PORTS

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IBIS Interconnect Task Group Meeting
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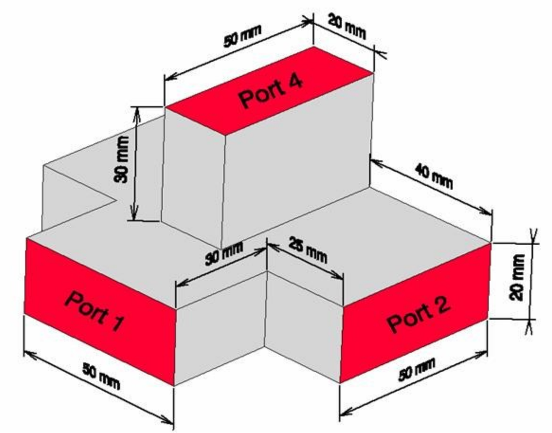


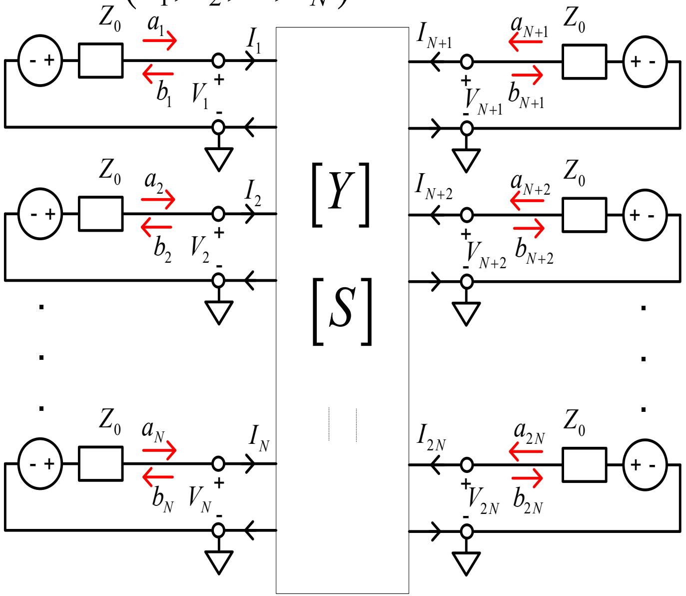
V, I, Waves and Multiport Descriptors

$\bar{V} = (V_1, V_2, ..., V_N)^t$ - vector of port voltages

$\bar{I} = (I_1, I_2, ..., I_N)^t$ - vector of port currents

$\bar{I} = Y \cdot \bar{V}$ - admittance matrix

$\bar{V} = Z \cdot \bar{I}$ - impedance matrix



$Z_0 = diag\{Z_{0i}, i = 1, ..., N\} \in C^{N \times N}$ normalization impedances

$\bar{a} = \frac{1}{2} Z_0^{-1/2} \cdot (\bar{V} + Z_0 \cdot \bar{I})$ - vector of incoming waves

$\bar{b} = \frac{1}{2} Z_0^{-1/2} \cdot (\bar{V} - Z_0 \cdot \bar{I})$ - vector of outgoing waves

Scattering matrix (exists always):

$$\bar{b} = S \cdot \bar{a}, \qquad S \in C^{N \times N}, \qquad S_{i,j} = \left.\frac{b_i}{a_j}\right|_{a_k = 0 \; k \neq j}$$

Potential of the reference terminals is unknown!

