Matrix Parameters in Touchstone

Bob Ross, Teraspeed Labs, USA
bob@teraspeedlabs.com

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Agenda

- Goals
- Touchstone V1.0, V1.1, V2.0, V2.1 differences
- Reference Impedances (resistances)
- n-Port matrices (S, Y, Z)
  - Conversions and mathematics
- 2-port matrices (H, G)
  - Conversions
- Conclusion

Goals

- Show features for an upcoming Touchstone Version 2.1 document
- Show conversion mathematics for different per-port reference impedances (resistances) for TSCHK2.1 parser development

- Note, reference impedance will be designated as reference resistance since complex references are not supported

Touchstone Version 2.1 Document

- Touchstone V1.0 and V1.1 formats in the Version 2.1 Document
  - No keywords, content based on strict formatting rules
  - V1.0 supports a single port reference resistance in the option line beginning with # … R <r value> …
  - V1.1 supports per-port reference resistances at the end of the option line with # … R $<r_1>$ $<r_2>$… $<r_n>$ syntax
  - S-parameter matrices are defined based on the option line resistance entries
  - All other matrices are NORMALIZED regardless of option line entries. For example, if R = 50.0 Ω, then $z_{1,1}$ = 1.0 in V1.0 when the measured value is $z_{1,1}$ = 50.0 Ω
  - Per-port reference resistances are already supported by several EDA tools (but they may have different formats)

Touchstone Version 2.1 Document

- Touchstone V2.0 and V2.1 rules in the Version 2.1 Document
  - Keyword based and [Version] 2.0 or [Version] 2.1 is required
  - V2.0 and V2.1 have identical matrix data
  - S-parameter matrices remain unchanged from V1.0 or V1.1 and are based on the reference resistance entries
  - Y-, Z-, H-, G-parameter matrices are UN-NORMALIZED (sensitive to reference resistor values) – as if measured directly in ohms or siemens (mhos)
  - [Reference] keyword lists the reference resistors
    - Values can wrap (unlike in V1.1 where all values are on a single options line)

TSCHK2.0 Conversion Syntax Between V1.0 and V2.0

tschk2 –canonical

```
tschk2 -canonical    <options> FILE  Shortcut for -canonical-v2.
```

tschk2 –canonical –v2

```
tschk2 -canonical-v2 <options> FILE  Checks the file, sending error and warning
                                       information to stderr, and writes a valid file
                                       to stdout in Touchstone v2 format.
```

tschk2 –canonical –v1

```
tschk2 -canonical-v1 <options> FILE  Checks the file, sending error and warning
                                       information to stderr, and writes a valid file
                                      to stdout in Touchstone v1 format, if possible.
```

A tschk2.1 parser should support the V1.1 and V2.1 conversions

Notation

- Z (normalized), Z^U (un-normalized)
- Y (normalized), Y^U (un-normalized)
- H (normalized), H^U (un-normalized), 2-port only
- G (normalized), G^U (un-normalized), 2-port only

- R $<r_1>$ $<r_2>$… $<r_n>$ per-port reference resistors
- R <r> for a single reference resistance

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General N-Port Z Matrix Conversion

- José Schutt-Ainé, ECE 546, Lecture 13, *Scattering Parameters*, Slides 28-29, Spring 2022, http://emlab.illinois.edu/ece546/Lect_13.pdf
- Formulas are restated using the notation in this presentation
- k = diagonal $[\sqrt{r_1},\ \sqrt{r_2},\ \ldots\ ,\ \sqrt{r_n}\ ]$ are based on power wave per-port normalization between incident and reflected waves (b = Sa)
- $Z = (I + S)(I - S)^{-1}$ (normalized to r = 1; I = unit matrix)
- $Z^U = k\,(I + S)(I - S)^{-1}\,k = k\,Z\,k$
- Multiplication by the diagonal matrix k produces the terms $z^u{}_{i,j} = z_{i,j}\sqrt{r_i r_j}$

