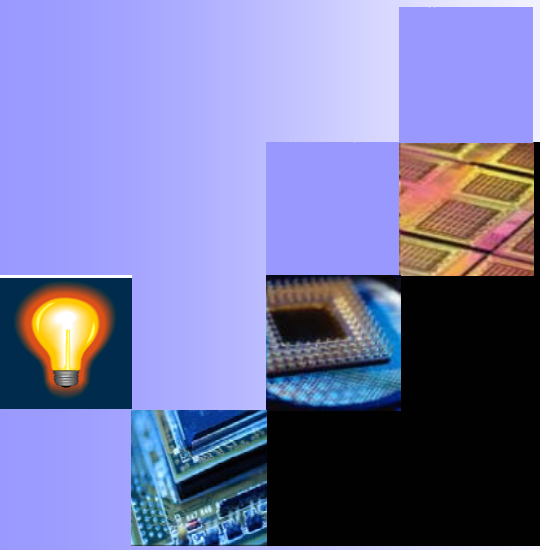

Issues with Interfacing "2N" and "N+ref" Behavioral Models

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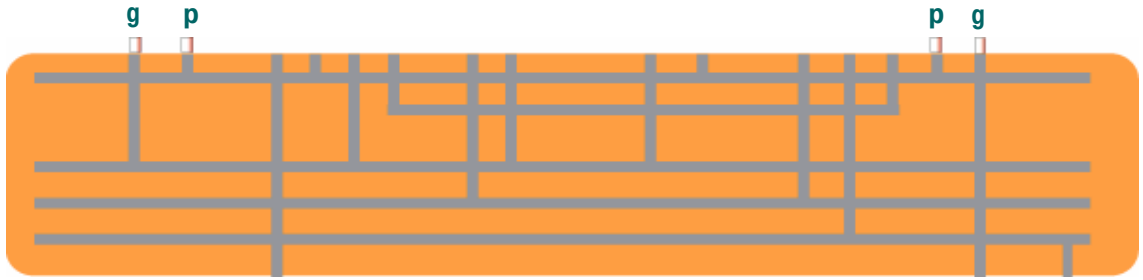
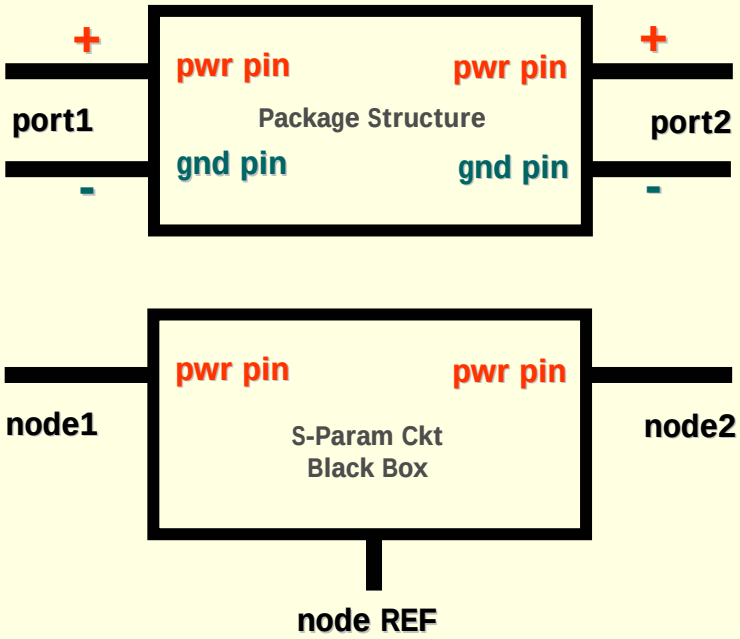
Outline

