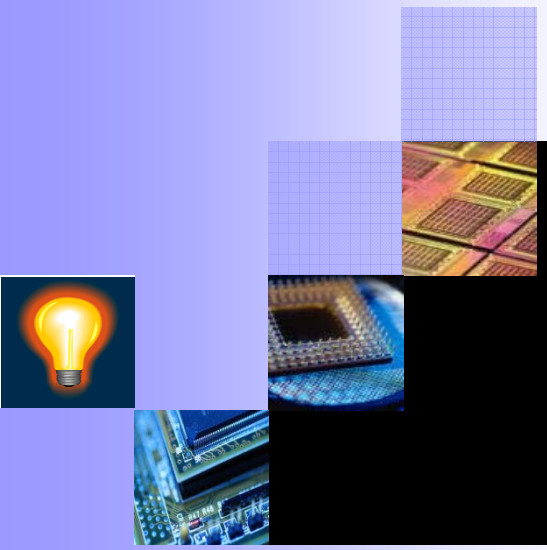

# Suggestions on the Representation of Mixed Mode Network Parameters

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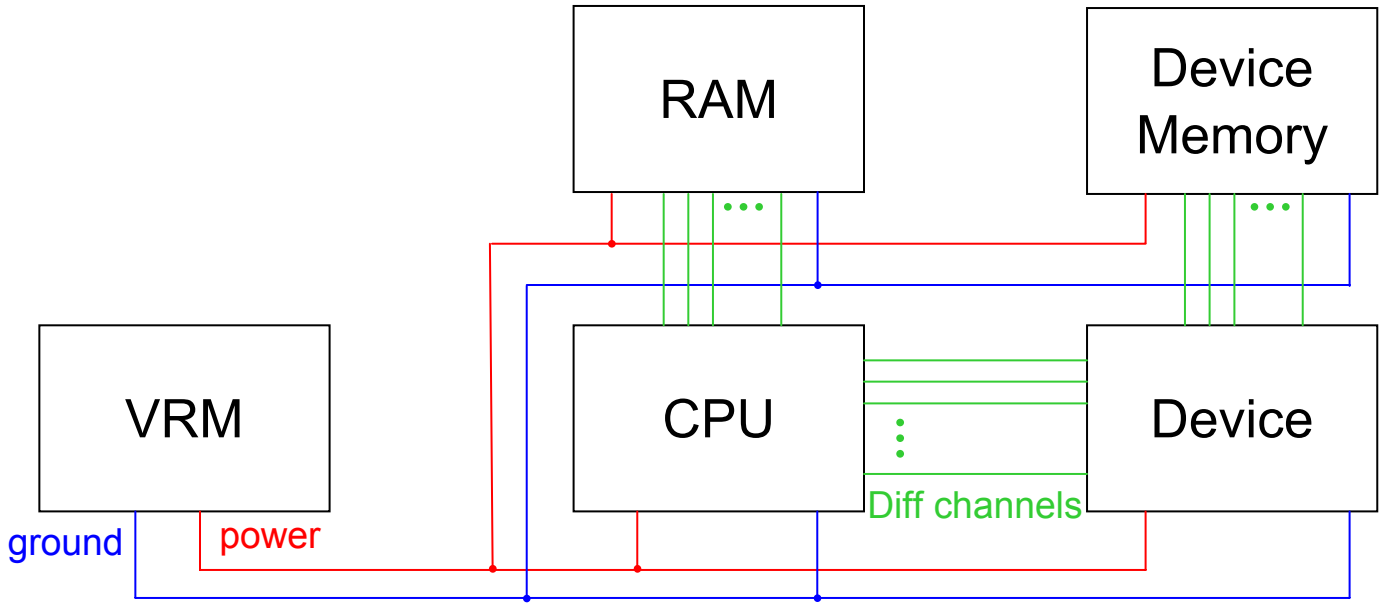
# Motivation

