L50, U2.L54, U2.L55, U2.L59, U2.L60, U2.L64, U2.L66, U2.L69, U2.L72, U2.L90, U2.L106, ...
! GROUP PORT 9 NAME:GND.U3, U3.L2, U3.L11, U3.L15, U3.L23, U3.L38, U3.L42, U3.L43, U3.L47, U3.L50, U3.L54, U3.L55, U3.L59, U3.L60, U3.L64, U3.L66, U3.L69, U3.L72, U3.L90, U3.L106, ...
! GROUP PORT 10 NAME:GND.U4, U4.L6, U4.L10, U4.L18, U4.L22, U4.L27, U4.L28, U4.L32, U4.L34, U4.R2, U4.R11, U4.R15, U4.R23, U4.R38, U4.R42, U4.R43, U4.R47, U4.R50, U4.R54, U4.R55, ...
! GROUP PORT 11 NAME:GND.U5, U5.L6, U5.L10, U5.L18, U5.L22, U5.L27, U5.L28, U5.L32, U5.L34, U5.R2, U5.R11, U5.R15, U5.R23, U5.R38, U5.R42, U5.R43, U5.R47, U5.R50, U5.R54, U5.R55, ...

! GROUP PORT 163 NAME:VDD.U1, U1.L4, U1.L8, U1.L17, U1.L20, U1.L33, U1.L36, U1.L40, U1.L45, U1.L49, U1.L52, U1.L57, U1.L62, U1.L65, U1.L67, U1.L68, U1.L73, U1.L92, U1.L107, ...
! GROUP PORT 163 NAME:GND.U1, U1.L2, U1.L11, U1.L15, U1.L23, U1.L38, U1.L42, U1.L43, U1.L47, U1.L50, U1.L54, U1.L55, U1.L59, U1.L60, U1.L64, U1.L66, U1.L69, U1.L72, U1.L90, ...
! GROUP PORT 164 NAME:VDD.U2, U2.L4, U2.L8, U2.L17, U2.L20, U2.L33, U2.L36, U2.L40, U2.L45, U2.L49, U2.L52, U2.L57, U2.L62, U2.L65, U2.L67, U2.L68, U2.L73, U2.L92, U2.L107, ...
! GROUP PORT 164 NAME:GND.U2, U2.L2, U2.L11, U2.L15, U2.L23, U2.L38, U2.L42, U2.L43, U2.L47, U2.L50, U2.L54, U2.L55, U2.L59, U2.L60, U2.L64, U2.L66, U2.L69, U2.L72, U2.L90, ...
! GROUP PORT 165 NAME:VDD.U3, U3.L4, U3.L8, U3.L17, U3.L20, U3.L33, U3.L36, U3.L40, U3.L45, U3.L49, U3.L52, U3.L57, U3.L62, U3.L65, U3.L67, U3.L68, U3.L73, U3.L92, U3.L107, ...
! GROUP PORT 165 NAME:GND.U3, U3.L2, U3.L11, U3.L15, U3.L23, U3.L38, U3.L42, U3.L43, U3.L47, U3.L50, U3.L54, U3.L55, U3.L59, U3.L60, U3.L64, U3.L66, U3.L69, U3.L72, U3.L90, ...
! GROUP PORT 166 NAME:VDD.U4, U4.L1, U4.L13, U4.L16, U4.L25, U4.L30, U4.L48, U4.R4, U4.R8, U4.R17, U4.R20, U4.R33, U4.R36, U4.R40, U4.R45, U4.R49, U4.R52, U4.R57, U4.R62, ...
! GROUP PORT 166 NAME:GND.U4, U4.L6, U4.L10, U4.L18, U4.L22, U4.L27, U4.L28, U4.L32, U4.L34, U4.R2, U4.R11, U4.R15, U4.R23, U4.R38, U4.R42, U4.R43, U4.R47, U4.R50, U4.R54, ...
! GROUP PORT 167 NAME:VDD.U5, U5.L1, U5.L13, U5.L16, U5.L25, U5.L30, U5.L48, U5.R4, U5.R8, U5.R17, U5.R20, U5.R33, U5.R36, U5.R40, U5.R45, U5.R49, U5.R52, U5.R57, U5.R62, ...
