Touchstone® File Format Specification

Version 2.0

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INTRODUCTION

A Touchstone file (also known as an SnP file) is an ASCII text file used for documenting the n-port network parameter data of an active device or passive interconnect network. While Touchstone files have been accepted as a defacto standard for the transfer of frequency dependent n-port parameters, up until this document no formal specification of the file format or syntax had been produced. This document, based upon information from Agilent Technologies, Inc. (the originator of Touchstone), is a formal specification of the Touchstone file format and is intended for use with documents and specifications produced by the IBIS Open Forum.

Version 2.0 was created based upon the original Touchstone definition, with added features in the style of IBIS (I/O Buffer Information Specification) and the ICM (IBIS Interconnect Model) specification. Files written using the original syntax are compatible with the updated specification and are treated as Version 1.0.

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GENERAL SYNTAX RULES AND GUIDELINES

The following are the general syntax rules and guidelines for a Touchstone file.

1. Touchstone files are case-insensitive.

2. Only US-ASCII
   a)   graphic characters (i.e., code values 20h through 7Eh),
   b)   tab characters (09h) and
   c)   line termination sequences -- LF (0Ah), CR+LF (0Dh + 0Ah) or CR (0Dh) --

   each encoded in 8 bits as defined in ISO/IEC 8859-1:1998 are permitted in a Touchstone file.

3. Comments are preceded by an exclamation mark (!). Comments may appear on a separate line, or after the last data value on a line. Comments are terminated by a line termination sequence (i.e., multi-line comments are not allowed).

4. Touchstone filenames have traditionally used a file extension of '.snp', where 'n' is the number of network ports of the device or interconnect being described. For example, a Touchstone file containing the network parameters for a 2-port device would be named 'filename'.s2p, while a Touchstone file containing the data for a 3-port network would be 'filename'.s3p, and so on.

   Not all operating systems may recognize filename extensions with variable contents or length as associated with the same type of file. To address this, the extension .s2p often has been applied to Touchstone files describing systems containing other than two ports. For the same reasons, the extension '.ts' is suggested for Touchstone 2.0 files.

   To preserve support of existing Touchstone files and ensure maximum compatibility across operating systems, the use of filename extensions other than those recommended here is permitted by this specification.

   For Version 2.0 and above, the [Number of Ports] keyword establishes the expected number of ports defined in the file.

5. All angles are measured in degrees.

6. Scientific notation is allowed (e.g., 1.2345e-12). No minimum or maximum limits are placed on numerical precision on individual data points.

7. Keywords (as used in Version 2.0 files) shall be enclosed in square brackets, [], and shall start in column 1 of the line. No space or tab is allowed immediately after the opening bracket '[' or immediately before the closing bracket ']'. The keyword syntax, including spelling of words and placement of non-alphabetic characters, shall follow exactly what is documented in this specification. If used, only one space (' ') or dash ('-') character separates the parts of a multi-word keyword.

8. Arguments after keywords shall be separated from the closing bracket of the keyword by at least one whitespace character. Except where otherwise noted, this whitespace separation shall not include carriage return or line feed characters.

FILE FORMAT DESCRIPTION

Introduction

Touchstone data files consist of an 'option line' followed by network parameters taken at specific frequencies. The option line specifies (among other things) the kind of n-port parameters the file contains (S-parameter, Z-parameter, etc.) and the format of the data values (magnitude-phase, real-imaginary, etc.). Data is arranged into groups of n-port parameters preceded by the frequency at which the data was taken or derived. For each frequency, data for a 1-port or 2-port network is contained on a single data line while data for 3-port and above networks is arranged in a matrix row-wise order. The Touchstone format supports matrices of unlimited size.

Version 2.0 adds to the above several additional keywords. Several of the keywords have a particular order and are placed at the beginning of the file. These are shown below.

- [Version] 2.0
- # (Option Line)
- [Number of Ports]

The following keywords shall appear after [Number of Ports] and before [Network Data], but may appear in any order relative to each other.

- [Two-Port Order]   (required if N=2)
- [Number of Frequencies]   (required)
- [Number of Noise Frequencies]   (required if [Noise Data] defined)
- [Reference]   (optional)
- [Matrix Format]   (optional)
- [Mixed-Mode Order]   (optional)
- [Begin Information]/[End Information]   (optional)

Touchstone 2.0 data is positioned under two required keywords in the order shown below. Network data is required and positioned after the required [Network Data] keyword. The [End] keyword marks the end of the file and is placed last.

- [Network Data]
- [Noise Data]   (required only if {Number of Noise Frequencies] given)
- [End]

Network data represents either conventional n-port parameters (corresponding to what is referred to as single-ended port configuration) or mixed-mode parameters associated with differential port configurations. The mixed-mode parameters can be the generalized mixed-mode parameters if not all single-ended ports are combined into differential ports. A differential port is formed from two single-ended ports having the same "reference" terminal (also referred to as the "-" terminal).

In addition to the above option lines, keywords and data lines, files that describe 2-port devices may also contain noise parameter data. Comment lines may be interspersed in the file as necessary.

These keywords and data formats are described in detail in the following sub-sections.

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Comment Lines

Touchstone data files may include comments. Comments are preceded by an exclamation mark (!). Comments may appear on a separate line, or after the last data value on a line. Comments are terminated by a line termination sequence (i.e., multi-line comments are not allowed).

The syntax rules for comments are identical for Version 1.0 and Version 2.0 files.

[Version]

Rules for Version 1.0 files:
The [Version] keyword is not permitted for Version 1.0 files.

Rules for Version 2.0 files:
The [Version] keyword is required for files using any Version 2.0 syntax.

Each Touchstone Version 2.0 data file shall contain one and only one [Version] keyword and entry. This shall precede all other non-comment lines. Both the opening and closing brackets are required. The [Version] keyword is followed by one string argument. The argument shall be preceded by whitespace.

The [Version] keyword provides information on the Version of the specification under which the file contents should be interpreted.

The only valid argument is '2.0'.

Option Line

Each Touchstone data file shall contain an option line (additional option lines after the first one shall be ignored). The option line is formatted as follows:

<frequency unit> <parameter> <format> R *<n>*

where
marks the beginning of the option line.

frequency unit   specifies the unit of frequency. Legal values are Hz, kHz, MHz and GHz,. The default value is GHz.

parameter   specifies what kind of network parameter data is contained in the file. Legal values are:
          S for Scattering parameters,
          Y for Admittance parameters,
          Z for Impedance parameters,
          H for Hybrid-h parameters,
          G for Hybrid-g parameters.
The default value is S.

format   specifies the format of the network parameter data pairs. Legal values are:
          DB for dB-angle (dB = $20 \times \log_{10}|magnitude|$)
          MA for magnitude-angle,
          RI for real-imaginary.
Angles are given in degrees. Note that this format does not apply to noise parameters (refer to the 'Adding Noise Parameters' section at the end of this specification). The default value is MA.

R n   specifies the reference resistance in ohms, where *n* is a real, positive number of ohms. The default reference resistance is 50 ohms. Note that this is overridden by the [Reference] keyword, described below, for files of [Version] 2.0 and above.

Option line parameters are separated by one or more whitespace; the option line itself is terminated with a newline character (either CR or CR/LF). If a parameter is missing, the default value is assumed. With the exception of the opening # (hash mark) symbol and the value following 'R', option line parameters can appear in any order.

In summary, the option line should read:

For 1-port files: # [Hz|kHz|MHz|GHz] [S|Y|Z] [DB|MA|RI] [R n]
For 2-port files: # [Hz|kHz|MHz|GHz] [S|Y|Z|G|H] [DB|MA|RI] [R n]
For 3-port and beyond files: # [Hz|kHz|MHz|GHz] [S|Y|Z] [DB|MA|RI] [R n]
For mixed-mode files: # [Hz|kHz|MHz|GHz] [S|Y|Z] [DB|MA|RI] [R n]

where the square brackets ([]) indicate optional information; ...|...|...| means to select one of the choices; and *n* is replaced by a positive integer or floating-point number. Though specific cases are used for the units above and throughout this specification (e.g., 'kHz'), Touchstone files are case-insensitive.

The reference impedance specified in the option line applies to all ports described in the data lines, if [Reference] is not present.

Rules for Version 1.0 Files:
For Version 1.0 files, the option line shall immediately precede any data lines and shall be the first non-comment line in the file.

The reference resistance defines the system reference for the S-parameter data and the normalization used on G-, H-, Y- and Z-parameter data.

Rules for Version 2.0 Files:
For Version 2.0 files, the option line shall follow the [Version] keyword and precede the [Number of Ports] keyword.

For Version 2.0 files, the reference resistance defines the system reference for the S-parameter data if the [Reference] keyword is not present. Normalization does not apply to Version 2.0 files. Therefore, the reference resistance and [Reference] keyword have no impact on G-, H-, Y- or Z-parameter data in Version 2.0 files.