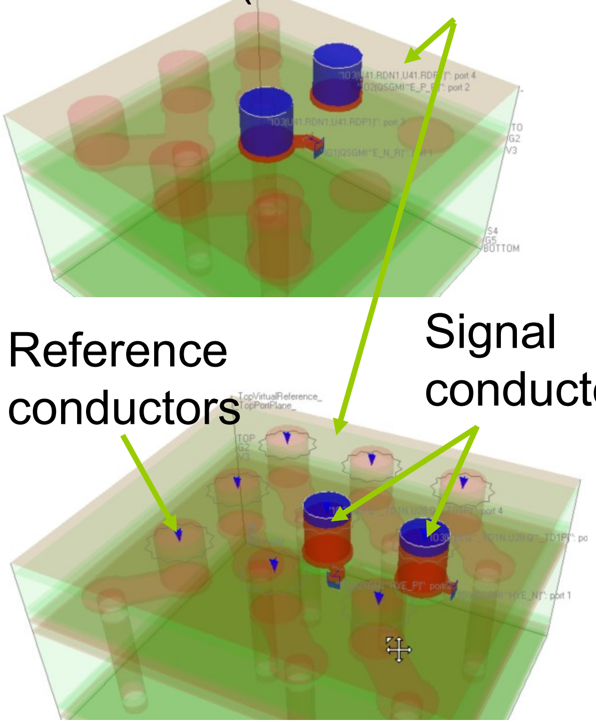
Port Types

- Lumped ports – universal, but have limited bandwidth due to parasitic L and C (useful as low frequency approximation)

$$V = -\int_{ref}^{sig} \bar{E} \cdot d\bar{l} \qquad I = \iint_S \bar{J}_p \cdot d\bar{s}$$

- Wave-ports or transmission line ports – preferable for decompositional analysis without frequency limits (deembedded)

$$V = \iint_S \bar{E} \times \bar{h} \cdot d\bar{s} \qquad I = \iint_S \bar{e} \times \bar{H} \cdot d\bar{s}$$



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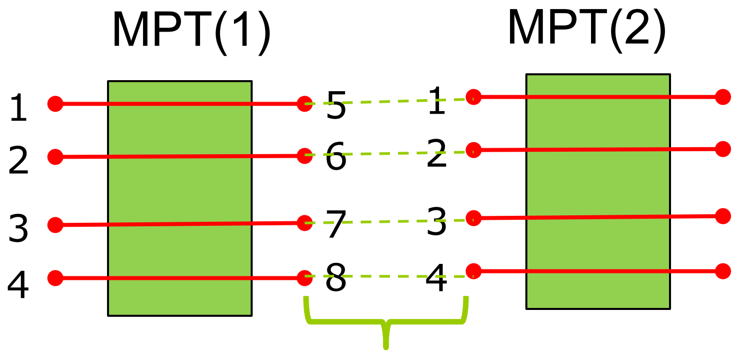
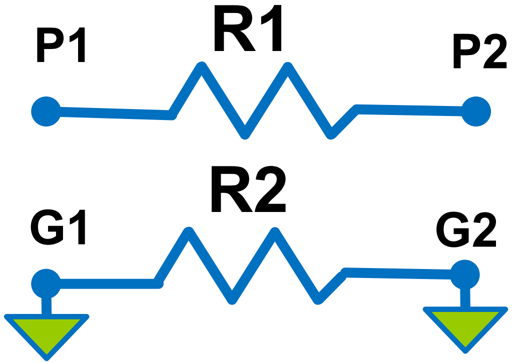
Conditions and Operations

- Port is two terminals (signal and reference) with voltage (difference of potentials) and currents flowing in opposite direction (**cannot be cross-probed or cross-referenced**)
- Current to the signal terminal must be equal to the current from the reference terminal (**current equality condition**)
  - Only 2 ports can be connected together to preserve the current equality
- Connected ports must have exactly the same physical signal and reference conductors or geometry (**continuity condition**)



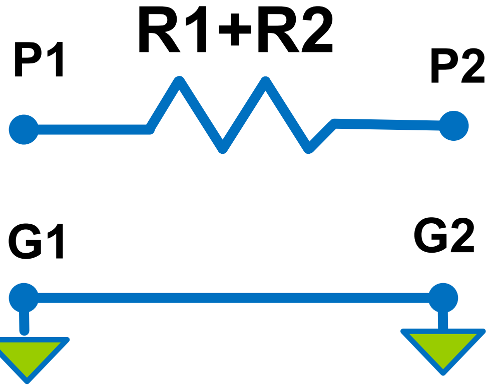
Connect port with identical definition (or at least same signal-reference conductors)