! GROUP PORT 167 NAME:GND.U5, U5.L6, U5.L10, U5.L18, U5.L22, U5.L27, U5.L28, U5.L32, U5.L34, U5.R2, U5.R11, U5.R15, U5.R23, U5.R38, U5.R42, U5.R43, U5.R47, U5.R50, U5.R54, ...
! GROUP PORT 168 NAME:VDD.BGA, BGA.A3, BGA.A4, BGA.A7, BGA.AB5, BGA.AB9, BGA.AB11, BGA.AB13, BGA.AC7, BGA.B1, BGA.B5, BGA.B9, BGA.B11, BGA.B13, BGA.C3, BGA.D1, BGA.D5, BGA.D12, BGA.D14, ...
! GROUP PORT 169 NAME:VTT.BGA, BGA.AA1, BGA.AA2, BGA.AA3, BGA.AA4, BGA.AB1, BGA.AB2, BGA.AB3, BGA.AB4, BGA.AC2, BGA.AC3, BGA.AC4
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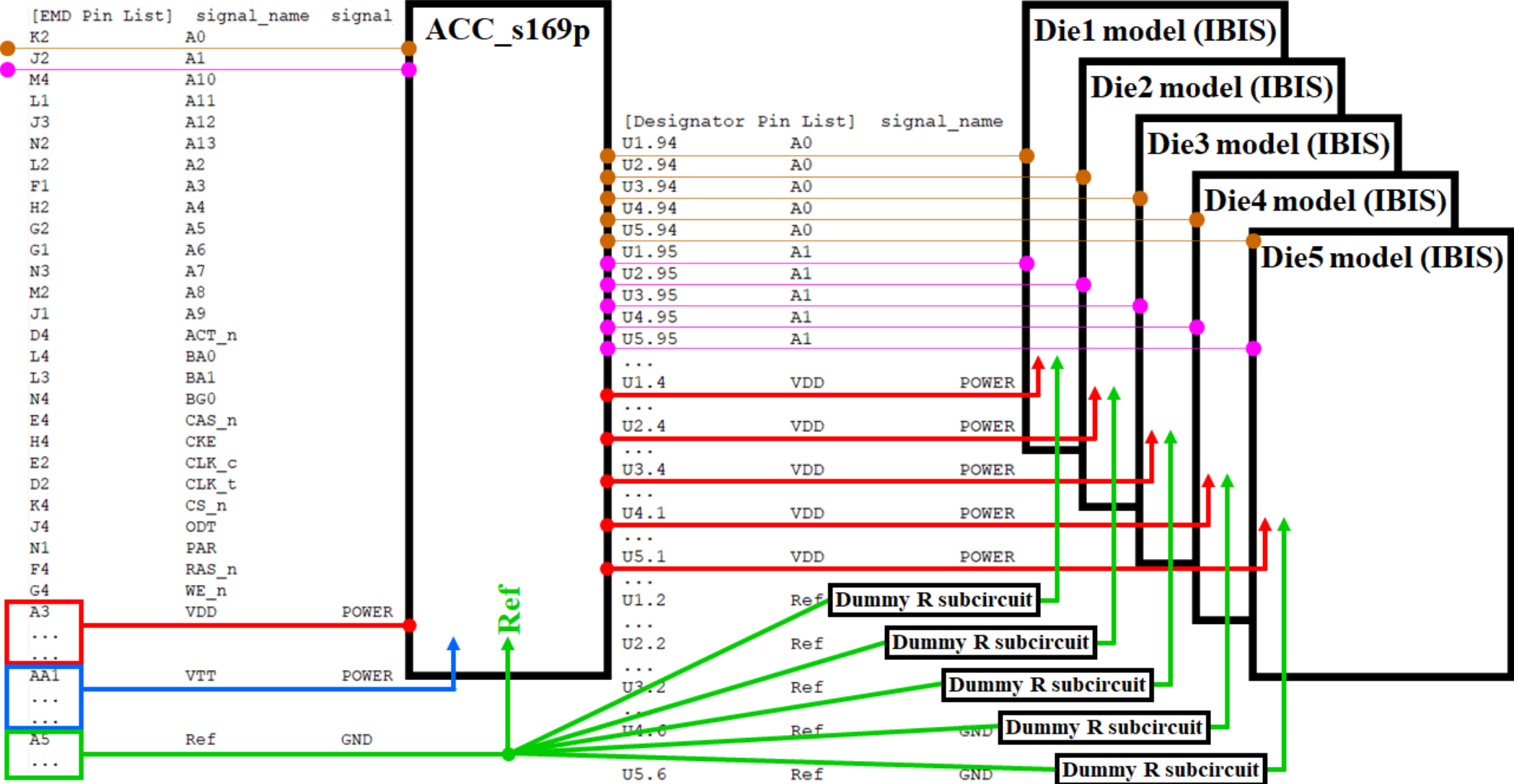
Example 3 - Missing ground pins on the EMD side with grounded IBIS side (better)



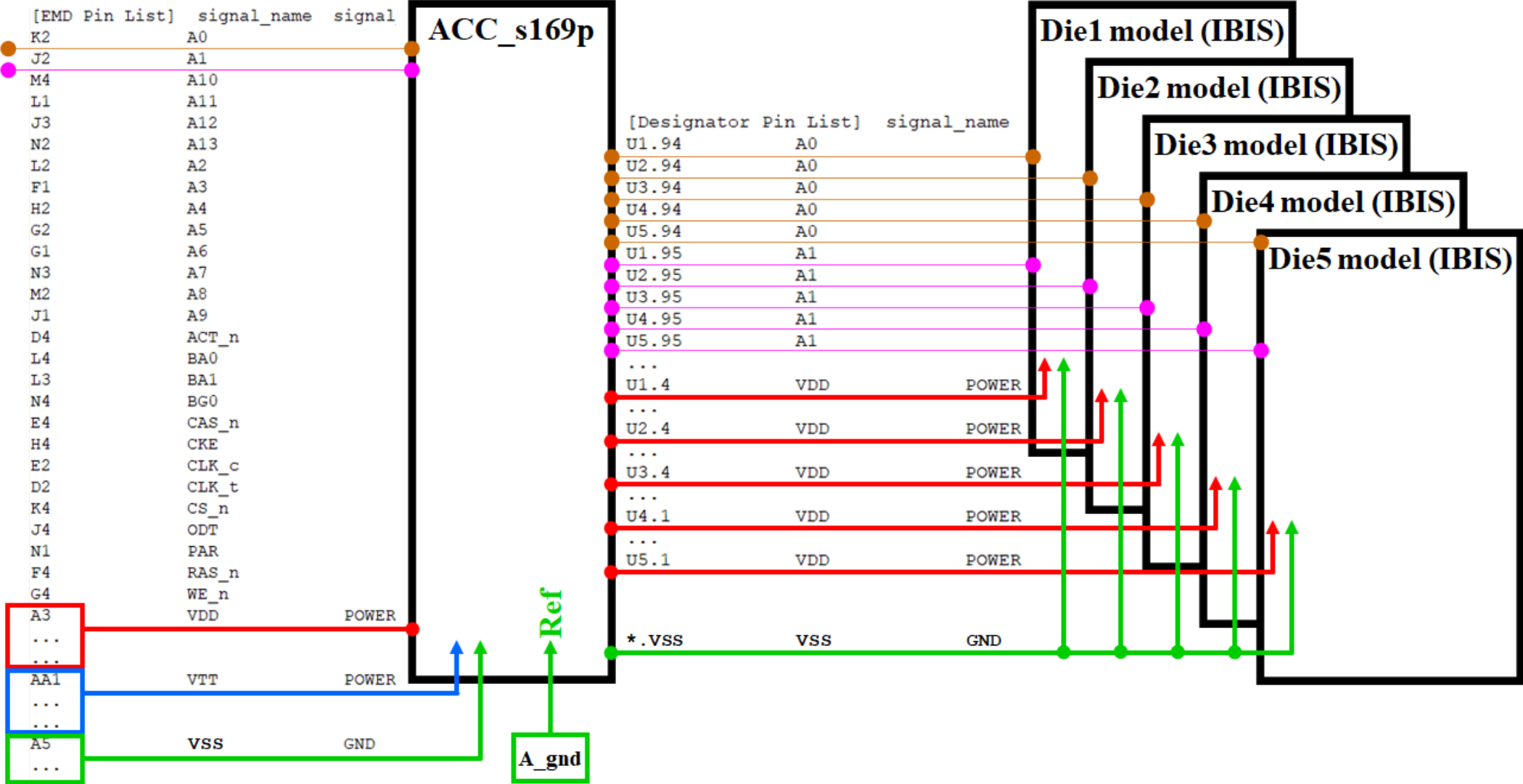
Example 4 – All ground connections are made through the EMD pins (best)

! PORT 1	(PIN U1.R94, A0, S)	-(GROUP:GND.U1, GND, P)
! PORT 2	(PIN U2.R94, A0, S)	-(GROUP:GND.U2, GND, P)