Mixed-mode network parameters are described in the file if the [Mixed-Mode Order] keyword is present. Mixed-mode parameters are only supported for S-, Y- and Z-parameter data.

Per the defaults above, an empty option line (a single hash mark without any non-comment characters following it) in a Version 1.0 file would indicate that the file uses GHz units for frequency, single-ended S-parameters for the network data, magnitude-angle (MA) for the network data format and 50 ohms as the reference or normalization resistance. In a Version 2.0 file, the same defaults would apply, except that no normalization would be assumed and any [Reference] entry would supersede the 50 ohm reference resistance assumption.

Option Line Examples

Minimum required option line example, using all default values:
#

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Frequency in GHz, S-parameters in real-imaginary format, referenced to 100 ohms:
```
# GHz S RI R 100
```

Frequency in kHz, Y-parameters in real-imaginary format, normalized to 100 ohms:
```
# kHz Y RI R 100
```

Frequency in Hz, Z-parameters in magnitude-angle format, normalized to 10 ohms:
```
# Hz Z MA R 10
```

Frequency in kHz, H-parameters in real-imaginary format normalized to 1 ohm:
```
# kHz H RI R 1
```

Frequency in MHz, G-parameters in decibel format normalized to 1 ohm:
```
# MHz G DB R 1
```

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[Number of Ports]

Rules for Version 1.0 Files:
The [Number of Ports] keyword is not permitted in Version 1.0 files.

Rules for Version 2.0 Files:
Each Touchstone Version 2.0 file shall contain one and only one [Number of Ports] keyword and entry. The [Number of Ports] keyword and associated data define the number of single-ended ports represented by data in the file.

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The [Number of Ports] keyword is followed by a single positive integer argument, separated from the keyword by whitespace.

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The [Number of Ports] keyword is required for Version 2.0 files. It shall be the first keyword after the option line.

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Example 1 (Version 2.0):

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```
! 4-port S-parameter data
! Data valid for 1.0, if [Version] and [Number of Ports] are removed
[Version] 2.0
# GHz S MA R 50
[Number of Ports] 4
```

[Two-Port Data Order]

Rules for Version 1.0 Files:
The [Two-Port Data Order] keyword is not permitted in Version 1.0 files.

Rules for Version 2.0 Files:
The [Two-Port Data Order] keyword is required only when the value for the [Number of Ports] keyword is 2. Otherwise, it is not permitted. When required, the [Two-Port Data Order] line shall appear after the [Number of Ports] keyword and before any network data. Multiple [Two-Port Data Order] keywords in the same file are not permitted.

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The [Two-Port Data Order] line shall begin with the keyword [Two-Port Data Order], in brackets as shown. This keyword is followed by one of two string arguments separated from the keyword by whitespace: 12_21 or 21_12.

The [Two-Port Data Order] keyword is used to signify the column ordering convention. The Version 1.0 convention for two-port network data is N11, N21, N12, N22, where N11, N12,etc. represent pairs of data values. However, some tools and users have adopted the convention N11, N12, N21, N22 (a more natural order consistent with all the other n-port ordering conventions). The keyword makes the ordering of 2-port network data explicit and unambiguous in Version 2.0 files.

[Number of Frequencies]

Rules for Version 1.0 Files:
The [Number of Frequencies] keyword is not permitted in Version 1.0 files.

Rules for Version 2.0 Files:
The [Number of Frequencies] keyword entry specifies the number of frequency points, and therefore blocks of network parameters, listed in the file.

The [Number of Frequencies] section shall begin with the keyword [Number of Frequencies], in brackets as shown. This keyword is followed by an integer greater than 0.

The [Number of Frequencies] is required in Version 2.0 files.

[Number of Frequencies] shall appear after the [Number of Ports] keyword and before any network data.

[Number of Frequencies] has no impact on noise parameters.

Example 2 (Version 2.0):

```
!1-port Z-parameter file, multiple frequency points
[Version] 2.0
# MHz Z MA
[Number of Ports] 1
[Number of Frequencies] 5
[Reference] 20.0
```

[Number of Noise Frequencies]

Rules for Version 1.0 Files:
The [Number of Noise Frequencies] keyword is not permitted in Version 1.0 files.

Rules for Version 2.0 Files:
The [Number of Noise Frequencies] keyword entry specifies the number of noise frequency points, and therefore blocks of noise parameters, listed in the file.

The [Number of Noise Frequencies] section shall begin with the keyword [Number of Noise Frequencies], in brackets as shown. This keyword is followed by an integer greater than 0.

The [Number of Noise Frequencies] is required in Version 2.0 files only if noise parameter data is provided.

[Number of Noise Frequencies] shall appear after the [Number of Ports] keyword and before any network data.

Example 3 (Version 2.0):
```
!2-port network, S-parameter and noise data
!Default MA format, GHz frequencies, 50 ohm reference, S-parameters
[Version] 2.0
#
[Number of Ports] 2
[Two-Port Data Order] 21_12
[Number of Frequencies] 2
[Number of Noise Frequencies] 2
[Reference] 50 25.0
```

[Reference]

Rules for Version 1.0 Files:
The [Reference] keyword is not permitted in Version 1.0 files.

Rules for Version 2.0 Files:
The [Reference] keyword and associated data provide a per-port definition of the reference environment used for the S-parameter measurements in the network data. It shall appear only once in the file.

The [Reference] section shall begin with the keyword [Reference], in brackets as shown. This keyword is followed by one or more positive integer or floating-point numbers, separated from the keyword and each other by whitespace. [Reference] data shall not be mixed with data for any other keyword in the file. [Reference] data may span multiple lines.

Each of the entries is a real-valued impedance (i.e., a resistance) and is assumed to be ordered per port numerically starting at 1 and ending with the value listed under [Number of Ports] (e.g., if [Number of Ports] contains the value "5", five entries are expected under [Reference], ordered starting with port 1's impedance and ending with port 5's impedance. The [Reference] keyword assumes and refers to single-ended ports.

The units of the [Reference] impedances are ohms.

[Reference] shall only appear after the [Number of Ports] keyword and before any network data.

Note that complex and imaginary impedance values are not supported.

[Reference] is optional. If [Reference] is not present, the reference impedances for the S-parameter data are assumed to be defined by the option line. If [Reference] is present, it shall contain an impedance entry for every port represented in the data (for example, a four-port data file using [Reference] shall contain four [Reference] impedance entries).

The [Reference] keyword has no impact on G-, H-, Y- or Z-parameter data.

[Reference] arguments may begin on the line following the closing bracket of the keyword (in other words, after a carriage return and/or line feed character).

Example 4 (Version 2.0):
```
! 4-port S-parameter data
! Default impedance is overridden by the [Reference] line
```

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```
! Data cannot be represented using 1.0 syntax.
! Note that the [Reference] keyword entries appear on a separate line
[Version] 2.0
# GHz S MA R 50
[Number of Ports] 4
[Reference]
50 75 0.01 0.01
[Number of Frequencies] 1
```

[Matrix Format]

Rules for Version 1.0 Files:
The [Matrix Format] keyword is not permitted in Version 1.0 files.

Rules for Version 2.0 Files:
The [Matrix Format] keyword entry specifies whether an entire matrix or a subset of all matrix elements is given for single-ended data. The latter case is applicable to symmetric matrices for which either only the lower triangular part (including the diagonal), or only the upper triangular part (including the diagonal) is included. This assumption is most appropriate for interconnects. Note that all ports are always represented, but the format for the data takes advantage of symmetry to reduce the overall file size.

The [Matrix Format] section shall begin with the keyword [Matrix Format], in brackets as shown. This keyword is followed by one of three possible strings: "Full", "Lower" or "Upper".

[Matrix Format] shall appear after the [Number of Ports] keyword and before any network data.

[Matrix Format] is optional. If [Matrix Format] is not present, the network data included in the file is assumed to be of type "Full" and the network data for each port as specified under [Number of Ports] shall be specified for each frequency point.

[Matrix Format] has no effect on noise data.