- 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

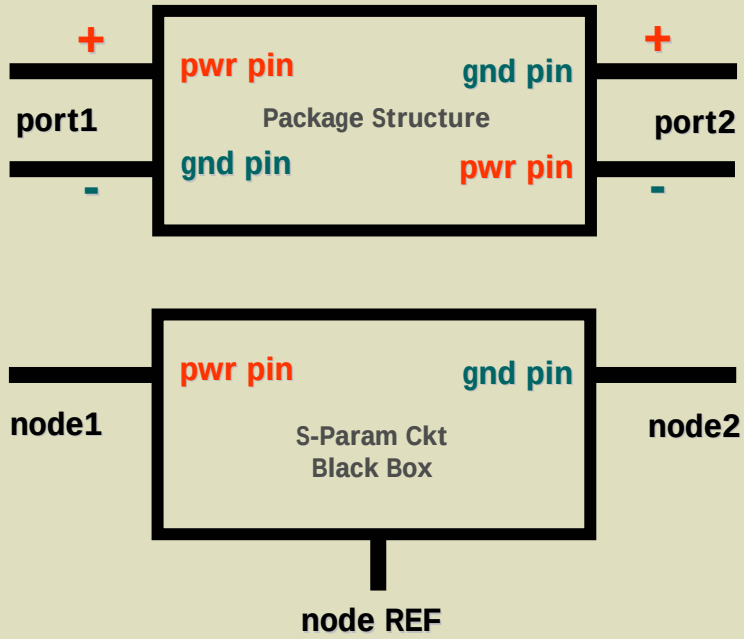
S-parameters and the REF Node: Port Connections and SPICE Usage