! PORT 3	(PIN U3.R94, A0, S)	-(GROUP:GND.U3, GND, P)
! PORT 4	(PIN U4.L94, A0, S)	-(GROUP:GND.U4, GND, P)
! PORT 5	(PIN U5.L94, A0, S)	-(GROUP:GND.U5, GND, P)
! PORT 6	(PIN BGA.K2, A0, S)	-(GROUP:GND.BGA, GND, P)
! PORT 7	(PIN U1.R95, A1, S)	-(GROUP:GND.U1, GND, P)
! PORT 8	(PIN U2.R95, A1, S)	-(GROUP:GND.U2, GND, P)
! PORT 9	(PIN U3.R95, A1, S)	-(GROUP:GND.U3, GND, P)
! PORT 10	(PIN U4.L95, A1, S)	-(GROUP:GND.U4, GND, P)
! PORT 11	(PIN U5.L95, A1, S)	-(GROUP:GND.U5, GND, P)
! PORT 12	(PIN BGA.J2, A1, S)	-(GROUP:GND.BGA, GND, P)
! PORT 163	(GROUP:VDD.U1, VDD, P)	-(GROUP:GND.U1, GND, P)
! PORT 164	(GROUP:VDD.U2, VDD, P)	-(GROUP:GND.U2, GND, P)
! PORT 165	(GROUP:VDD.U3, VDD, P)	-(GROUP:GND.U3, GND, P)
! PORT 166	(GROUP:VDD.U4, VDD, P)	-(GROUP:GND.U4, GND, P)
! PORT 167	(GROUP:VDD.U5, VDD, P)	-(GROUP:GND.U5, GND, P)
! PORT 168	(GROUP:VDD.BGA, VDD, P)	-(GROUP:GND.BGA, GND, P)