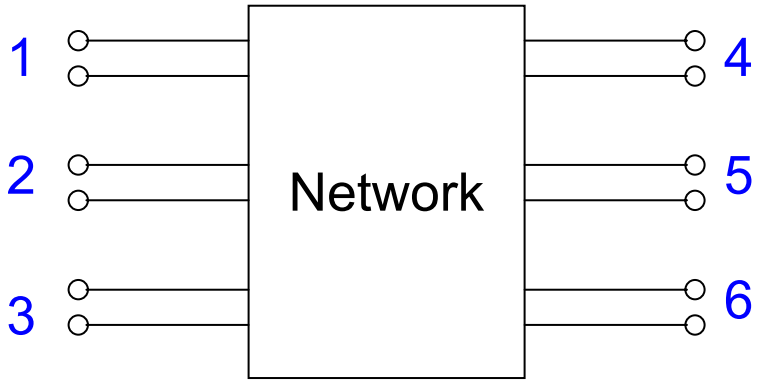
- There is an increasing demand to include the mixed mode network parameters into the Touchstone format.
- The description of a system is not complete if the differential channels are separated from the single-ended channels.



# Key Considerations

- True mixed mode -- differential, common, and single-ended modes in the same matrix
- Matrix element ordering, mapping between the differential modes and the single-ended modes
- Generalized representation, not limited to the differential and common modes
- Device mapping
- Compatibility with Touchstone 1.0

# Review: Network Parameters




- The network can be seen as a black box. The network parameters describes the behavior of the network
- Ports define the connections between the network and the measurement device
- Normalized network parameters (S, normalized Y and Z) further include a description of the measurement system

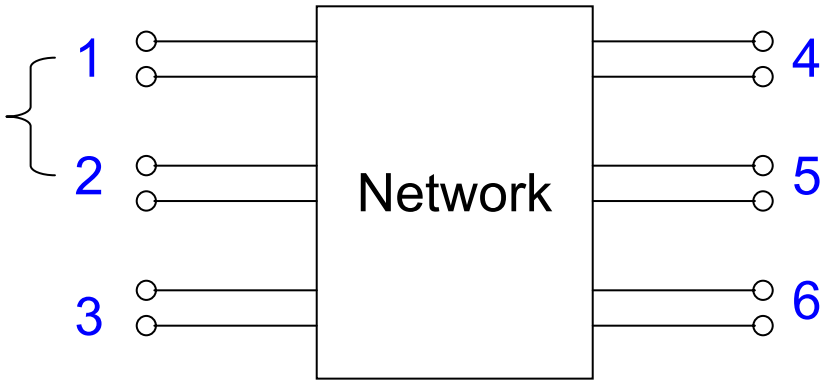
# Review: Differential and Common Modes

$$V_{d1} = V_1 - V_2$$

$$I_{d1} = \frac{I_1 - I_2}{2}$$

$$V_{c1} = \frac{V_1 + V_2}{2}$$

$$I_{c1} = I_1 + I_2$$




- Two modes D1 and C1 are introduced to replace the original single-ended modes S1 and S2.
- The voltage and current measurement for the modes are defined by relating them to the port voltage and currents.

# That's it?

- Yes. That completes the definition
- What about the differential and common modes at the other end of the pair, if there were any?
  - Their definition is separate
  - The system description is complete (although inconvenient) without those modes
- What about the impedance?
  - The impedance is the property of the measurement device, not the system itself
  - The impedance is required if normalized network parameters are desired. For compatibility with the conventional Touchstone format, they should be defined.
  - The impedance can be chosen to be any value, the conventional $2Z_0$ and $Z_0/2$ is just a physical choice

# Conversion Relationship

$$\begin{bmatrix} V_{d1} \\ V_{c1} \end{bmatrix} = \begin{bmatrix} 1 & -1 \\ 1/2 & 1/2 \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \end{bmatrix} \qquad \begin{bmatrix} I_{d1} \\ I_{c1} \end{bmatrix} = \begin{bmatrix} 1/2 & -1/2 \\ 1 & 1 \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \end{bmatrix}$$

$$\begin{bmatrix} a_i \\ b_i \end{bmatrix} = \frac{1}{2\sqrt{\mathrm{Re}(Z_i)}} \begin{bmatrix} 1 & Z_i \\ 1 & -Z_i \end{bmatrix} \begin{bmatrix} V_i \\ I_i \end{bmatrix} \qquad i = 1,2,d1,c1$$