Typical PDS Port Connections





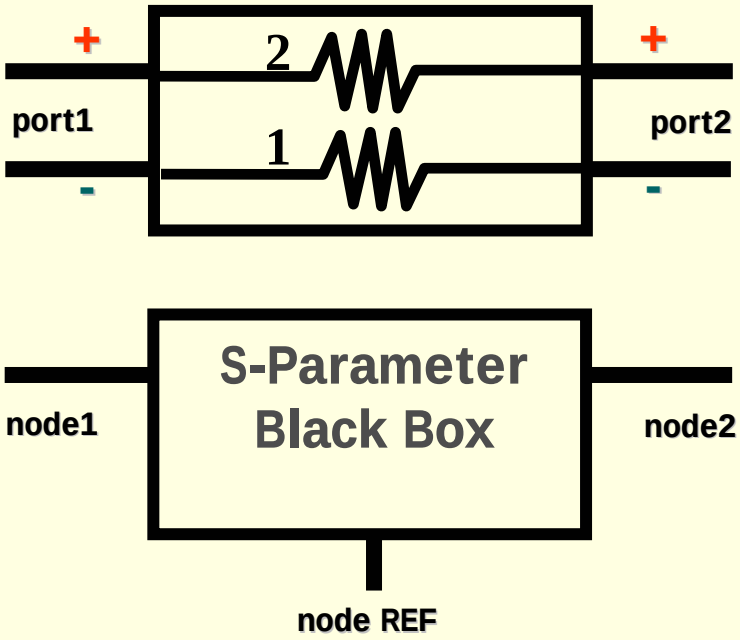
- Correct and recommended



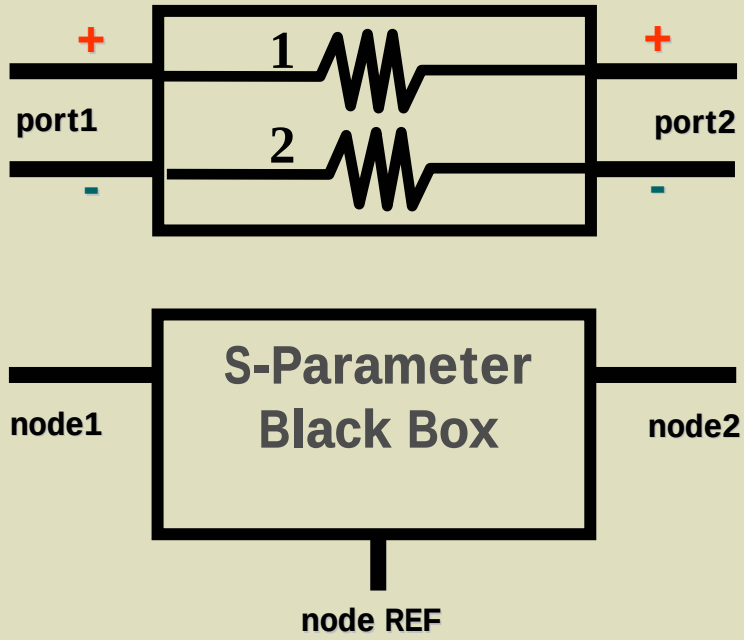
- Correct but not recommended

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).



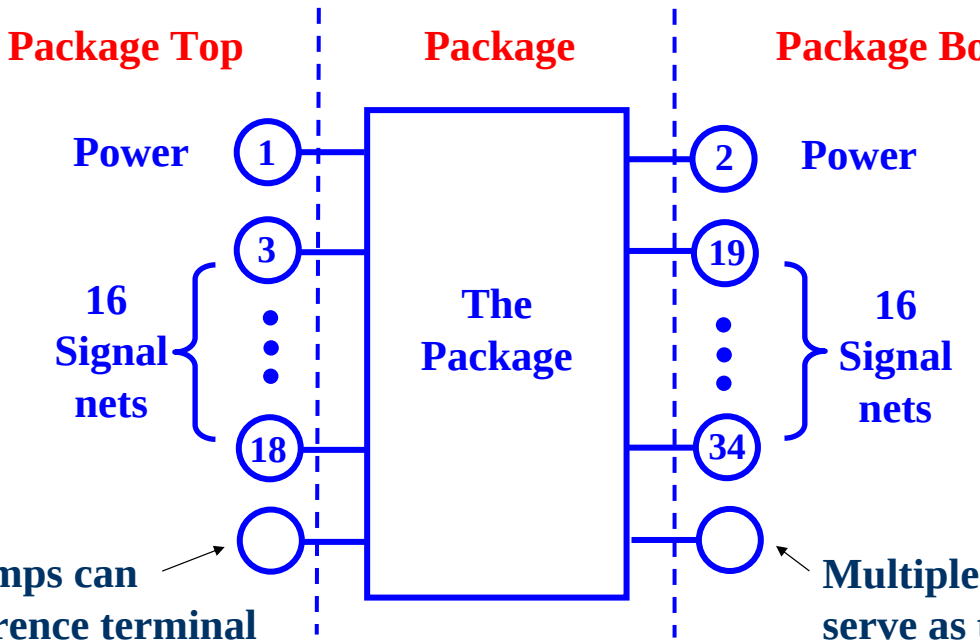
- **Geometry 1**



- **Geometry 2**

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.