! PORT 169	(GROUP:VTT.BGA, VTT, P)	-(GROUP:GND.BGA, GND, P)
! GROUP PORT 1	NAME:GND.U1, U1.L1, U1.L11, U1.L15, U1.L23, U1.L38, U1.L42, U1.L43, U1.L47, U1.L50, U1.L54, U1.L55, U1.L59, U1.L60, U1.L64, U1.L66, U1.L69, U1.L72, U1.L90, U1.L106, U1.L110, U1.R6, ...	
! GROUP PORT 2	NAME:GND.U2, U2.L2, U2.L11, U2.L15, U2.L23, U2.L38, U2.L42, U2.L43, U2.L47, U2.L50, U2.L54, U2.L55, U2.L59, U2.L60, U2.L64, U2.L66, U2.L69, U2.L72, U2.L90, U2.L106, U2.L110, U2.R6, ...	
! GROUP PORT 3	NAME:GND.U3, U3.L2, U3.L11, U3.L15, U3.L23, U3.L38, U3.L42, U3.L43, U3.L47, U3.L50, U3.L54, U3.L55, U3.L59, U3.L60, U3.L64, U3.L66, U3.L69, U3.L72, U3.L90, U3.L106, U3.L110, U3.R6, ...	
! GROUP PORT 4	NAME:GND.U4, U4.L6, U4.L10, U4.L18, U4.L22, U4.L27, U4.L28, U4.L32, U4.L34, U4.R2, U4.R11, U4.R15, U4.R23, U4.R38, U4.R42, U4.R43, U4.R47, U4.R50, U4.R54, U4.R55, U4.R59, U4.R60, ...	