Example 5 (Version 2.0):
```
! 4-port S-parameter data
! Default impedance is overridden by the [Reference] line
! Data cannot be represented using 1.0 syntax.
[Version] 2.0
# GHz S MA R 50
[Number of Ports] 4
[Number of Frequencies] 1
[Reference] 50 75 0.01 0.01
[Matrix Format] Full
[Network Data]
5.00000 0.60 161.24 0.40 -42.20 0.42 -66.58 0.53 -79.34 !row 1
        0.40 -42.20 0.60 161.20 0.53 -79.34 0.42 -66.58 !row 2
        0.42 -66.58 0.53 -79.34 0.60 161.24 0.40 -42.20 !row 3
        0.53 -79.34 0.42 -66.58 0.40 -42.20 0.60 161.24 !row 4
```

Example 6 (Version 2.0):
```
! 4-port S-parameter data
! Default impedance is overridden by the [Reference] line
! Data cannot be represented using 1.0 syntax.
[Version] 2.0
```

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```
# GHz S MA R 50
[Number of Ports] 4
[Number of Frequencies] 1
[Reference] 50 75 0.01 0.01
[Matrix Format] Lower
[Network Data]
5.00000 0.60 161.24                                      !row 1
        0.40 -42.20 0.60 161.20                          !row 2
        0.42 -66.58 0.53 -79.34 0.60 161.24              !row 3
        0.53 -79.34 0.42 -66.58 0.40 -42.20 0.60 161.24 !row 4
```

[Network Data]

Rules for Version 1.0 Files:
The [Network Data] keyword is not permitted in Version 1.0 files.

Rules for Version 2.0 Files:
The [Network Data] keyword explicitly identifies the beginning of the network data in a Touchstone 2.0 file. Each Touchstone Version 2.0 file shall contain one and only one [Network Data] keyword and entry.

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The [Network Data] line is required for Version 2.0 files. It shall appear after the [Number of Ports] keyword and immediately before any network data.

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Example 7 (Version 2.0):
```
!1-port Z-parameter file, multiple frequency points
[Version] 2.0
# MHz Z MA
[Number of Ports] 1
[Number of Frequencies] 5
[Reference] 20.0
[Network Data]
!freq  magZ11 angZ11
100    74.25   -4
200    60      -22
300    53.025  -45
400    30      -62
500    0.75    -89
```

Single-Ended Network Parameter Data

Following the option line (Version 1.0 files) or [Network Data] keyword (Version 2.0 files) are the network parameters (S-parameter, Z-parameter, etc.) of the type specified by the option line. Groups of n-port parameters are preceded by the frequency value for which the data was obtained, and the n-port parameters themselves are formatted as pairs of values (magnitude-angle, dB-angle or real-imaginary).

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Network data is grouped into one or more lines which end with a line termination character. In Version 1.0 files, for each frequency, n-port parameters for 1-port and 2-port networks are contained on one data line, while data for 3-port and larger networks are arranged on multiple data lines in a matrix row-wise order.

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In summary, there are five general rules for formatting network data into lines:

1. In Version 1.0 files, no more than four pairs of n-port parameters are allowed per network data line. No restriction exists on the number of data pairs on a line in Version 2.0 files.

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2. Individual entries in network data lines are separated by whitespace.
3. A network data line is terminated by a line termination character.
4. All network data lines shall be arranged in increasing order of frequency.
5. Frequency values shall only appear at the beginning of lines, after the newline character.

Detailed descriptions for arranging the data for various n-port networks follow.

Note that H- and G- parameters are defined for 2-port networks only. These hybrid parameters cannot be used to describe networks containing any other number of ports.

Rules for Version 2.0:
In Version 2.0 files, the data associated with any one frequency may be split across any number of lines or may be placed on a single line of arbitrary length. Data in a Version 2.0 file is parsed using the [Number of Ports] entry and the [Matrix Format] entry. For a Full matrix, a new frequency point is expected every $2 \times n^2 + 1$ values, where n is the number of ports, regardless of intervening newline characters. For a Lower or Upper matrix, a new frequency point is expected every $n^2 + n + 1$ values

Note that data is represented in mixed-mode format when the [Mixed-Mode Order] keyword is present. Note that the traditional (conventional) single-ended data used in Touchstone 1.0 and the mixed-mode representation are mutually exclusive; the same file cannot contain both as separate sets of data, since the [Mixed-Mode Order] keyword and associated data can include single-ended network parameters.

1-port and 2-port Networks

Network parameter data for 1-port and 2-port networks at a single frequency can be contained on a single data line. As shown below, the data line consists of a frequency value followed by either one or four pairs of data values.

1-port data (line)
<frequency value> <N11>

2-port data (line)
<frequency value> <N11> <N21> <N12> <N22>

where
frequency value   frequency at which the network parameter data was taken or derived.

N11, *N21*, *N12*, *N22*   network parameter data points, where N*ij* represents a pair of data values.

Note that Version 2.0 files containing 2-port network data require the [Two-Port Data Order] keyword with the argument 21_12 to designate the order above. Use of the [Two-Port Data Order] keyword with the argument 12_21 permits the alternate order, shown below, to be used.

2-port data (line)
<frequency value> <N11> <N12> <N21> <N22>

where
frequency value   frequency at which the network parameter data was taken or derived.

N11, *N12*, *N21*, *N22*   network parameter data points, where N*ij* represents a pair of data values.

Network parameter data points shall be in magnitude-angle, dB-angle or real-imaginary format (i.e., pairs of values) as specified by the option line. For 1-port networks, only '11' data is allowed for Full, Upper or Lower format.

For Full 2-port networks, all four port data pairs are required. If [Matrix Format] is specified as Lower or Upper, 2-port network data includes only '11', '21' and '22' data, in that order (as '21' and '12' are assumed identical, Lower and Upper 2-port network data matrices are identical).

All entries in a data line are separated by one or more whitespace characters; a data line itself is terminated by a newline character (CR or CR/LF). Multiple data lines are allowed but, as mentioned above, they shall be arranged in increasing order of frequency.

Shown below are some examples of Touchstone files for 1-port and 2-port networks.

Example 8 (Version 1.0):
```
!1-port S-parameter file, single frequency point
# MHz S MA R 50
!freq magS11 angS11
2.000 0.894  -12.136
```

In the above example, the value of S11 at a frequency of 2 MHz is given in magnitude-angle format. The reference impedance is 50 ohms.

Example 9 (Version 1.0):
```
!1-port Z-parameter file, multiple frequency points
# MHz Z MA R 75
!freq  magZ11 angZ11
100    0.99   -4
200    0.80   -22
300    0.707  -45
400    0.40   -62
500    0.01   -89
```

Note that, in the above example, Z11 is normalized to 75 ohms, as given by the reference impedance (R 75) in the option line.

Example 10 (Version 2.0):
```
!1-port Z-parameter file, multiple frequency points
[Version] 2.0
# MHz Z MA
[Number of Ports] 1
[Number of Frequencies] 5
[Reference] 20.0
[Network Data]
!freq  magZ11 angZ11
100    74.25  -4
200    60     -22
300    53.025 -45
400    30     -62
500    0.75   -89
```

This example duplicates the data in Example 8, using Version 2.0 syntax. Note that normalization does not apply.

Example 11 (Version 1.0):
```
!2-port H-parameter file, single frequency point
# kHz H MA R 1
```

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```
! freq magH11 angH11 magH21 angH21 magH12 angH12 magH22 angH22
2 .95 -26 3.57 157 .04 76 .66 -14
```

In the above example, the H-parameters are given in magnitude-angle format, normalized to 1 ohm.

Example 12 (Version 2.0):
```
!2-port H-parameter file, single frequency point
[Version 2.0]
# kHz H MA R 1
[Number of Ports] 2
[Two-Port Data Order] 21_12
[Number of Frequencies] 1
[Matrix Format] Full
[Network Data]
! freq magH11 angH11 magH21 angH21 magH12 angH12 magH22 angH22
2 .95 -26 3.57 157 .04 76 .66 -14
```

In the above example, the H-parameters are given in magnitude-angle format.

Example 13 (Version 1.0):
```
!2-port S-parameter file, three frequency points
# GHz S RI R 50.0
!freq  ReS11   ImS11    ReS21   ImS21   ReS12   ImS12  ReS22    ImS22
1.0000 0.3926 -0.1211 -0.0003 -0.0021 -0.0003 -0.0021 0.3926 -0.1211
2.0000 0.3517 -0.3054 -0.0096 -0.0298 -0.0096 -0.0298 0.3517 -0.3054
10.000 0.3419  0.3336 -0.0134  0.0379 -0.0134  0.0379 0.3419  0.3336
```

In the above example, the S-parameter data is given in real-imaginary format, with a 50 ohm reference impedance.

3-port and 4-port Networks

Rules for Version 1.0 Files:
The network parameter data for a 3-port or 4-port network is arranged in a matrix row-wise order, with each line of data representing one row of the matrix. In other words (as shown below), the data for a 3-port network is entered as three lines of data, with each line containing three data pairs (i.e. a 3x3 matrix of network parameter values). Likewise, the data for a 4-port network is entered as four lines with four data pairs per line (a 4×4 matrix). As required by the general rules, each network parameter data group is preceded by the frequency value at which the data was taken.