Illustrating $z^u_{i,j}$ Term Calculation

$$z^u_{i,j} = \begin{bmatrix} k_1 & 0 & 0 \\ 0 & k_i & 0 \\ 0 & 0 & k_n \end{bmatrix} \begin{bmatrix} z_{1,1} & z_{1,j} & z_{1,n} \\ z_{i,1} & z_{i,j} & z_{i,n} \\ z_{n,1} & z_{n,j} & z_{n,n} \end{bmatrix} \begin{bmatrix} k_1 & 0 & 0 \\ 0 & k_j & 0 \\ 0 & 0 & k_n \end{bmatrix} =$$

$$\begin{bmatrix} k_1 & 0 & 0 \\ 0 & k_i & 0 \\ 0 & 0 & k_n \end{bmatrix} \text{ X } \begin{bmatrix} z_{1,1}k_1 & z_{1,j}k_j & z_{1,n}k_n \\ z_{i,1}k_1 & z_{i,j}k_j & z_{i,n}k_n \\ z_{n,1}k_1 & z_{n,j}k_j & z_{n,n}k_n \end{bmatrix} =$$

$$\begin{bmatrix} k_1z_{1,1}k_1 & k_1z_{1,j}k_j & k_1z_{1,n}k_n \\ k_iz_{i,1}k_1 & k_iz_{i,j}k_j & k_iz_{i,n}k_n \\ k_nz_{n,1}k_1 & k_nz_{n,j}k_j & k_nz_{n,n}k_n \end{bmatrix} = z_{i,j}\sqrt{r_ir_j}$$

N-Port Matrix Conversions

$Z^U \leftarrow Z$

$$z^u_{i,j} = \sqrt{r_i r_j}\, z_{i,j}$$

$Z \leftarrow Z^U$

$$z_{i,j} = z^u_{i,j} / \sqrt{r_i r_j}$$

$Y^U \leftarrow Y$

$$y^u_{i,j} = y_{i,j} / \sqrt{r_i r_j}$$

$Y \leftarrow Y^U$

$$y_{i,j} = \sqrt{r_i r_j}\, y^u_{i,j}$$

In V1.0 and V2.0, R <r> is used if $r_i = r_j$

V2.0 cannot be converted to V1.0 if $r_i \neq r_j$

2-Port H-Parameter Conversions

$H^U \leftarrow H$

$$\begin{bmatrix} h^u_{1,1} & h^u_{1,2} \\ h^u_{2,1} & h^u_{2,2} \end{bmatrix} = \begin{bmatrix} h_{1,1}\, r_1 & h_{1,2} \\ h_{2,1} & h_{2,2}\, / r_2 \end{bmatrix}$$

$H \leftarrow H^U$

$$\begin{bmatrix} h_{1,1} & h_{1,2} \\ h_{2,1} & h_{2,2} \end{bmatrix} = \begin{bmatrix} h^u_{1,1}\, / r_1 & h^u_{1,2} \\ h^u_{2,1} & h^u_{2,2}\, r_2 \end{bmatrix}$$

2-Port G-Parameter Conversions

$G^U \leftarrow G$

$$\begin{bmatrix} g^u_{1,1} & g^u_{1,2} \\ g^u_{2,1} & g^u_{2,2} \end{bmatrix} = \begin{bmatrix} g_{1,1}/r_1 & g_{1,2} \\ g_{2,1} & g_{2,2}\, r_2 \end{bmatrix}$$

$G \leftarrow G^U$

$$\begin{bmatrix} g_{1,1} & g_{1,2} \\ g_{2,1} & g_{2,2} \end{bmatrix} = \begin{bmatrix} g^u_{1,1}\, r_1 & g^u_{1,2} \\ g^u_{2,1} & g^u_{2,2}/r_2 \end{bmatrix}$$

Conclusion

- Differences in Touchstone V1.0, V1.1, V2.0, V2.1 are shown
- New V1.1 option line syntax is shown
- Transformations between normalized and un-normalized matrix data are given for different per-port reference resistances
- TSCHK2.1 parser developer should add the per-port reference matrix transformation capability