Reference Conductor Disappearance



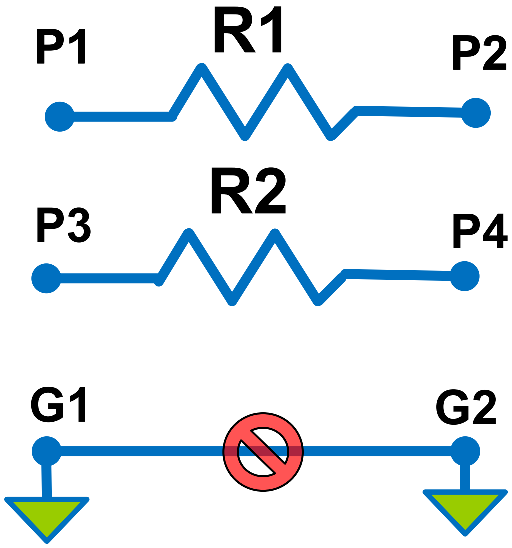
Y11=Y22=1/(**R1+R2**)
Y12=Y21=-1/(**R1+R2**)

S11=S22=**R1+R2**/(**R1+R2**+2*Zo)
S12=S21=2*Zo/(**R1+R2**+2*Zo)



- Information about what is in the signal path and what is in the reference path is lost!
  - There is no way to separate R1 and R2 from sum in Y or S parameters;
- Association of the local reference with the global one will not neglect the information about ground resistance R2;
  - The relative port voltages and currents will be correct, though, there is no way to recover potential difference (voltage) between G1 and G2 and between P1 and P2;

Separate Reference Conductor (Virtual)

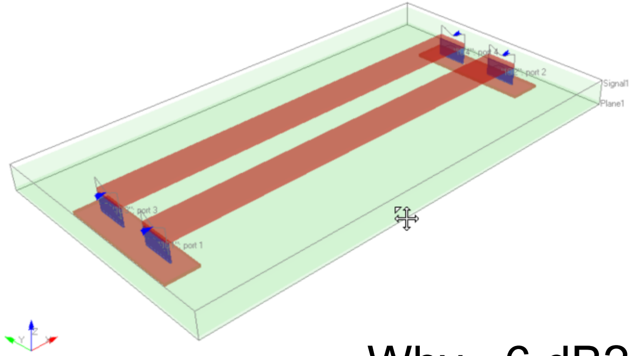


Y11=Y22=1/**R1**
Y12=Y21=-1/**R1**
Y33=Y44=1/**R2**
Y34=Y43=-1/**R2**

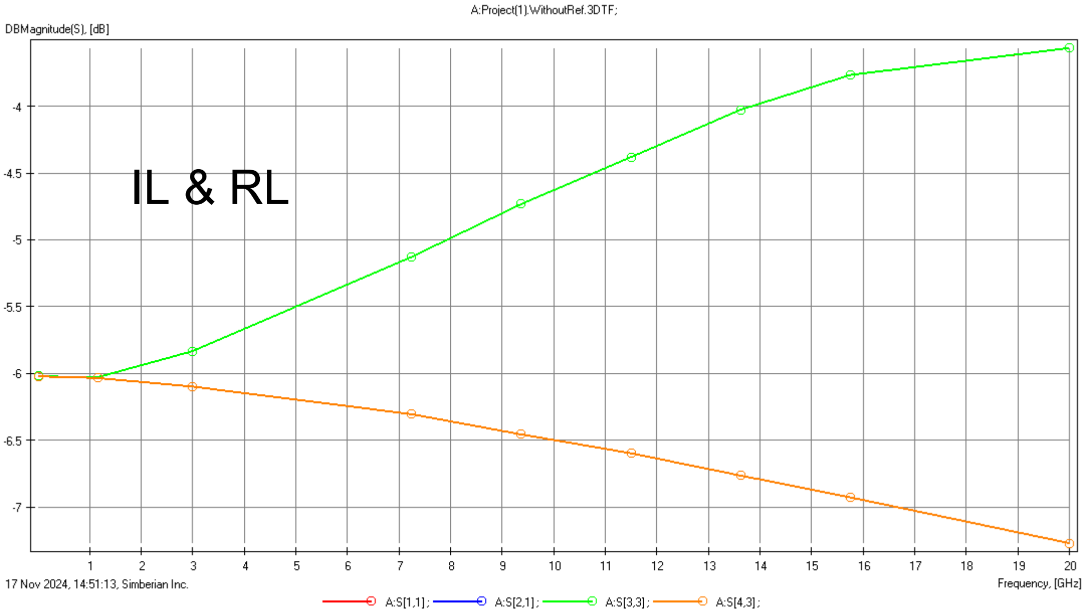
S11=S22=**R1**/(**R1**+2*Zo)
S12=S21=2*Zo/(**R1**+2*Zo)
S33=S44=**R2**/(**R2**+2*Zo)
S34=S43=2*Zo/(**R2**+2*Zo)