3-port Full network description
<frequency value> <N11> <N12> <N13>
<N21> <N22> <N23>
<N31> <N32> <N33>

4-port Full network description
<frequency value> <N11> <N12> <N13> <N14>
<N21> <N22> <N23> <N24>
<N31> <N32> <N33> <N34>
<N41> <N42> <N43> <N44>

where
frequency value   frequency at which the network parameter data was taken or derived.

N11, *N12*, etc.   network parameter data, where N*ij* represents a pair of data values.

As usual, network parameter data is entered in magnitude-angle, dB-angle or real-imaginary format (i.e. pairs of values) as specified by the option line. All entries in a data line are separated by one or more whitespace characters; a data line itself is terminated by a newline character (CR or CR/LF).

Shown below is an example of an S-parameter description of a 4-port network.

Example 14 (Version 1.0):
```
! 4-port S-parameter data, taken at three frequency points
! note that data points need not be aligned
# GHz S MA R 50
5.00000 0.60 161.24 0.40 -42.20 0.42 -66.58 0.53 -79.34 !row 1
        0.40 -42.20 0.60 161.20 0.53 -79.34 0.42 -66.58 !row 2
        0.42 -66.58 0.53 -79.34 0.60 161.24 0.40 -42.20 !row 3
        0.53 -79.34 0.42 -66.58 0.40 -42.20 0.60 161.24 !row 4

6.00000 0.57 150.37 0.40 -44.34 0.41 -81.24 0.57 -95.77 !row 1
        0.40 -44.34 0.57 150.37 0.57 -95.77 0.41 -81.24 !row 2
        0.41 -81.24 0.57 -95.77 0.57 150.37 0.40 -44.34 !row 3
        0.57 -95.77 0.41 -81.24 0.40 -44.34 0.57 150.37 !row 4

7.00000 0.50 136.69 0.45 -46.41 0.37 -99.09 0.62 -114.19 !row 1
0.45  -46.41 0.50  136.69 0.62 -114.19 0.37 -99.09 !row 2
0.37  -99.09 0.62 -114.19 0.50  136.69 0.45 -46.41 !row 3
0.62 -114.19 0.37  -99.09 0.45  -46.41 0.50 136.69 !row 4
```

Note that the data pairs do not have to be aligned in columns; the only requirement is that there be 3 (3-port networks) or 4 (4-port networks) pairs of n-port parameters per data line.

Rules for Version 2.0 Files:
As noted earlier and as required by the general rules, each group of network parameter data is preceded by the frequency value at which the data was taken. The rest of the data for that frequency may follow on the same line or be split across multiple lines with intervening line-termination characters. Each frequency point shall begin after a line-termination character on the first column of the line.

For files using a [Matrix Format] of Lower or Upper, data is still represented in a row-wise format. "Row" here refers to the arrangement of port data into rows and columns by relationship, not in terms of actual lines of data in the Touchstone file text (e.g., Sij refers to the S-parameters from port j to port i; the data is therefore associated with row i and column j). In a Full Matrix, data for all elements in a matrix row shall be shown before data for the next row can be shown.

Matrices using the Upper format shall include explicit data for row 1 ports (i.e., S11, S12…S1n) before any data for row 2 is shown (i.e., S22, S23…S2n). In the Upper format, each successive row shall contain one fewer element than the previous row. The element removed is the column number (current row – 1). For example, the first element of the second row of data is S22. S21 is not shown, as it is assumed to be identical to S12 from symmetry. The final element in an Upper matrix shall be Snn, where n is the total number of ports, representing the only data for that row.

In the Lower format, each successive row shall contain one more element than the previous row. The first row consists of only one element, S11. The final row shall contain elements for each column from 1 to n, where n is the total number of ports.

Therefore, for a three-port matrix, data would be ordered as shown below.

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[Matrix Format] Lower *<frequency value> <N11> <N21> <N22> <N31> <N32> <N33>*

[Matrix Format] Upper *<frequency value> <N11> <N12> <N13> <N22> <N23> <N33>*

where
frequency value   frequency at which the network parameter data was taken or derived.

N11, *N12*, etc.   network parameter data, where N*ij* represents a pair of data values.

5-port and Above Networks

The n-port parameters for 5-port and above networks are also arranged in a matrix row-wise order.

Rules for Version 1.0 Files:
Version 1.0 files are limited to a maximum of 4 network parameter data pairs per line, additional entries beyond the first four pairs in the matrix row shall be continued on the following line(s). Each row of the matrix shall start on a new line.

Rules for Version 2.0 Files:
Version 2.0 files may continue data on the same line, or across multiple lines. As usual, each group of network data pairs is preceded by the frequency value at which this data was taken.

For files using a [Matrix Format] of Lower or Upper, data is still represented in a row-wise format, as shown for 3- and 4-port networks above.

These rules are illustrated by showing the format for a 6-port network:

6-port Full network format (single frequency point)
<frequency value> <N11> <N12> <N13> <N14>   !row 1
<N15> <N16>
<N21> <N22> <N23> <N24>   !row 2
<N25> <N26>
<N31> <N32> <N33> <N34>   !row 3
<N35> <N36>
<N41> <N42> <N43> <N44>   !row 4
<N45> <N46>
<N51> <N52> <N53> <N54>   !row 5
<N55> <N56>
<N61> <N62> <N63> <N64>   !row 6
<N65> <N66>

6-port Lower network format (single frequency point)
<frequency value> <N11>   !row 1
<N21> <N22>   !row 2
<N31> <N32> <N33>   !row 3
<N41> <N42> <N43> <N44>   !row 4
<N51> <N52> <N53> <N54><N55>   !row 5
<N61> <N62> <N63> <N64>   !row 6
<N65> <N66>

6-port Upper network format (single frequency point)
<frequency value> <N11> <N12> <N13> <N14>   !row 1
<N15> <N16>
<N22> <N23> <N24>   !row 2

<N25> <N26>
<N33> <N34>   !row 3
<N35> <N36>
<N44><N45> <N46>   !row 4
<N55> <N56>   !row 5
<N66>   !row 6

where
frequency value   frequency at which the network parameter data was taken or derived.

N11, *N12*, etc.   network parameter data, where N*ij* represents a pair of data values.

As shown, each row of matrix data extends over two lines of the file, and each new row of the matrix starts on a new line. As usual, n-port parameters values are entered in pairs according to the format specified in the option line and each entry is separated by whitespace.

Following is a more detailed example illustrating the Full data matrix for a 10-port network. The Y-parameter data is in magnitude-angle format, and is for a single frequency.

Example 15 (Version 1.0):
```
# frequency_unit Y MA R impedance
freq magY11 angY11 magY12 angY12 magY13 angY13 magY14 angY14 ! 1st row
magY15 angY15 magY16 angY16 magY17 angY17 magY18 angY18
magY19 angY19 magY1,10 angY1,10
magY21 angY21 magY22 angY22 magY23 angY23 magY24 angY24        ! 2nd row
magY25 angY25 magY26 angY26 magY27 angY27 magY28 angY28
magY29 angY29 magY2,10 angY2,10
magY31 angY31 magY32 angY32 magY33 angY33 magY34 angY34        ! 3rd row
magY35 angY35 magY36 angY36 magY37 angY37 magY38 angY38
magY39 angY39 magY3,10 angY3,10
magY41 angY41 magY42 angY42 magY43 angY43 magY44 angY44        ! 4th row
magY45 angY45 magY46 angY46 magY47 angY47 magY48 angY48
magY49 angY49 magY4,10 angY4,10
magY51 angY51 magY52 angY52 magY53 angY53 magY54 angY54       ! 5th row
magY55 angY55 magY56 angY56 magY57 angY57 magY58 angY58
magY59 angY59 magY5,10 angY5,10
magY61 angY61 magY62 angY62 magY63 angY63 magY64 angY64       ! 6th row
magY65 angY65 magY66 angY66 magY67 angY67 magY68 angY68
magY69 angY69 magY6,10 angY6,10
magY71 angY71 magY72 angY72 magY73 angY73 magY74 angY74       ! 7th row
magY75 angY75 magY76 angY76 magY77 angY77 magY78 angY78
magY79 angY79 magY7,10 angY7,10
magY81 angY81 magY82 angY82 magY83 angY83 magY84 angY84       ! 8th row
magY85 angY85 magY86 angY86 magY87 angY87 magY88 angY88
magY89 angY89 magY8,10 angY8,10
magY91 angY91 magY92 angY92 magY93 angY93 magY94 angY94       ! 9th row
magY95 angY95 magY96 angY96 magY97 angY97 magY98 angY98
magY99 angY99 magY9,10 angY9,10
!10th row
magY10,1 angY10,1 magY10,2 angY10,2 magY10,3 angY10,3 magY10,4 angY10,4
magY10,5 angY10,5 magY10,6 angY10,6 magY10,7 angY10,7 magY10,8 angY10,8
magY10,9 angY10,9 magY10,10 angY10,10
```

Introduction to Mixed-Mode Concepts

This section provides the basic definitions and terminology regarding mixed-mode n-port parameters.