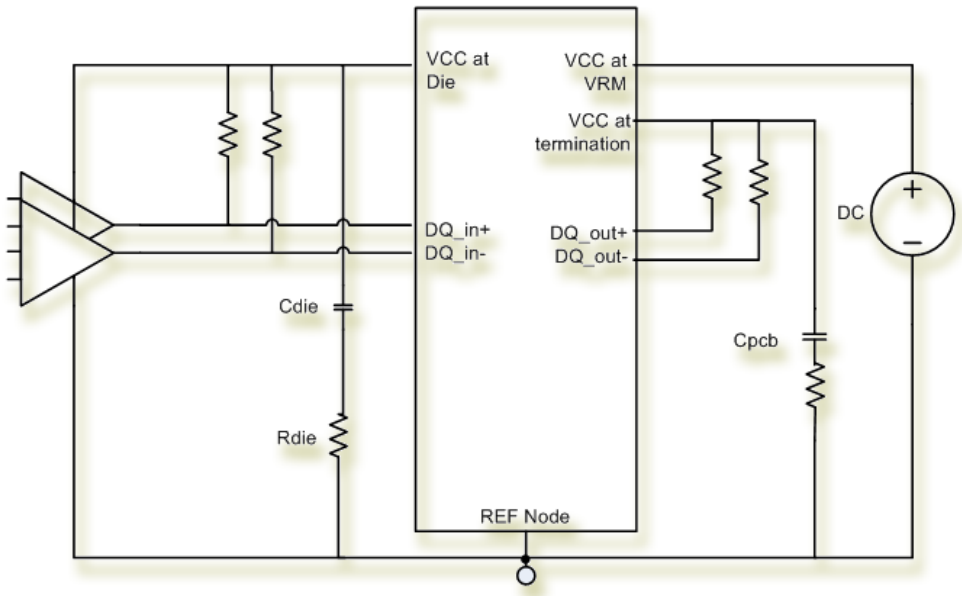


Questions on the Single Reference Node (REF) in Many SPICE Implementations

- 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.

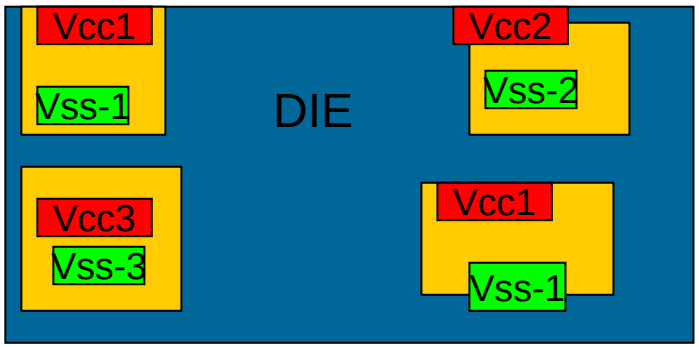


"2N" Behavioral Models

- 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.