Not usable if it is not real
Can be always done in circuit domain, **but not in EM analysis**
Transmission lines: N+1 conductors - **+1 conductor should be natural**

Un-Connected Reference Conductors



Why ~6 dB?



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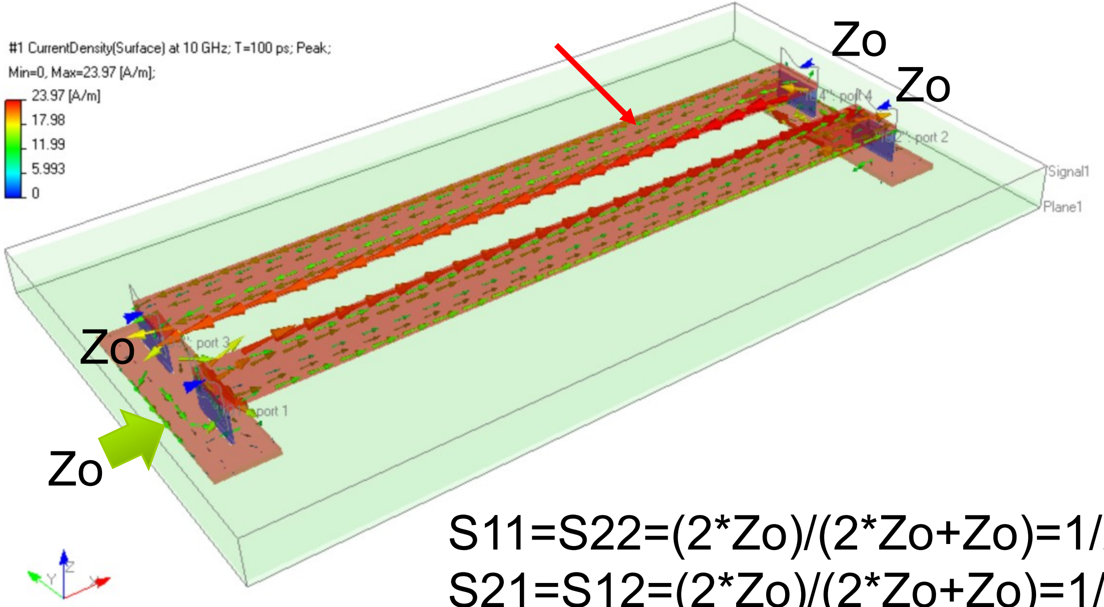
Reference