A differential port is formed from two single-ended ports having the same "reference" terminal (also referred to as the "-" terminal). Electrical quantities associated with a differential port formed from two single-ended ports i and j are established from the single-ended port quantities V_i, I_i, V_j and I_j as

common mode voltage $\quad\quad V_{Ci,j} = (V_i + V_j)/2$ $\quad\quad\quad\quad$ (a)

common mode current $\quad\quad I_{Ci,j} = I_i + I_j$ $\quad\quad\quad\quad\quad$ (b)

differential mode voltage $\quad\quad V_{Di,j} = V_i - V_j$ $\quad\quad\quad\quad\quad$ (c)

differential mode current $\quad\quad I_{Di,j} = (I_i - I_j)/2$ $\quad\quad\quad\quad$ (d)

The notation Ci,j and Di,j signifies the mode, common or differential, respectively, as well as the indices and the order of the single-ended ports from which the differential port is formed.

For mixed-mode S parameters, the relationships between the mixed-mode incident and reflected waves and the aforementioned mixed-mode voltages and currents are similar to those for the conventional quantities, specifically

common mode incident wave $\quad a_{Ci,j} = (V_{Ci,j} + R_{Ci,j} \times I_{Ci,j})/(2 \times \sqrt{R_{Ci,j}})$ $\quad$ (e)

common mode reflected wave $\quad b_{Ci,j} = (V_{Ci,j} - R_{Ci,j} \times I_{Ci,j})/(2 \times \sqrt{R_{Ci,j}})$ $\quad$ (f)

differential mode incident wave $\quad a_{Di,j} = (V_{Di,j} + R_{Di,j} \times I_{Di,j})/(2 \times \sqrt{R_{Di,j}})$ $\quad$ (g)

differential mode reflected wave $\quad b_{Di,j} = (V_{Di,j} - R_{Di,j} \times I_{Di,j})/(2 \times \sqrt{R_{Di,j}})$ $\quad$ (h)

In general, and as is the case for the conventional S parameters, the mixed-mode reference impedances $R_{Ci,j}$ and $R_{Di,j}$ could be selected as any positive real numbers. However, this is further limited in Version 2.0 files, as explained below. Furthermore, complex reference impedances are not supported.

The relationships between the conventional and mixed-mode incident and reflected waves depend on the actual values of the reference impedances $R_{Ci,j}$ and $R_{Di,j}$ relative to the reference impedances R_i and R_j for the conventional incident and reflected waves for the two single-ended ports i and j forming the differential port. One common selection for this relationship is such that R_i and R_j are equal, $R_{Ci,j}$ is half that value and $R_{Di,j}$ is twice that value.

Specifically, if

Condition 1: $\quad\quad\quad\quad R_i = R_j = R$

and

Condition 2: $\quad\quad\quad\quad R_{Ci,j} = R/2 \quad$ and $\quad R_{Di,j} = 2R$

then

$$a_{Ci,j} = (a_i + a_j)/\sqrt{2} \quad\quad\quad\quad\quad\quad\quad\quad\quad (i)$$
$$a_{Di,j} = (a_i - a_j)/\sqrt{2} \quad\quad\quad\quad\quad\quad\quad\quad\quad (j)$$

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$$b_{Ci,j} = (b_i + b_j)/\sqrt{2} \qquad\qquad\qquad\qquad (k)$$

$$b_{Di,j} = (b_i - b_j)/\sqrt{2} \qquad\qquad\qquad\qquad (l)$$

Version 2.0 files do not provide the means to specify directly the mixed mode reference impedances $R_{Ci,j}$ and $R_{Di,j}$. Instead the single-ended port reference impedances R_i and R_j are specified by means of the [Reference] keyword, or by the Option line. Thus, the mixed-mode reference impedances need to be unambiguously defined form the [Reference] data, and therefore **Condition 1** and **Condition 2** above are adopted for Version 2.0 files. Note that under these conditions the relationships (*i*)-(*l*) do not depend on the actual values of the reference impedances, and take a very simple form.

The value *R* in **Condition 1** and **Condition 2** can be different for different pairs *i*,*j* of the single-ended ports forming different differential ports.

Similarly to the conventional *n*-port parameters the term mixed-mode *n*-port parameters refers to any one of the $n \times n$ matrices **S**, **Y**, or **Z** linking the voltages, currents or the wave quantities as

$$\mathbf{V = Z\,I} \qquad\qquad \mathbf{I = Y\,V} \qquad\qquad \mathbf{b = S\,a}$$

The difference is that for the mixed-mode *n*-port parameters the vectors **V**, **I**, **b** and **a**, are defined using the aforementioned common and differential mode quantities while the single-ended port quantities are used in the conventional relationships. The mixed mode *n*-port parameters can be the generalized mixed-mode parameters when not all single-ended ports are combined into differential ports. For those ports that remain single-ended, the single-ended quantities appear in the vectors **V**, **I**, **b** and **a**.

All the single-ended ports of any *n*-port circuit characterized by the Touchstone files are assumed to be ordered with consecutive numbers from 1 to *n*. This is the "reference port order" which also determines the matrix entries in the conventional **S**, **Y** or **Z** matrices. Specifically, the kth elements in the vectors **V**, **I**, **b** and **a** in the conventional relationships are those of the kth single-ended port.

Version 2.0 files do not impose any specific order of the mixed-mode quantities in the vectors **V**, **I**, **b** and **a** in the mixed-mode relationships. Instead the keyword [Mixed-Mode Order] provides the means to specify how these quantities are ordered with respect to the reference port order. The only requirement is that the same order (specified by [Mixed-Mode Order]) applies to all the vectors **V**, **I**, **b** and **a**.

Appendix A provides the formulas for the relationships between the conventional and mixed-mode *n*-port parameter for the case when the **Condition 1** and **Condition 2** are satisfied.

[Mixed-Mode Order]

Rules for Version 1.0 Files:
The [Mixed-Mode Order] keyword is not permitted in Version 1.0 files.

Rules for Version 2.0 Files:
The [Mixed-Mode Order] keyword entry specifies a list or vector of ports and port descriptors described with mixed-mode network data elsewhere in the file. The [Mixed-Mode Order] list determines the content and the row/column arrangement used for the network data.

The [Mixed-Mode Order] keyword is only required if mixed-mode data is present elsewhere in the file.

Port numbers used under [Mixed-Mode Order] are single-ended. No definition or syntax is used to define mixed-mode ports, only mixed-mode relationships between single-ended ports.

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Every single-ended port (the number described under [Number of Ports]) shall be mentioned in a descriptor under [Mixed-Mode Order].

[Mixed-Mode Order] uses one of the following characters combinations to represent descriptors:

S<port>
C<port>,<port>
D<port>,<port>

where

C,D,S   specifies whether the descriptor is common-mode, differential-mode or single-ended. Legal values are S (for single-ended), C (for common-mode) and D (for differential-mode). If the letter S is present and followed by a single integer, a single-ended descriptor is being defined. A letter shall not appear by itself, nor shall an integer appear by itself. When a pair of ports is present, the second port listed is assumed to be the reference port.

port   an integer, specifies the number of the single-ended port(s) described in the descriptor. The integer number corresponds to the order of the ports as described under the [Reference] keyword. Only non-zero integers shall be used. For single-ended descriptor groups, a single integer is used. For mixed-mode data, two port integers are used, separated by a single comma without whitespace, carriage returns, or line feeds. Multiple commas without separation by integers are not permitted.

Descriptor groups are separated by whitespace, including carriage returns and/or line feeds.

Note that any one port number shall only appear in one single-ended or two mixed-mode descriptors. Additionally, any common-mode descriptor present between ports necessitates that a differential-mode descriptor be present between the same ports, and vice-versa. For example, if D1,3 is included under [Mixed-Mode Order], C1,3 shall also be included. S3 would be prohibited. C2,3 would also be prohibited.

The number of ports described under the [Number of Ports] keyword shall match the number of descriptors described under [Mixed-Mode Order]. Similarly, the numeric value described under [Number of Ports] shall match the highest integer port number listed in any descriptor under [Mixed-Mode Order].

[Mixed-Mode Order], if used, shall appear after the [Number of Ports] keyword and before any network data.

[Mixed-Mode Order] arguments may begin on the line following the closing bracket of the keyword (in other words, after a carriage return and/or line feed character).

Mixed-Mode Network Parameter Data

Rules for Version 1.0 Files:
Mixed-mode data is not permitted in Version 1.0 files.

Rules for Version 2.0 Files:
Mixed-mode data consists of matrices using the relationships and order described under the [Mixed-Mode Order] keyword.