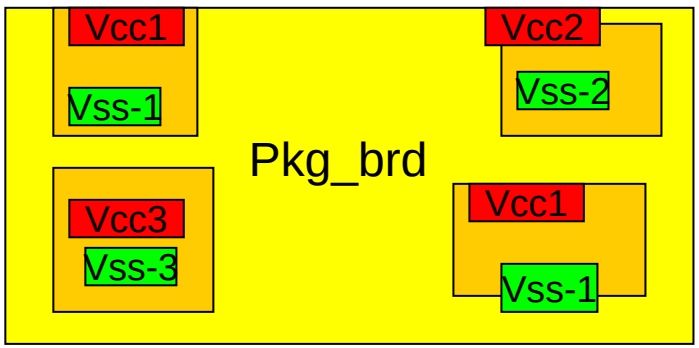
```
.subckt PowerModel  n1 n2 n3 n4 n5 n6 n7 n8
Vd1         n1  n1_p  0
Rp1         n1_p  n8  2.000000
Gd1_1       n8  n1_p  n1  n8  -3.7036112142644201e-01
Fd1_1       n8  n1_p  Vd1  -7.4072224285288413e-01
Gd1_2       n8  n1_p  n2  n8  1.8288902037848827e-02
Fd1_2       n8  n1_p  Vd2  3.6577804075697662e-02
...
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



2N Die Model

.subcircuit vcc1 vss1 vcc2 vss2 vcc3 vss3 vcc4 vss4 die



N+ref Model (with conventional port connections)

