Issues with Interfacing “2N” and “N+ref” Behavioral Models

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Outline

- Review of typical S-parameter connections and “N+ref” implementation in SPICE
- Comparison of “2N” and “N+ref” modeling techniques
- “2N” Connection Techniques in Simulation
- Comparison of the Resulting Models
- Summary and Conclusions
S-parameters and the REF Node: Port Connections and SPICE Usage
Typical PDS Port Connections

- **Correct and recommended**
  - Port 1 Package Structure
  - Node 1 S-Param Ckt Black Box
  - Node REF

- **Correct but not recommended**
  - Port 1 Package Structure
  - Node 1 S-Param Ckt Black Box
  - Node REF
S-parameters are a “loop” concept

- For the two geometries below, the resulting S-parameters are identical.
- Properties of individual nets cannot be derived from S-parameters.
- This is one of the reasons why explicit negative terminals are not provided by many simulation tools. (REF is a very useful technique – more details later).

**Geometry 1**

- S-Parameter Black Box
- node REF

**Geometry 2**

- S-Parameter Black Box
- node REF
Typical Port Connection Guidelines

- Use the same net (ex. VSS) as the “-” reference terminals for all ports.
- Mixed referencing (using different nets for “-” port terminals) is allowed, but not recommended. (NOT allowed if you hookup circuits across the ports.)
- These guidelines are intended for external circuits with 1 PWR & 1 GND.

Multiple ground bumps can serve as the “-” reference terminal

Multiple ground balls can serve as the “-” reference terminal
Questions on the Single Reference Node (REF) in Many SPICE Implementations

- The physical structure has N ports. Each port has one “+” terminal and one “-” local reference terminal, resulting in a total of 2N physical terminals.

- The SPICE circuit model has N+1 nodes. The N nodes correspond to the N physical “+” terminals, whereas the +1 node is a virtual reference node commonly named “REF”.

- The “REF” node is not a physical ground node, nor a power node. Rather, the circuit is created such that the response or behavior at each + node with respect to the REF node models the response or behavior of each of the original "+" port nodes with respect to their individual "-" port nodes. REF is a mathematical construct.
Circuit Connection Guidelines for S-parameter Models in SPICE

- When using the REF node with a specific “+” terminal, think of the REF node as that port’s corresponding “-” terminal.

- If you do not already have node 0 in your circuit, you should connect REF to node 0 since SPICE requires as least one node 0. This also makes voltage measurement easy!

- If you unfortunately already have node 0 somewhere in the driver or receiver circuits, do not make the additional connection of REF to node 0. Measure voltage as V(n)-V(ref).

- If the Driver and Receiver models both contain global node names for their negative terminals (ex: ground, gnd, 0), the REF technique accurately models the PDS because those negative terminals are meant to be connected in this technique.

- If the models are encrypted, unfortunately the user does not know if global names are used or not… REF must be used.
“2N” Behavioral Models

- Some extraction tools may provide “2N” behavioral models (note the 2 ohm resistor). They intend to reproduce the distributed response between all physical terminals.

- These models have unique terminals for multiple power and ground pins.

- Unfortunately, these models cannot be interfaced with (or connected to) typical S-parameters due to the REF technique in many SPICE tools.