Only S-, Y- or Z-parameter data shall be represented using the mixed-mode format.

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Note that the port numbering does not necessarily determine the arrangement of data under mixed-mode data. Only the [Mixed-Mode Order] keyword determines how mixed-mode data is arranged. Only relationships and ports specified under [Mixed-Mode Order] shall appear as part of mixed-mode data.

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Reference impedances for mixed-mode data are assumed single-ended, as presented under the [Reference Impedance] keyword. For common-mode and differential-mode relationships, the same value of reference impedance shall be used under [Reference Impedance] for both ports. Differential-mode relationships assume an impedance across the ports of twice the single-ended value specified for either port in the relationship. Common-mode relationships assume an impedance across the ports of half the single-ended value specified for either port in the relationship..

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The rules for presenting frequency, line breaks and other aspects of formatting follow those for traditional single-ended network data.

[Matrix Format] may be used with mixed-mode data, so long as the data follows the keyword's symmetry requirements.

The mixed-mode matrix arrangement assumes that the vector in [Mixed-Mode Order] describes the diagonal of the mixed-mode matrix. In other words, the i-th value of the vector is used for both the stimulus and response used for the resulting matrix value Nii. The matrix value Nij would result from vector value i as the response value in row i and the vector value j as the stimulus value in column j. This follows the stimulus-response convention used both widely in the industry for proprietary mixed-mode data formats, as well as the traditional Touchstone 1.0 single-ended data format.

For example, for a 3-port network, the [Mixed-Mode Order] keyword would contain the values:

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D1,2 S3 C1,2

This specifies a differential relationship for ports 1 and 2, followed by a single-ended data relationship for port 3 and a common-mode relationship for ports 1 and 2. The mixed-mode data matrix would therefore use the following format:

<frequency value> <D1,2 D1,2> <D1,2 S3> <D1,2 C1,2>
*   <S3 D1,2>   <S3 S3>   <S3 C1,2>*
*   <C1,2 D1,2> <C1,2 S3> <C1,2 C1,2>*

For each frequency value, where the < and > characters denote magnitude/angle or real/imaginary data pairs or a frequency value, only for the purposes of this example.

Example 16 (Version 2.0):
```
!6-port component shown; note that all five ports are used in some
!relationship
[Version] 2.0
# MHz Y RI R 50
[Number of Ports] 6
[Number of Frequencies] 1
[Reference] 50 7575 50 0.01 0.01
# MHz Y RI R 50

[Mixed-Mode Order] D2,3 D6,5 C2,3 C6,5 S4 S1
[Network Data]
5.00 8.0  9.0  2.0  -1.0  3.0 -2.0  1.0  3.0  1.0   0.1  0.2 -0.2
     2.0 -1.0  7.0   7.0  1.8 -2.0 -1.0 -1.0 -0.5   0.5  0.2 -0.1
     3.0 -2.0  1.8  -2.0  5.8  6.0  1.2  0.8  0.9   0.7  0.3 -0.5
```

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```
1.0  3.0 -1.0  -1.0  1.2  0.8  6.3  8.0  2.0 -0.5  1.5  0.6
1.0  0.1 -0.5   0.5  0.9  0.7  2.0 -0.5  4.7 -6.0 -1.0  2.0
0.2 -0.2  0.2  -0.1  0.3 -0.5  1.5  0.6 -1.0  2.0  5.5 -7.0
```

[Noise Data]

Rules for Version 1.0 Files:
The [Noise Data] keyword is not permitted in Version 1.0 files.

Rules for Version 2.0 Files:
The [Noise Data] keyword identifies the block of noise parameter data, if present in the file. Each Touchstone Version 2.0 file shall contain one and only one [Noise Data] keyword and entry, if and only if [Number of Noise Frequencies] is defined.

[Noise Data] shall only appear after the [Network Data] keyword and entries.

Example 17 (Version 2.0):
```
!2-port network, S-parameter and noise data
!Default MA format, GHz frequencies, 50 ohm reference, S-parameters
[Version] 2.0
#
[Number of Ports] 2
[Two-Port Data Order] 21_12
[Number of Frequencies] 2
[Number of Noise Frequencies] 2
[Reference] 50 25.0
[Network Data]
2  .95 -26  3.57 157 .04 76 .66 -14
22 .60 -144 1.30 40  .14 40 .56 -85
[Noise Data]
4   .7 .64  69 19
18 2.7 .46 -33 20
```

Noise Parameter Data

Noise parameters may be included in Touchstone data files. However, they shall only be included in files describing 2-port networks. Noise parameters follow the G-, H-, S-, Y-, or Z-parameter data (Version 1.0 files) and the [Noise Data] keyword (Version 2.0 files) for all frequency points. Note that the rules for noise parameters are significantly different than the rules for the S-parameter, Z-parameter, etc. data elsewhere in Touchstone files.

Each line of noise parameters has the following five entries:
<x1> <x2> <x3> <x4> <x5>

where
$x1$ Frequency, in the units specified on the option line, or GHz, if no units are specified. The first group of noise data shall have a frequency less than or equal to the highest frequency used for the S-parameter, Z-parameter, etc. data earlier in the file.

$x2$ Minimum noise figure in dB.

$x3$ Source reflection coefficient to realize minimum noise figure. This is a magnitude, regardless of the format specified on the option line. The values

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used for *x3* and *x4* form a complex pair, taken with reference to the impedance value specified on the option line. If no impedance is listed on the option line, the assumed reference is 50 ohms.

x4   Phase of the reflection coefficient, in degrees. As noted above, this is taken with respect to the reference specified on the option line or, if no impedance is listed, an assumed value of 50 ohms.

x5   Effective noise resistance. A simulator requires this parameter to meet physical requirements. If the user-supplied *x5* value is less than allowed for this requirement, then a simulator may force this *x5* value to the lowest physical limit. For Version 1.0 files, this is normalized to the impedance specified on the option line, or 50 ohms if no value is given specified. No normalization is assumed for Version 2.0 files.

Note that the frequencies for noise parameters and network parameters need not match. The only requirement is that the first noise parameter frequency be less than or equal to the highest network parameter frequency. For Version 1.0 files, this allows the file processor to determine where the network parameters end and the noise parameters begin. For Version 2.0 files, the [Number of Frequencies] keyword specifies, the size of the network parameter data expected before any noise parameters begin. As with network parameter data, all noise parameter data shall be arranged in increasing order of frequency

The [Number of Noise Frequencies] keyword is required if any noise parameters are present in the file. The [Number of Noise Frequencies] keyword is prohibited if no noise parameters are present in the file.

The [Reference] keyword has no effect on noise parameter data.

If noise parameters are present in the file, the [Number of Ports] keyword shall have "2" as its argument.

In both Version 1.0 and Version 2.0, each noise parameter frequency and associated data shall be grouped into a single line, terminated with a newline character.

Example 18 (Version 1.0):
```
!2-port network, S-parameter and noise data
!Default MA format, GHz frequencies, 50 ohm reference, S-parameters
#
! NETWORK PARAMETERS
2   .95 -26  3.57 157 .04 76 .66 -14
22 .60 -144 1.30 40   .14 40 .56 -85
! NOISE PARAMETERS
4    .7 .64  69 .38
18 2.7 .46 -33 .40
```

Example 19 (Version 2.0):
```
!2-port network, S-parameter and noise data
!Default MA format, GHz frequencies, 50 ohm reference, S-parameters
[Version] 2.0
#
[Number of Ports] 2
[Number of Frequencies] 2
[Number of Noise Frequencies] 2
[Reference] 50 25.0
[Network Data]
! NETWORK PARAMETERS
```

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```
2  .95 -26  3.57 157 .04 76 .66 -14
22 .60 -144 1.30 40  .14 40 .56 -85
[Noise Data]
! NOISE PARAMETERS
4   .7 .64  69 19
18 2.7 .46 -33 20
```
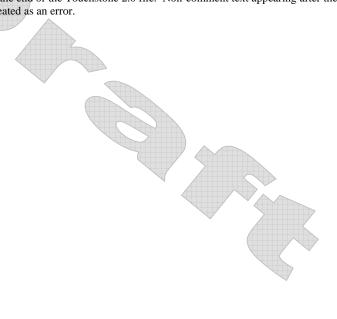
[End]

Rules for Version 1.0 Files:
The [End] keyword is not permitted in Version 1.0 files.

Rules for Version 2.0 Files:
The [End] keyword defines the end of the Touchstone 2.0 file. Non-comment text appearing after the [End] keyword should be treated as an error.

INFORMATION DESCRIPTION

Introduction

This section is reserved for future expansion with new informational keywords for specific applications. While this information could be documented by comment lines, the keywords in this section allow descriptions to be standardized and to be electronically parsed. These keywords are optional and can be ignored or be overridden by external references to the Touchstone 2.0 file.