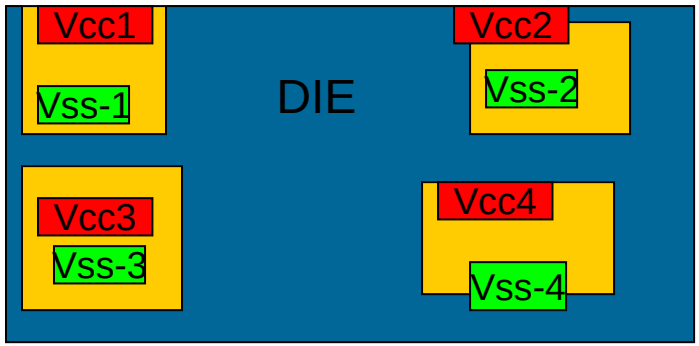
.subcircuit pwr1 pwr2 pwr3 pwr4 REF pkg_brd

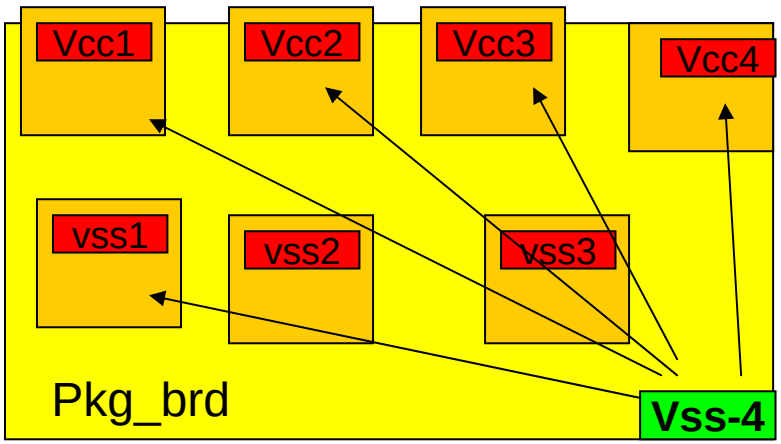
There is a mapping problem!

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

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

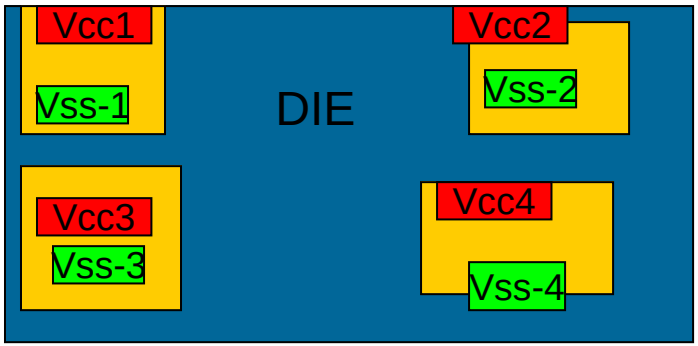
S-parameters (with alternative port connection technique)

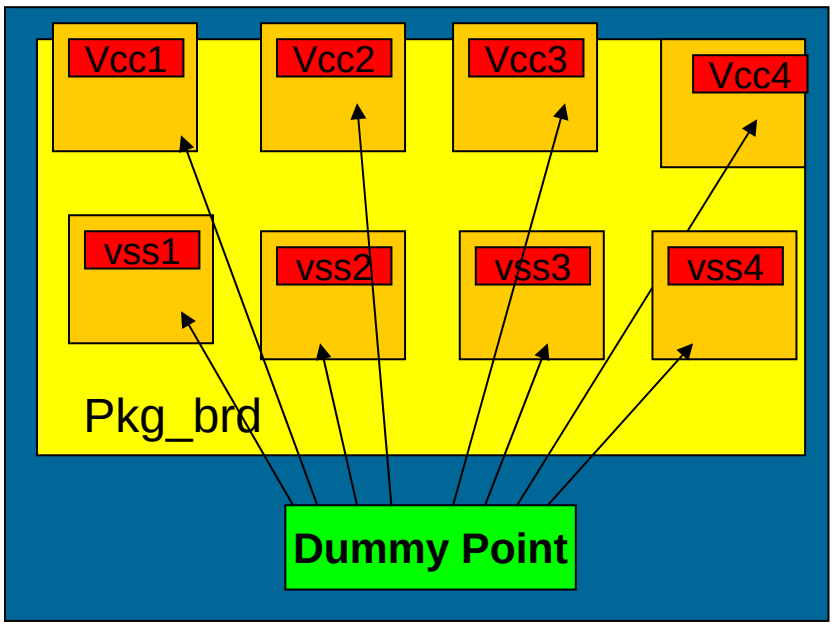
.subcircuit pwr1 pwr2 pwr3 pwr4 gnd1 gnd2 gnd3 REF pkg_brd

Node Mapping

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