! GROUP PORT 5	NAME:GND.U5, U5.L6, U5.L10, U5.L18, U5.L22, U5.L27, U5.L28, U5.L32, U5.L34, U5.R2, U5.R11, U5.R15, U5.R23, U5.R38, U5.R42, U5.R43, U5.R47, U5.R50, U5.R54, U5.R55, U5.R59, U5.R60, ...	
! GROUP PORT 6	NAME:GND.BGA, BGA.A5, BGA.A9, BGA.A11, BGA.A14, BGA.AA5, BGA.AA13, BGA.AC5, BGA.AC9, BGA.AC11, BGA.AC14, BGA.B2, BGA.C1, BGA.C4, BGA.C5, BGA.C13, BGA.D3, BGA.D6, BGA.D8, BGA.D11, BGA.E1, BGA.E12, ...	
! GROUP PORT 7	NAME:GND.U1, U1.L2, U1.L11, U1.L15, U1.L23, U1.L38, U1.L42, U1.L43, U1.L47, U1.L50, U1.L54, U1.L55, U1.L59, U1.L60, U1.L64, U1.L66, U1.L69, U1.L72, U1.L90, U1.L106, U1.L110, U1.R6, ...	
! GROUP PORT 8	NAME:GND.U2, U2.L2, U2.L11, U2.L15, U2.L23, U2.L38, U2.L42, U2.L43, U2.L47, U2.L50, U2.L54, U2.L55, U2.L59, U2.L60, U2.L64, U2.L66, U2.L69, U2.L72, U2.L90, U2.L106, U2.L110, U2.R6, ...	
! GROUP PORT 9	NAME:GND.U3, U3.L2, U3.L11, U3.L15, U3.L23, U3.L38, U3.L42, U3.L43, U3.L47, U3.L50, U3.L54, U3.L55, U3.L59, U3.L60, U3.L64, U3.L66, U3.L69, U3.L72, U3.L90, U3.L106, U3.L110, U3.R6, ...	
! GROUP PORT 10	NAME:GND.U4, U4.L6, U4.L10, U4.L18, U4.L22, U4.L27, U4.L28, U4.L32, U4.L34, U4.R2, U4.R11, U4.R15, U4.R23, U4.R38, U4.R42, U4.R43, U4.R47, U4.R50, U4.R54, U4.R55, U4.R59, U4.R60, ...	
! GROUP PORT 11	NAME:GND.U5, U5.L6, U5.L10, U5.L18, U5.L22, U5.L27, U5.L28, U5.L32, U5.L34, U5.R2, U5.R11, U5.R15, U5.R23, U5.R38, U5.R42, U5.R43, U5.R47, U5.R50, U5.R54, U5.R55, U5.R59, U5.R60, ...	
! GROUP PORT 12	NAME:GND.BGA, BGA.A5, BGA.A9, BGA.A11, BGA.A14, BGA.AA5, BGA.AA13, BGA.AC5, BGA.AC9, BGA.AC11, BGA.AC14, BGA.B2, BGA.C1, BGA.C4, BGA.C5, BGA.C13, BGA.D3, BGA.D6, BGA.D8, BGA.D11, BGA.E1, BGA.E12, ...	
! GROUP PORT 163	NAME:VDD.U1, U1.L4, U1.L8, U1.L17, U1.L20, U1.L33, U1.L36, U1.L40, U1.L45, U1.L49, U1.L52, U1.L57, U1.L62, U1.L65, U1.L67, U1.L68, U1.L73, U1.L92, U1.L107, U1.L109, U1.R1, ...	
! GROUP PORT 163	NAME:GND.U1, U1.L2, U1.L11, U1.L15, U1.L23, U1.L38, U1.L42, U1.L43, U1.L47, U1.L50, U1.L54, U1.L55, U1.L59, U1.L60, U1.L64, U1.L66, U1.L69, U1.L72, U1.L90, U1.L106, U1.L110, ...	
! GROUP PORT 164	NAME:VDD.U2, U2.L4, U2.L8, U2.L17, U2.L20, U2.L33, U2.L36, U2.L40, U2.L45, U2.L49, U2.L52, U2.L57, U2.L62, U2.L65, U2.L67, U2.L68, U2.L73, U2.L92, U2.L107, U2.L109, U2.R1, ...	