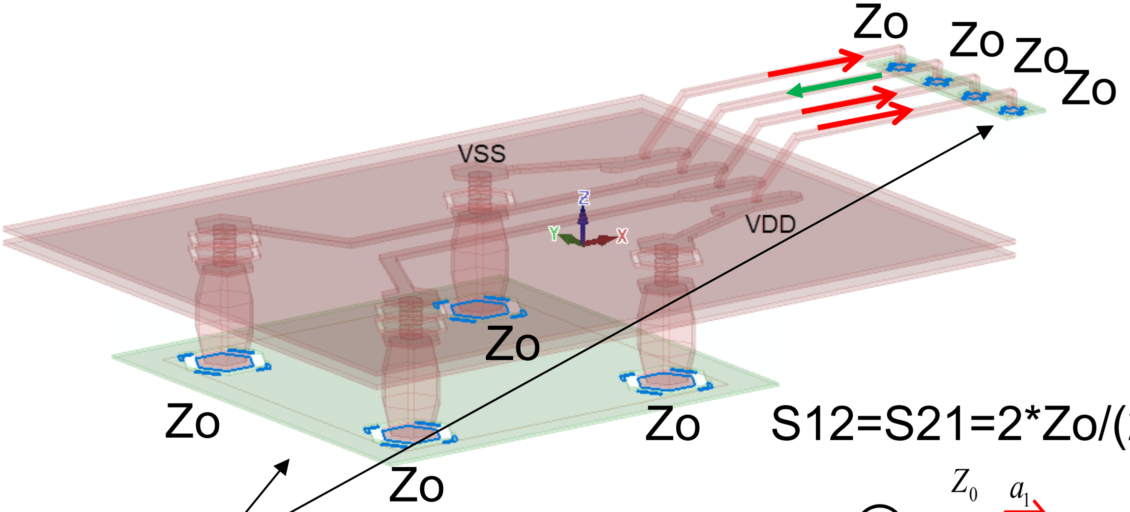
Return current through 2*Zo



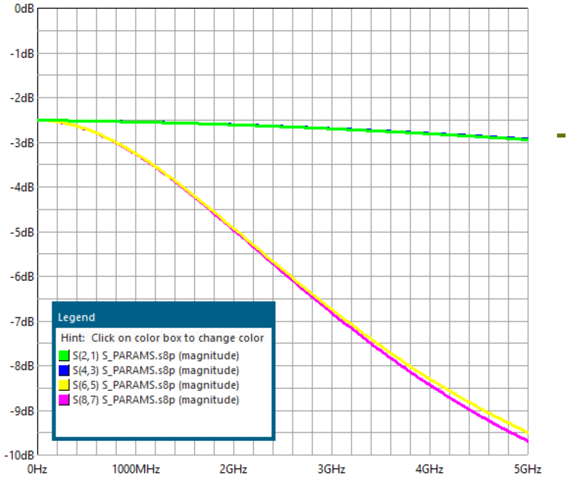
S11=S22=(2*Zo)/(2*Zo+Zo)=1/2 (-6dB)
S21=S12=(2*Zo)/(2*Zo+Zo)=1/2 (-6dB)

Only Local References

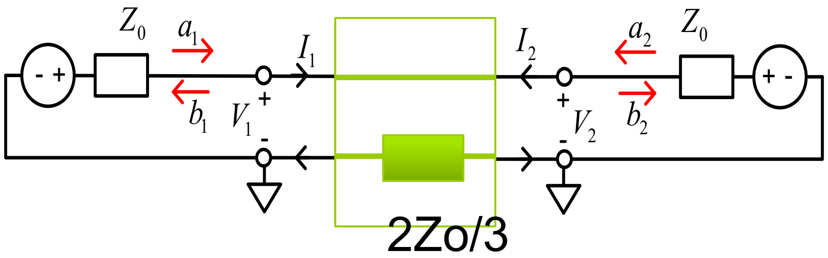
From W. Beal, Floating Reference for S-Parameter Measurement



Virtual floating reference conductors



S12=S21=2*Zo/(**2Zo/3**+2*Zo)=0.75(-2.47dB)



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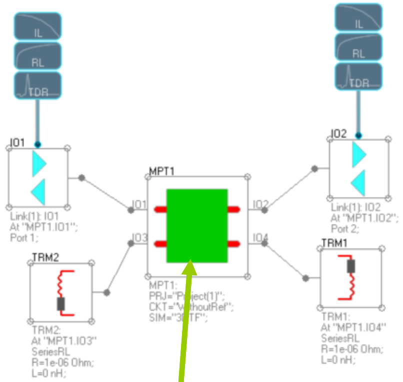
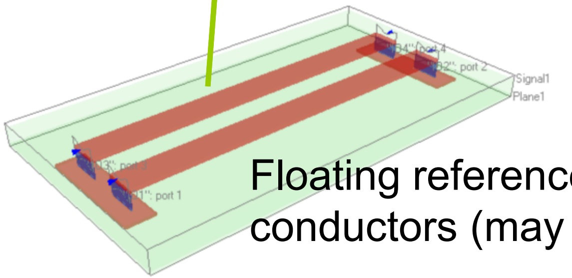
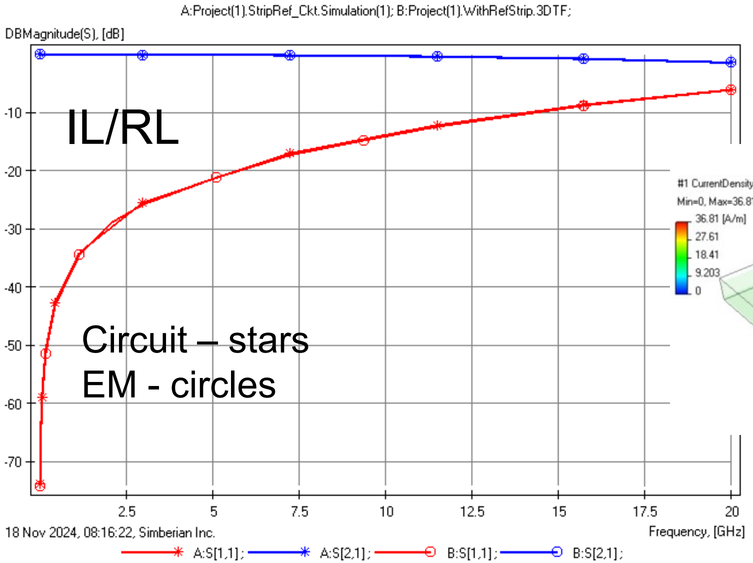
Getting Common Reference