[Begin Information], [End Information]

Rules for Version 1.0 Files:
The [Begin Information] and [End Information] keywords are not permitted in Version 1.0 files.

Rules for Version 2.0 Files:
The [Begin Information] keyword and associated data define information about the derivation and usage of Touchstone data for specific applications. The [Begin Information] and [End Information] keywords are optional for Version 2.0 files. If used, the keywords shall only appear after the [Number of Ports] keyword and before any network data. Each Touchstone Version 2.0 file shall contain one and only one [Begin Information] keyword. Each Touchstone Version 2.0 file that contains a [Begin Information] keyword shall also contain one [End Information] keyword. The [End Information] keyword shall follow the [Begin Information] keyword, and shall occur before any network data.

The data between the [Begin Information] and [End Information] keywords shall consist of information sections. Each information section shall begin with an information keyword as defined below. The data associated with each information keyword may be on the same line as the information keyword or on subsequent lines prior to the next keyword. Each keyword or keyword-plus-data within [Begin Information] and [End Information] terminates either with another keyword or with the [End Information] keyword. Therefore, information keywords can have data or arguments that apply to fewer than the number of ports in the file documented by the [Number of Ports] keyword.

Information Keywords

This section is reserved for future expansion.

COMPATIBILITY NOTES

In the original proprietary Touchstone specification, several restrictions existed that may not apply across implementations and do not apply to Version 1.0 or 2.0 files:

- The dB/angle form was not allowed for G-, H-, Y- and Z-parameters. Only magnitude/angle and real/imaginary pairs were permitted for non-S-parameter data.
- Y- and Z-parameters were not allowed for 3-port networks or larger.
- The total number of ports that could be represented in any Touchstone file was 99.

Version 1.0 and Version 2.0 files differ in three additional respects:

- G-, H-, Y- and Z- parameters are normalized in Version 1.0 but are not normalized in Version 2.0.
- Effective noise resistance in noise parameter data is considered normalized in Version 1.0 but is not normalized in Version 2.0.
- Mixed-mode support is added in Version 2.0, so that network parameter data in the file is interpreted differently in the presence of the [Mixed-Mode Order] keyword.

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APPENDIX A: Transformations Between Conventional and Mixed-Mode Matrices for a Pair of Ports

For the discussion below, the pair of single ended ports is assumed to have a common reference and to be normalized to the same impedance value r_0. In its mixed-mode representation, the reference impedance for the differential and common mode components is assumed to be $2 \times r_0$ and $r_0/2$ respectively.

Shown below are the relationships between the vectors and matrices for a port pair, participating in standard-to mixed-mode transformation.

For convenience, two matrices are used:

$$\mathbf{M} = \begin{bmatrix} \gamma & -\gamma \\ \gamma & \gamma \end{bmatrix} \quad \text{and} \quad \mathbf{K} = \begin{bmatrix} 1/\gamma & 0 \\ 0 & \gamma \end{bmatrix}, \text{ where } \gamma = \frac{1}{\sqrt{2}}.$$

The inverse of the matrix $\mathbf{M}$ is also its transpose: $\mathbf{M^{-1}} = \mathbf{M^t}$.

S-parameters

The incident and reflected waves in standard and mixed-mode are related as follows:

$$\mathbf{a_{mm}} = \begin{bmatrix} a_{D1,2} \\ a_{C1,2} \end{bmatrix} = \mathbf{M} \begin{bmatrix} a_1 \\ a_2 \end{bmatrix} = \mathbf{Ma_{std}} \tag{S1}$$

$$\mathbf{b_{mm}} = \begin{bmatrix} b_{D1,2} \\ b_{C1,2} \end{bmatrix} = \mathbf{M} \begin{bmatrix} b_1 \\ b_2 \end{bmatrix} = \mathbf{Mb_{std}} \tag{S2}$$

$$\mathbf{b_{std}} = \mathbf{S_{std}a_{std}} \tag{S3}$$

$$\mathbf{b_{mm}} = \mathbf{S_{mm}a_{mm}} \tag{S4}$$

By substituting (S1), (S2) into (S4), it is possible to find the relations between the mixed-mode and standard mode **S**-matrices:

$$\mathbf{S_{std}} = \mathbf{M^t S_{mm} M} \tag{S5}$$

$$\mathbf{S_{mm}} = \mathbf{M S_{std} M^t} \tag{S6}$$

Y and Z-parameters

First, the mixed-mode voltages and currents (vectors) are expressed via standard mode vectors.

$$\mathbf{V_{mm}} = \begin{bmatrix} v_{D1,2} \\ v_{C1,2} \end{bmatrix} = \begin{bmatrix} 1 & -1 \\ 0.5 & 0.5 \end{bmatrix} \begin{bmatrix} v_1 \\ v_2 \end{bmatrix} = \begin{bmatrix} 1/\gamma & 0 \\ 0 & \gamma \end{bmatrix} \begin{bmatrix} \gamma & -\gamma \\ \gamma & \gamma \end{bmatrix} \begin{bmatrix} v_1 \\ v_2 \end{bmatrix} = \mathbf{KMV_{std}} \tag{YZ1}$$

$$\mathbf{I_{mm}} = \begin{bmatrix} i_{D1,2} \\ i_{C1,2} \end{bmatrix} = \begin{bmatrix} 0.5 & -0.5 \\ 1 & 1 \end{bmatrix}\begin{bmatrix} i_1 \\ i_2 \end{bmatrix} = \begin{bmatrix} \gamma & 0 \\ 0 & 1/\gamma \end{bmatrix}\begin{bmatrix} \gamma & -\gamma \\ \gamma & \gamma \end{bmatrix}\begin{bmatrix} i_1 \\ i_2 \end{bmatrix} = \mathbf{K^{-1}MI_{std}} \qquad (YZ2)$$

Then, relationships are defined between voltages and currents, in standard and mixed-mode.

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$$\mathbf{I_{std} = Y_{std}V_{std}} \qquad (YZ3)$$
$$\mathbf{V_{std} = Z_{std}I_{std}} \qquad (YZ4)$$
$$\mathbf{I_{mm} = Y_{mm}V_{mm}} \qquad (YZ5)$$
$$\mathbf{V_{mm} = Z_{mm}I_{mm}} \qquad (YZ6)$$

By substituting (YZ1), (YZ2) into (YZ3-6), relationships can be found between the standard and mixed-mode $\mathbf{Y}$ and $\mathbf{Z}$-matrices:

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$$\mathbf{Y_{mm} = (K^{-1}M)Y_{std}(K^{-1}M)^t} \qquad (YZ7)$$
$$\mathbf{Y_{std} = (KM)^t Y_{mm}(KM)} \qquad (YZ8)$$
$$\mathbf{Z_{mm} = (KM)Z_{std}(KM)^t} \qquad (YZ9)$$
$$\mathbf{Z_{std} = (K^{-1}M)^t Z_{mm}(K^{-1}M)} \qquad (YZ10)$$

Mutual Transformations in Cases of Several Port Pairs

All above relationships apply only to individual port pairs participating in MM to STD transformations. In case of many such pairs, and also in presence of single ended components together with mixed-mode, a more general description is needed. The transformation matrix in this case consists of several 2x2 diagonal blocks - each one for every mixed-mode port pair - and a unit matrix diagonal block that corresponds to single ended ports.

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For example, the combined mixed-mode vector $\mathbf{X_{mm\_blk}}$ and single ended component vector $\mathbf{X_{std}}$ could be related as:

$$\mathbf{X_{mm\_blk}} = \begin{bmatrix} X_{D1,2} \\ X_{C1,2} \\ X_{D3,4} \\ X_{C3,4} \\ X_5 \end{bmatrix} = \begin{bmatrix} \mathbf{T_{X2}} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{T_{X2}} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{E_1} \end{bmatrix}\begin{bmatrix} X_1 \\ X_2 \\ X_3 \\ X_4 \\ X_5 \end{bmatrix} = \mathbf{T_X X_{std\_blk}} \qquad (P1)$$

Here, $\mathbf{T_{X2}}$ is an elementary 2x2 transformation matrix block. Depending on the type of variables in X (incident or reflected wave, voltage or current), it is:

$$\mathbf{T_{A2} = T_{B2} = M} \qquad \text{(for incident and reflected wave)} \qquad (P2)$$
$$\mathbf{T_{V2} = KM} \qquad \text{(for port voltage vector)} \qquad (P3)$$
$$\mathbf{T_{I2} = K^{-1}M} \qquad \text{(for port current vector)} \qquad (P4)$$

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$\mathbf{E_1}$ is 1x1 identity matrix. The size of it is defined by the number of individual single ended ports in the left side 'extended' mixed-model vector. The matrix components designated by zeros are square or rectangular all-zero block matrices. Their size is determined by the size of the corresponding diagonal blocks.