! GROUP PORT 164	NAME:GND.U2, U2.L2, U2.L11, U2.L15, U2.L23, U2.L38, U2.L42, U2.L43, U2.L47, U2.L50, U2.L54, U2.L55, U2.L59, U2.L60, U2.L64, U2.L66, U2.L69, U2.L72, U2.L90, U2.L106, U2.L110, ...	
! GROUP PORT 165	NAME:VDD.U3, U3.L4, U3.L8, U3.L17, U3.L20, U3.L33, U3.L36, U3.L40, U3.L45, U3.L49, U3.L52, U3.L57, U3.L62, U3.L65, U3.L67, U3.L68, U3.L73, U3.L92, U3.L107, U3.L109, U3.R1, ...	
! GROUP PORT 165	NAME:GND.U3, U3.L2, U3.L11, U3.L15, U3.L23, U3.L38, U3.L42, U3.L43, U3.L47, U3.L50, U3.L54, U3.L55, U3.L59, U3.L60, U3.L64, U3.L66, U3.L69, U3.L72, U3.L90, U3.L106, U3.L110, ...	
! GROUP PORT 166	NAME:VDD.U4, U4.L1, U4.L13, U4.L16, U4.L25, U4.L30, U4.L48, U4.R4, U4.R8, U4.R17, U4.R20, U4.R33, U4.R36, U4.R40, U4.R45, U4.R49, U4.R52, U4.R57, U4.R62, U4.R65, U4.R67, ...	
! GROUP PORT 166	NAME:GND.U4, U4.L6, U4.L10, U4.L18, U4.L22, U4.L27, U4.L28, U4.L32, U4.L34, U4.R2, U4.R11, U4.R15, U4.R23, U4.R38, U4.R42, U4.R43, U4.R47, U4.R50, U4.R54, U4.R55, U4.R59, ...	
! GROUP PORT 167	NAME:VDD.U5, U5.L1, U5.L13, U5.L16, U5.L25, U5.L30, U5.L48, U5.R4, U5.R8, U5.R17, U5.R20, U5.R33, U5.R36, U5.R40, U5.R45, U5.R49, U5.R52, U5.R57, U5.R62, U5.R65, U5.R67, ...	
! GROUP PORT 167	NAME:GND.U5, U5.L6, U5.L10, U5.L18, U5.L22, U5.L27, U5.L28, U5.L32, U5.L34, U5.R2, U5.R11, U5.R15, U5.R23, U5.R38, U5.R42, U5.R43, U5.R47, U5.R50, U5.R54, U5.R55, U5.R59, ...	
! GROUP PORT 168	NAME:VDD.BGA, BGA.A3, BGA.A4, BGA.A7, BGA.AB5, BGA.AB9, BGA.AB11, BGA.AB13, BGA.AC7, BGA.B1, BGA.B5, BGA.B9, BGA.B11, BGA.B13, BGA.C3, BGA.D1, BGA.D5, BGA.D12, BGA.D14, BGA.E3, BGA.E5, ...	
! GROUP PORT 168	NAME:GND.BGA, BGA.A5, BGA.A9, BGA.A11, BGA.A14, BGA.AA5, BGA.AA13, BGA.AC5, BGA.AC9, BGA.AC11, BGA.AC14, BGA.B2, BGA.C1, BGA.C4, BGA.C5, BGA.C13, BGA.D3, BGA.D6, BGA.D8, BGA.D11, BGA.E1, ...	
! GROUP PORT 169	NAME:VTT.BGA, BGA.AA1, BGA.AA2, BGA.AA3, BGA.AA4, BGA.AB1, BGA.AB2, BGA.AB3, BGA.AB4, BGA.AC2, BGA.AC3, BGA.AC4	
! GROUP PORT 169	NAME:GND.BGA, BGA.A5, BGA.A9, BGA.A11, BGA.A14, BGA.AA5, BGA.AA13, BGA.AC5, GA.AC9, BGA.AC11, BGA.AC14, BGA.B2, BGA.C1, BGA.C4, BGA.C5, BGA.C13, BGA.D3, BGA.D6, BGA.D8, BGA.D11, BGA.E1, ...	