Choose $Z_1=Z_2=Z_{d1}/2=2Z_{c1}$

$$\begin{bmatrix} a_{d1} \\ a_{c1} \\ b_{d1} \\ b_{c1} \end{bmatrix} = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 & -1 & 0 & 0 \\ 1 & 1 & 0 & 0 \\ 0 & 0 & 1 & -1 \\ 0 & 0 & 1 & 1 \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \\ b_1 \\ b_2 \end{bmatrix}$$

It correlates the wave modes in the two measurement devices, but is not necessary to describe the system

# Matrix Conversion

$$\begin{array}{c|cccccc} & 1 & 2 & 3 & 4 & 5 & 6 \\ 1 & S_{11} & S_{12} & S_{13} & S_{14} & S_{15} & S_{16} \\ 2 & S_{21} & S_{22} & S_{23} & S_{24} & S_{25} & S_{26} \\ 3 & S_{31} & S_{32} & S_{33} & S_{34} & S_{35} & S_{36} \\ 4 & S_{41} & S_{42} & S_{43} & S_{44} & S_{45} & S_{46} \\ 5 & S_{51} & S_{52} & S_{53} & S_{54} & S_{55} & S_{56} \\ 6 & S_{61} & S_{62} & S_{63} & S_{64} & S_{65} & S_{66} \end{array}$$

$$\Rightarrow$$

$$\begin{array}{c|cccccc} & d1 & c1 & 3 & 4 & 5 & 6 \\ d1 & S_{d1-1} & S_{d1-c1} & S_{d1-3} & S_{d1-4} & S_{d1-5} & S_{d1-6} \\ c1 & S_{c1-d1} & S_{c1-c1} & S_{c1-3} & S_{c1-4} & S_{c1-5} & S_{c1-6} \\ 3 & S_{3-d1} & S_{3-c1} & S_{33} & S_{34} & S_{35} & S_{36} \\ 4 & S_{4-d1} & S_{4-c1} & S_{43} & S_{44} & S_{45} & S_{46} \\ 5 & S_{5-d1} & S_{5-c1} & S_{53} & S_{54} & S_{55} & S_{56} \\ 6 & S_{6-d1} & S_{6-c1} & S_{63} & S_{64} & S_{65} & S_{66} \end{array}$$

- Both matrices are *COMPLETE* description of the network, so they are equivalent and can be converted back and forth
- The order of the modes is *NOT* important, as long as it is consistent with the matrix elements

# **Proposal**: General Description of the Mixed Mode Matrices

- In the new Touchstone format, the modes should be explicitly defined, by giving the voltage and current relationships with the single-ended modes
- The definition order determines the matrix storage, so the matrix data format is the same for all matrices
- More than one set of modes can be defined in the same file, even if the corresponding matrices are not saved in the file
- Each matrix needs to refer to a set of mode definitions
- An optional mode name is helpful to characterize the mode, but it is not required

# Example

```
[Mode Definition] Mixed mode1
V 1 1.0 2 -1.0 | I 1 0.5 2 -0.5 | R 100 | Diff1
V 1 0.5 2 0.5 I 1 1.0 2 1.0 R 25 Comm1
V 3 1.0 I 3 1.0 R 50 S3
V 4 1.0 I 4 1.0 R 50 S4
V 5 1.0 I 5 1.0 R 50 S5
V 6 1.0 I 6 1.0 R 50 S6
[Network Parameter] Mixed mode1
# GHz S RI R 50
.....
```

Name of this set of modes

port index

coefficient

Mode name

Voltage calculation

Current calculation

Impedance

Refer to the definition by name

# Advantages

- No confusion on the differential mode to port correlation
- No confusion on the element order
- Unified matrix storage, even compatible with Touchstone 1.0 except for the single port impedance definition
- Differential/common modes and single-ended modes can exist in the same matrix
- More than one matrices can be stored in the same file
- Not limited to differential and common modes
- Valid for both passive and active networks
- Allows error checking of the modes
  - Completeness, Orthogonality…

# Other Considerations

- Device Mapping?
  - Too application specific
  - Maybe just put it in the mode name?
- Definition keywords: V, I, a, b, R, Z…
- Reserve keywords for simplicity?
  - Differential, Common, Single-Ended…
- Default definition for single-ended modes?
- More than one matrix in one file?
- Frequency dependent impedance?

# Thank You!