Alternative Port Connection Technique #2





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.

Port1 vcc1 – d.p.	Port2 vcc2 – d.p.
Port3 vcc3 – d.p.	Port4 vcc4 – d.p.
Port5 vss1 – d.p.	Port6 vss2 – d.p.
Port7 vss3 – d.p.	Port8 vss4 – d.p.

2N Die Model

.subcircuit vcc1 vss1 vcc2 vss2 vcc3 vss3 vcc4 vss4 die

S-parameters (with alternative port connection technique)

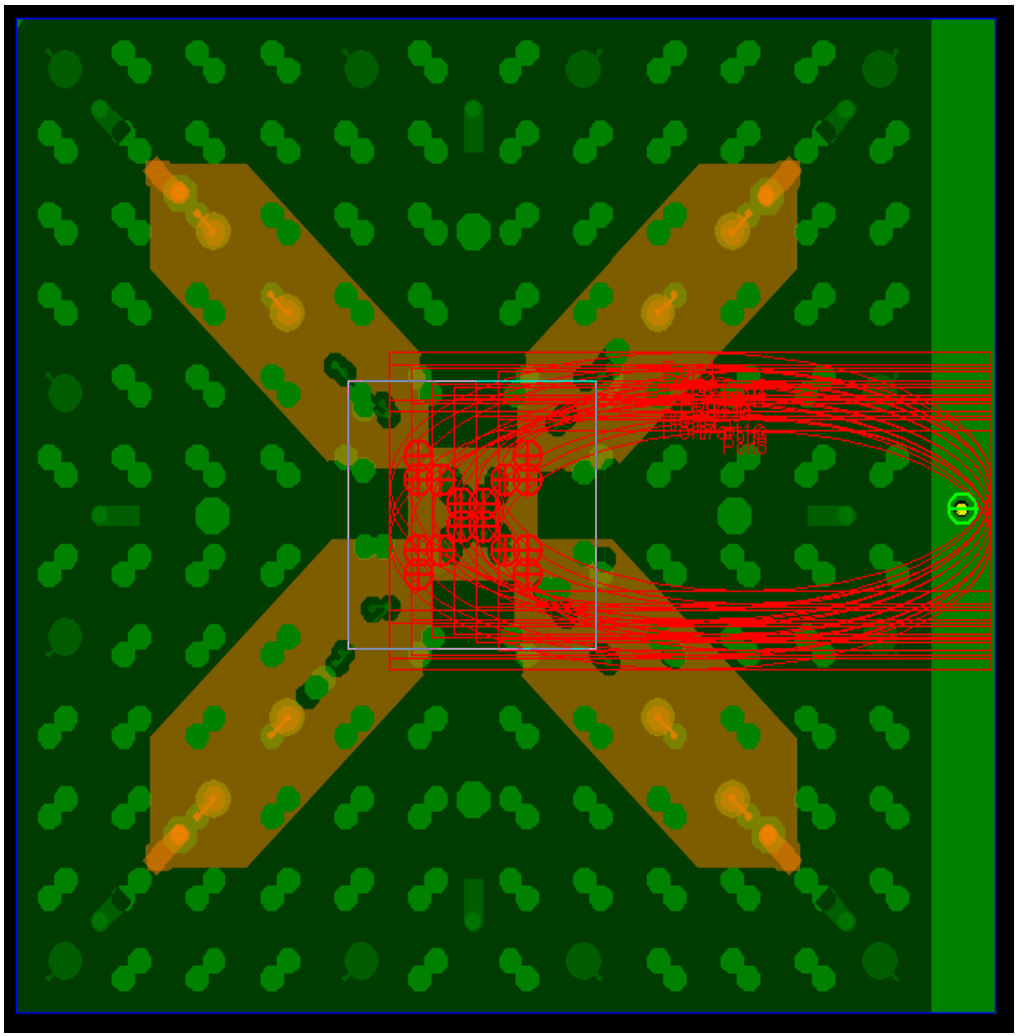
.subcircuit pwr1 pwr2 pwr3 pwr4 gnd1 gnd2 gnd3 gnd4 REF pkg_brd

Node Mapping