Establish common reference by shorting some ports





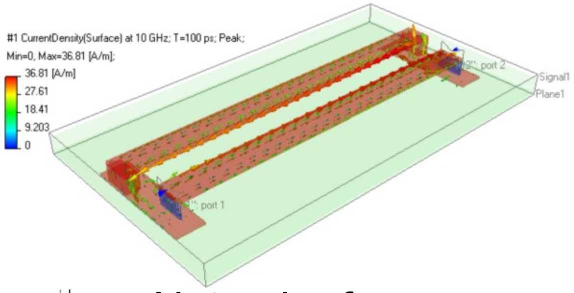
Floating reference conductors (may be virtual)



IL/RL

Circuit – stars
EM - circles

Establish common reference in EM model



Natural reference conductor

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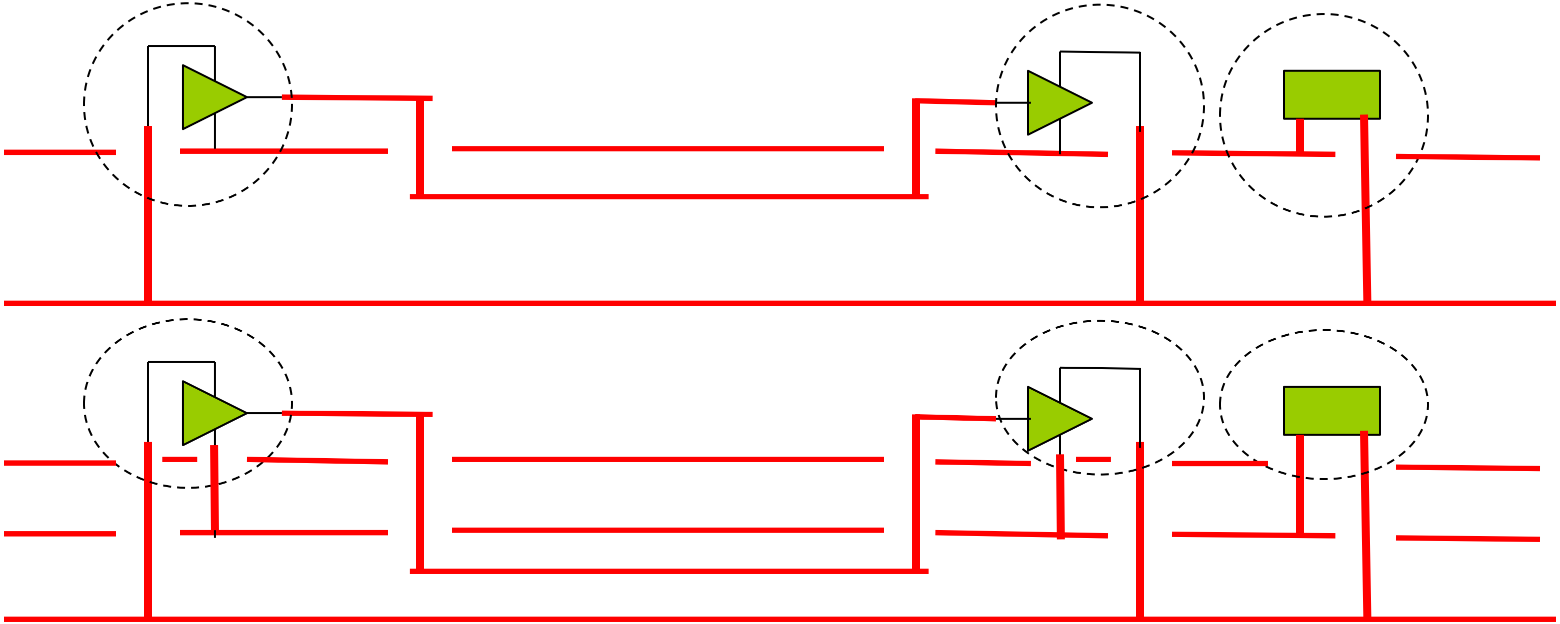
Virtual/Floating vs. Natural