Example 4 – All ground connections are made through the EMD pins (best)



Example 5 - Ground connections are made through separate ports in Touchstone (ideal)

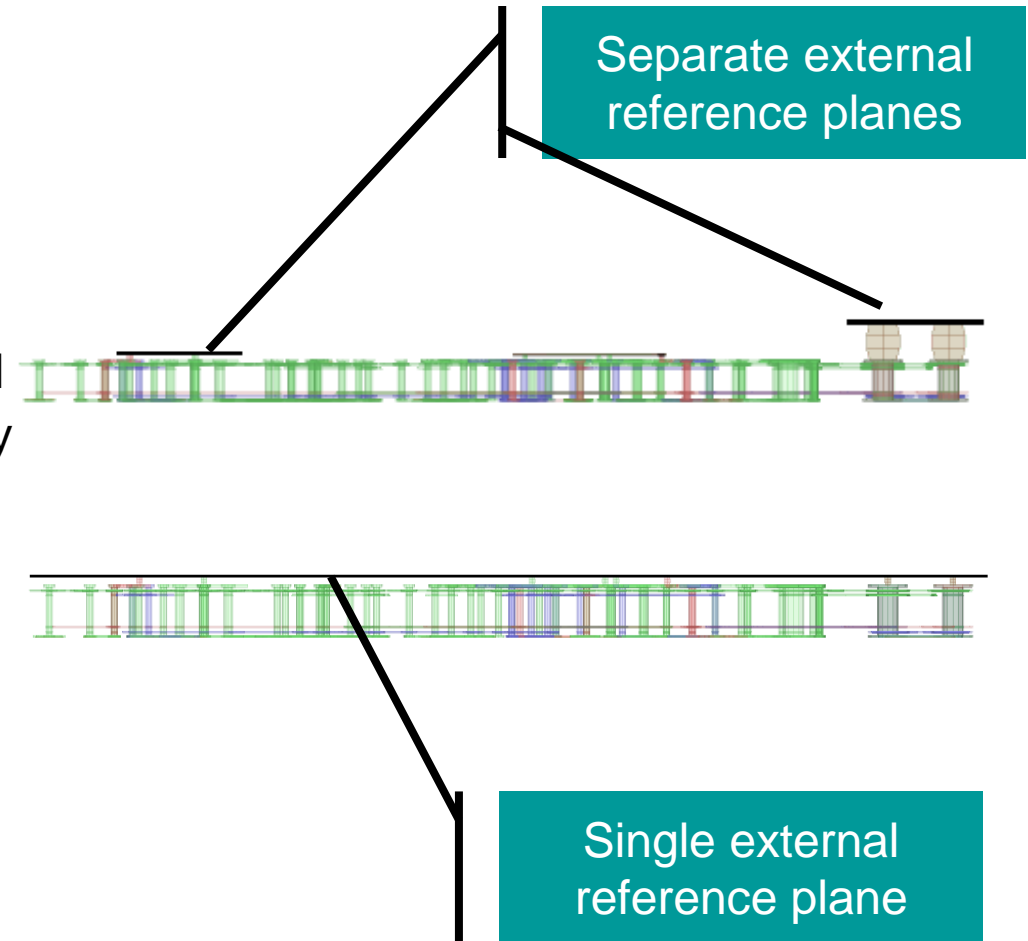


Where is the reference terminal for the S-parameter EMD Model

- During extraction, the reference terminal for the S-parameter ports can be on any conductor that is not part of the nets modeled
- During simulation, the reference terminals for the S-parameter ports may all be connected to one node
 - usually A_gnd (node 0 in SPICE)
- The single reference node in EMD models will make the ports electrically connected
 - Remember, this doesn't mean "shorted"
- Only the voltages between ports positive terminals are considered
- The voltage at any port positive node by itself (referenced to A_gnd) is usually meaningless

Abstract Reference in 3D field solver

- In this scenario it is important to include “Power” and “Ground” nets in the same S-parameter model
- The reference terminal for ports in the electrical modeling procedure (extraction) can be an external conductor not connected to any net in the geometry
 - Same for all ports
 - One external conductor at module pins and another at die pins
 - Separate for every port
- The port length must be short relative to the wavelength of the highest frequency in the extraction



Thank you!