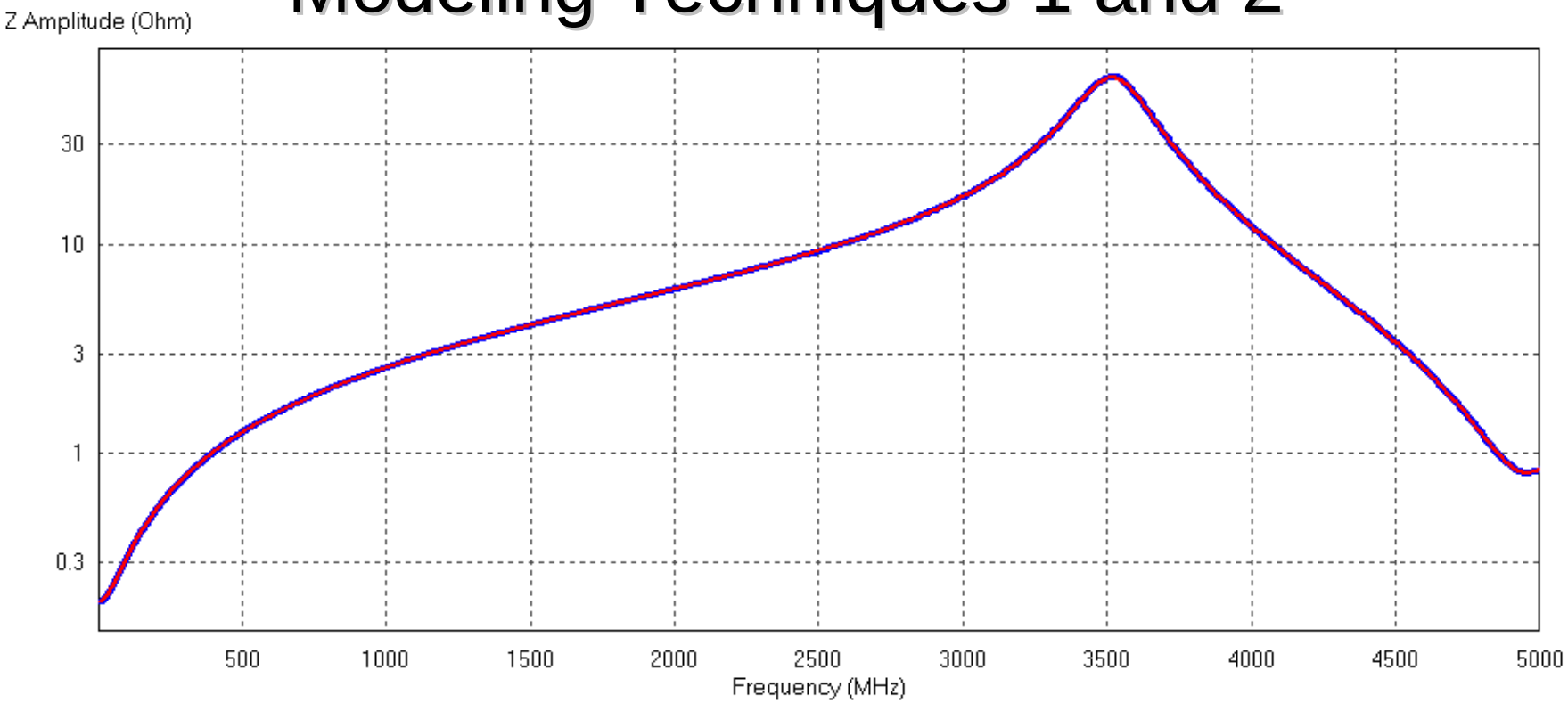
vcc1->pwr1, vcc2->pwr2, vcc3-> pwr3, vcc4->pwr4, vss1->gnd1, vss2->gnd2, vss3->gnd3, vss4->gnd4

REF is not connected to the 2N Die model (it floats)

Graphical Representation of Alternative Technique #2



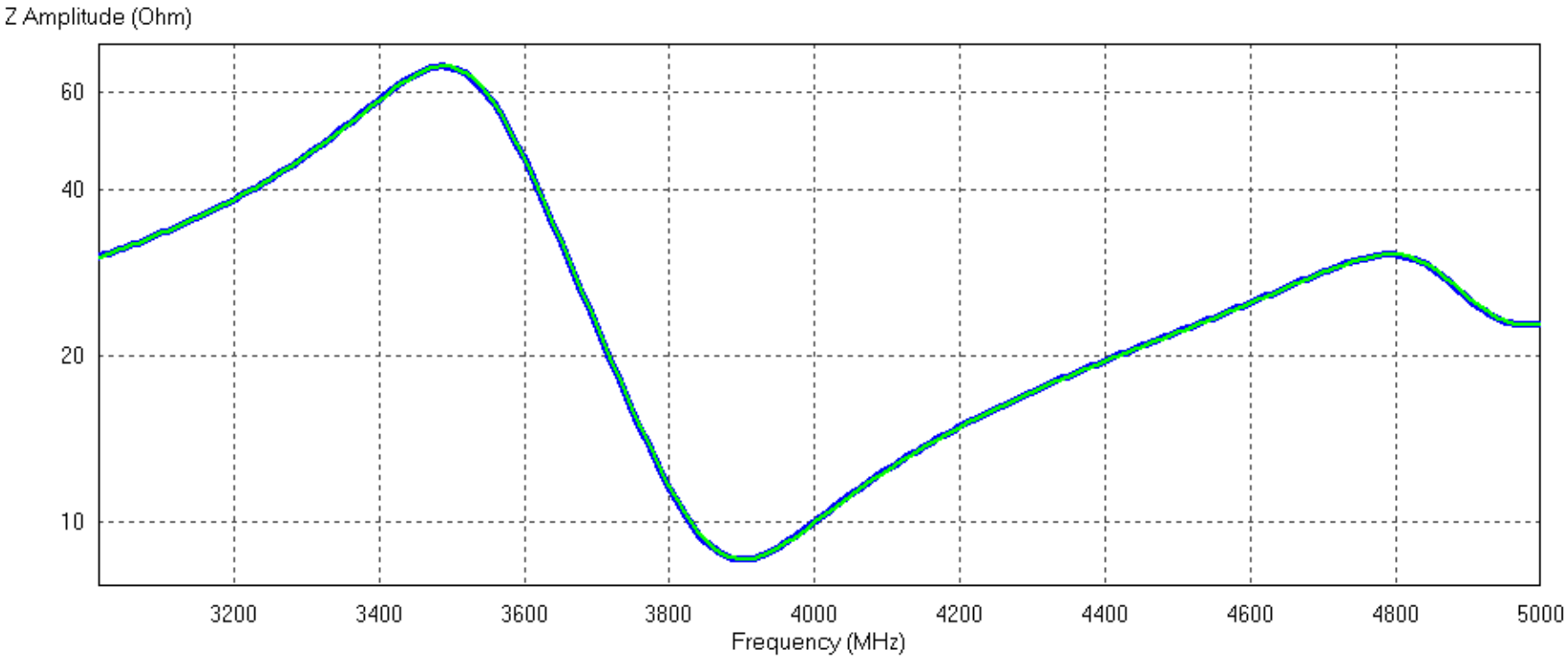
Die-side Impedance Comparison of Modeling Techniques 1 and 2



Technique #1 – Red **Technique #2 – Blue**

- 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 **Technique #2 – Blue**

- 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!