- Virtual/floating reference is convenient to establish common reference for a group of ports
- There are always parasitics associated with that
- Virtual references can be used only at lower frequencies or if the effect is removed (deembedded)
- Natural referencing is always preferable choice (GND, VDD, VSS or all of them – depends on a particular case)
- All PDNs are natural references for transmission lines – interaction of signal nets with PDNs takes place only at transition points (change of reference conductors)

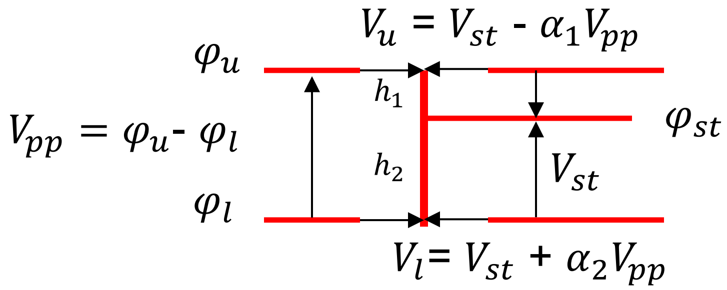
Change of Reference in a Link

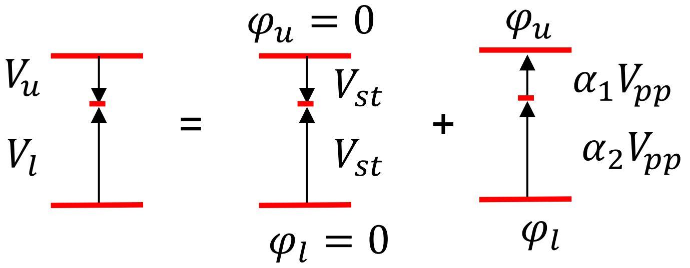
Same reference conductors should be used for ports to connect circuits