- Warning: Global node “0” is used in this model. If node “0” exists elsewhere in the SPICE deck, incorrect results are likely.

```plaintext
.subckt PowerModel n1 n2 n3 n4 n5 n6 n7 n8
Vd1 n1 n1_p 0
Rp1 n1_p n8 2.000000
Gd1_1 n8 n1_p n1 n8 -3.7036112142644201e-01
Fd1_1 n8 n1_p Vd1 -7.4072224285288413e-01
Gd1_2 n8 n1_p n2 n8 1.8288902037848827e-02
Fd1_2 n8 n1_p Vd2 3.6577804075697662e-02
...
Vd2 n2 n2_p 0
Rp2 n2_p n8 2.000000
Gd2_1 n8 n2_p n1 n8 1.0051775904867706e-01
Fd2_1 n8 n2_p Vd1 2.0103551809735415e-01
Gd2_2 n8 n2_p n2 n8 -4.4313952195018808e-01
Fd2_2 n8 n2_p Vd2 -8.8627904390037626e-01
Gd2_3 n8 n2_p n3 n8 4.5860899569942673e-02
...
Rlarge_n1 nn1 0 1.0e6
Cn1 nn1 0 1.0
Gb1_1 0 nn1 n1 n8 0.707107
Fb1_1 0 nn1 Vd1 1.4142135623730951e+00
Ga1_1 0 nn1 nn1 0 -2.8955106355430019e+08
...
**Typical S-parameter connectivity is not compatible with other “2N” models**

There is a mapping problem!

The multiple “vss” nodes in the 2N model cannot be shorted together at the REF node.

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**2N Die Model**

```plaintext
.subcircit vcc1 vss1 vcc2 vss2 vcc3 vss3 vcc4 vss4 die
```

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**N+ref Model (with conventional port connections)**

```plaintext
.subcircit pwr1 pwr2 pwr3 pwr4 REF pkg_brd
```
S-parameter Connection Techniques to Generate 2N External Terminals
Alternative Port Connection Technique #1

Instead of the conventional 4 port technique, select one vss bump and let it serve as the negative port terminal for all other ports.

Port1 vcc1-vss4       Port2 vcc2-vss4
Port3 vcc3-vss4       Port4 vcc4-vss4
Port5 vss1-vss4       Port6 vss2-vss4
Port7 vss3-vss4

2N Die Model
.subcircuit vcc1 vss1 vcc2 vss2 vcc3 vss3 vcc4 vss4 die

S-parameters (with alternative port connection technique)
.subcircuit pwr1 pwr2 pwr3 pwr4 gnd1 gnd2 gnd3 REF pkg_brd

Node Mapping
vcc1->pwr1, vcc2->pwr2, vcc3->pwr3, vcc4->pwr4, vss1->gnd1, vss2->gnd2, vss3->gnd3, vss4->REF
Instead of the conventional 4 port technique, some tools allow a “dummy reference point”. It serves as the negative port terminal for all other ports.

Port 1: vcc1 – d.p.
Port 5: vss1 – d.p.
Port 8: vss4 – d.p.

**2N Die Model**

```
.subcircuit vcc1 vss1 vcc2 vss2 vcc3 vss3 vcc4 vss4 die
```

**S-parameters** (with alternative port connection technique)

```
.subcircuit pwr1 pwr2 pwr3 pwr4 gnd1 gnd2 gnd3 gnd4
REF pkg_brd
```

**Node Mapping**

vcc1->pwr1, vcc2->pwr2, vcc3->pwr3, vcc4->pwr4, vss1->gnd1, vss2->gnd2, vss3->gnd3, vss4->gnd4

REF is not connected to the 2N Die model (it floats)
Graphical Representation of Alternative Technique #2
Die-side Impedance Comparison of Modeling Techniques 1 and 2

- The “loop inductance” test is the impedance at the die with all BGA balls shorted.
- The same results can be achieved with either connection technique.
Comparison of Results for $Z(vcc1, vss1)$

- **Technique #1 – Green**
  - $Z(vcc1, vss1)$ is the impedance at the top-left of the die. All BGA balls were shorted.
  - Again, the same results can be achieved with either technique.
Summary and Conclusions

- Typical “N+ref” S-parameters do not provide unique reference terminals in SPICE. This is extremely useful due to encrypted models and global “gnd” node names.

- The choice between “2N” and “N+ref” modeling techniques should be determined by the connectivity of the intended external circuits

- If distributed reference terminals are desired, two connection techniques were presented that yield S-parameters with explicit connections at all pins

- The “2N” simulation methodologies were shown to produce correlated results
Thank You!