Distributed EM model should take care of the rest…

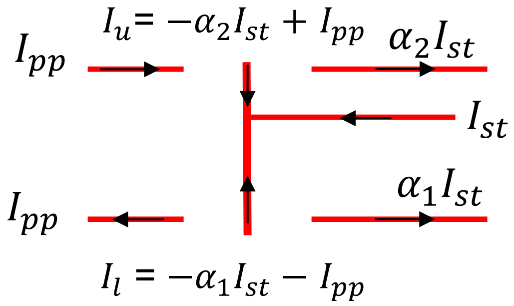
Change of Reference in PDNs



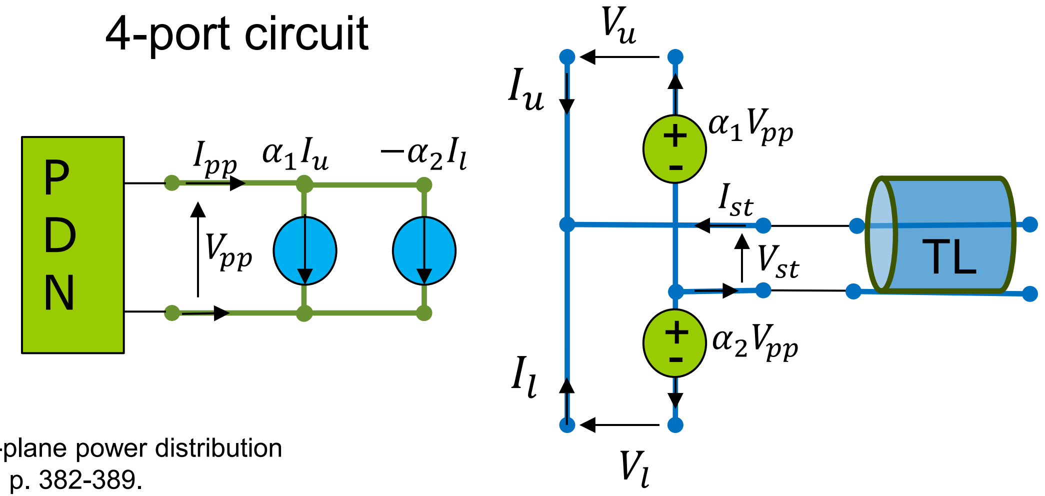


$$\alpha_1 = \frac{h_1}{h_1 + h_2}$$

$$\alpha_2 = \frac{h_2}{h_1 + h_2}$$

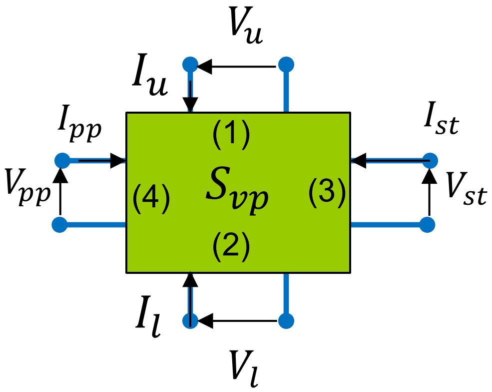


4-port circuit



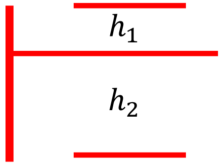
Y.O. Shlepnev, "Transmission plane models for parallel-plane power distribution system and signal integrity analysis", *ACES'2006*, 2006, p. 382-389.

Change of Reference Junction



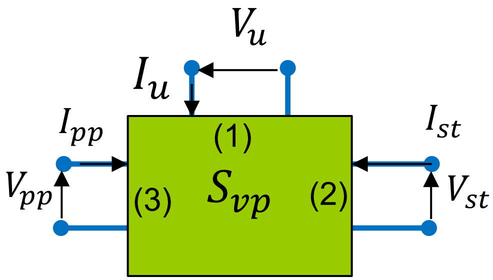
$$S_{vp} = \frac{1}{\beta}\begin{pmatrix} \alpha_1^2 - \alpha_2^2 & -2\alpha_1\alpha_2 + 2 & 2\alpha_2 + 2 & -2\alpha_1 - 2 \\ -2\alpha_1\alpha_2 + 2 & -\alpha_1^2 + \alpha_2^2 & 2\alpha_1 + 2 & 2\alpha_2 + 2 \\ 2\alpha_2 + 2 & 2\alpha_1 + 2 & \alpha_1^2 + \alpha_2^2 - 2 & 2\alpha_1 - 2\alpha_2 \\ -2\alpha_1 - 2 & 2\alpha_1 - 2\alpha_2 & 2\alpha_1 - 2\alpha_2 & 2 - \alpha_1^2 - \alpha_2^2 \end{pmatrix}$$

$$\beta = \alpha_1^2 + \alpha_2^2 + 4$$



$$\alpha_1 = \frac{h_1}{h_1 + h_2}$$

$$\alpha_2 = \frac{h_2}{h_1 + h_2}$$



$$S_{vp} = \frac{1}{\gamma}\begin{pmatrix} \alpha_1^2 & 2 & -2\alpha_1 \\ 2 & \alpha_1^2 & 2\alpha_1 \\ -2\alpha_1 & 2\alpha_1 & 2 - \alpha_1^2 \end{pmatrix}$$

$$\gamma = \alpha_1^2 + 2$$

Possible Touchstone Extensions

- Add information about ports physical structure
  - Lumped or wave-port (t-line port)
  - Reference conductors