Note that (P1) only describes the case when variables on the left and right are 'properly' ordered. The proposed standard allows arbitrary ordering of components in the mixed-mode vector. In addition to the block-wise transformation, as shown in (P1), a chain of several transformations may be considered, including permutations and MM/STD transformations:

$$\mathbf{X}_{mm} \Leftarrow perm\_mm \Rightarrow \mathbf{X}_{mm\_blk} \Leftarrow MM\_to\_STD \Rightarrow \mathbf{X}_{std\_blk} \Leftarrow perm\_std \Rightarrow \mathbf{X}_{std}$$

For example, possible transformations are:

$$\begin{bmatrix} X_{D3,2} \\ X_{D5,4} \\ X_1 \\ X_{C3,2} \\ X_{C5,4} \end{bmatrix} \Leftrightarrow \begin{bmatrix} X_{D3,2} \\ X_{C3,2} \\ X_{D5,4} \\ X_{C5,4} \\ X_1 \end{bmatrix} \Leftrightarrow \begin{bmatrix} X_3 \\ X_2 \\ X_5 \\ X_4 \\ X_1 \end{bmatrix} \Leftrightarrow \begin{bmatrix} X_1 \\ X_2 \\ X_3 \\ X_4 \\ X_5 \end{bmatrix}. \tag{P5}$$

Given a vector $\mathbf{X}_{mm}$ (on the left) with components ordered as defined in [Mixed-Mode Order], first those components shall be permuted so as to group the mixed-mode pairs and block of single ended components (see $\mathbf{X}_{mm\_blk}$, next vector). Then, vector $\mathbf{X}_{mm\_blk}$ is represented as a result of STD-to-MM transformation by way of (P1) applied to respectively grouped vector $\mathbf{X}_{std\_blk}$. Finally, the single ended vector shall be permuted so as to get the components in $\mathbf{X}_{std}$ properly ordered.

Note that two permutations (with mixed-mode and standard mode components) are independent and therefore require two permutation matrices, $\mathbf{P}_{std}$ and $\mathbf{P}_{mm}$ respectively. The chain of transformations in (P5), if seen from right to left becomes:

$$\mathbf{X}_{std\_blk} = \mathbf{P}_{std}\mathbf{X}_{std} \tag{P6}$$
$$\mathbf{X}_{mm\_blk} = \mathbf{T}_X\mathbf{X}_{std\_blk} \tag{P7}$$
$$\mathbf{X}_{mm} = \mathbf{P}_{mm}\mathbf{X}_{mm\_blk} \tag{P8}$$

For example, the matrices used in (P5) are:

$$\mathbf{P}_{std} = \begin{bmatrix} 0 & 0 & 1 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1 & 0 \\ 1 & 0 & 0 & 0 & 0 \end{bmatrix}, \mathbf{T}_X = \begin{bmatrix} \mathbf{T}_{X2} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{T}_{X2} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{E_1} \end{bmatrix}, \mathbf{P}_{mm} = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \end{bmatrix}.$$

From (P6-P8):

$$X_{mm} = (P_{mm}T_X P_{std})X_{std} \tag{P9}$$

$$X_{std} = (P_{std}^t T_X^{-1} P_{mm}^t)X_{mm}. \tag{P10}$$

For each type of matrix (**S**, **Y** or **Z**) a certain type of input and output vectors has been defined. Assume that **X** is an input vector (**a**, **V** or **I** respectively) and **U** is an output vector (respectively, **b**, **I** or **V**). Then, similar to (P9) and (P10) there exist relationships for the output vector:

$$U_{mm} = (P_{mm}T_U P_{std})U_{std} \tag{P11}$$

$$U_{std} = (P_{std}^t T_U^{-1} P_{mm}^t)U_{mm}. \tag{P12}$$

Note, that permutation matrices are the same (since the components in the input/output vectors shall be identically ordered) but the block-wise transformation matrix could be different. As follows from (P3), (P4), in case of *Y* or *Z*-parameters using different elementary transformation blocks for voltage and current vectors is necessary. However, in all cases the transformation matrices used in (P9-P12) obey the relations:

$$T_U^t = T_X^{-1} \tag{P13}$$

$$T_X^t = T_U^{-1} \tag{P14}$$

In addition to general type input and output vectors (general for **S/Y/Z** cases), general transformation matrices, F_{std} and F_{mm} may be defined (where **F** stands for **S**, **Y** or **Z**):

$$U_{std} = F_{std}X_{std} \tag{P15}$$

$$U_{mm} = F_{mm}X_{mm}. \tag{P16}$$

By substituting (P9), (P11) into (P16):

$$F_{std} = (P_{std}^t T_U^{-1} P_{mm}^t)F_{mm}(P_{mm}T_X P_{std}) \tag{P17}$$

$$F_{mm} = (P_{mm}T_U P_{std})F_{mm}(P_{std}^t T_X^{-1} P_{mm}^t). \tag{P18}$$

(P17) shows how the mixed-mode matrix, arbitrarily ordered, possibly with single ended terms, can be converted directly into properly ordered single ended form. (P18) shows the reverse transformation.

Note that because of (P13), (P14) the side matrices in (P17), (P18) enclosed in parenthesis are mutually transpose $P_{std}^t T_U^{-1} P_{mm}^t = (P_{mm}T_X P_{std})^t$, $P_{mm}T_U P_{std} = (P_{std}^t T_X^{-1} P_{mm}^t)^t$. The property is related to the fact that transformations (P17) and (P18) shall preserve matrix symmetry. For example, if the standard mode matrix is symmetric, so should be the mixed-mode matrix, regardless of the permutations and the parameter type.

Example A-1:
If the vectors shown in (P5) correspond to incident and reflected waves, and the matrix type is '**S**' then the elementary transformation blocks are those of (P2), and therefore:

$$\mathbf{T_X} = \begin{bmatrix} \gamma & -\gamma & 0 & 0 & 0 \\ \gamma & \gamma & 0 & 0 & 0 \\ 0 & 0 & \gamma & -\gamma & 0 \\ 0 & 0 & \gamma & \gamma & 0 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix}.$$

Combining this matrix with permutation matrices shown above, (P15) reduces to:

$$\mathbf{S_{std}} = \begin{bmatrix} 0 & 0 & 1 & 0 & 0 \\ -\gamma & 0 & 0 & \gamma & 0 \\ \gamma & 0 & 0 & \gamma & 0 \\ 0 & -\gamma & 0 & 0 & \gamma \\ 0 & \gamma & 0 & 0 & \gamma \end{bmatrix} \mathbf{S_{mm}} \begin{bmatrix} 0 & -\gamma & \gamma & 0 & 0 \\ 0 & 0 & 0 & -\gamma & \gamma \\ 1 & 0 & 0 & 0 & 0 \\ 0 & \gamma & \gamma & 0 & 0 \\ 0 & 0 & 0 & \gamma & \gamma \end{bmatrix}.$$

Example A-2:

Let the touchstone data type by **Y** (admittance matrix) and mixed-mode order is defined as
$\text{column}[X_{D2,3}, X_{D6,5}, X_{C2,3}, X_{C6,5}, X_4, X_1]$, and the matrix – at certain frequency – is defined as:

$$\mathbf{Y_{mm}} = \begin{bmatrix} 8+9j & 2-j & 3-2j & 1+3j & 1+0.1j & 0.2-0.2j \\ 2-j & 7+7j & 1.8-2j & -1-j & -0.5+0.5j & 0.2-0.1j \\ 3-2j & 1.8-2j & 5.8+6j & 1.2+0.8j & 0.9+0.7j & 0.3-0.5j \\ 1+3j & -1-j & 1.2+0.8j & 6.3+8j & 2-0.5j & 1.5+0.6j \\ 1+0.1j & -0.5+0.5j & 0.9+0.7j & 2-0.5j & 4.7-6j & -1+2j \\ 0.2-0.2j & 0.2-0.1j & 0.3-0.5j & 1.5+0.6j & -1+2j & 5.5-7j \end{bmatrix}$$

By inspecting mixed-mode order, the mixed-mode permutation matrix $\mathbf{P_{mm}}$ can be defined as:

$$\mathbf{X_{mm}} = \mathbf{P_{mm}} \mathbf{X_{mm\_blk}} \text{ , or } \begin{bmatrix} X_{D3,2} \\ X_{D6,5} \\ X_{C3,2} \\ X_{C6,5} \\ X_4 \\ X_1 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} X_{D3,2} \\ X_{C3,2} \\ X_{D6,5} \\ X_{C6,5} \\ X_4 \\ X_1 \end{bmatrix}.$$

Similarly, standard mode permutation can be seen from:

$$\mathbf{X_{std\_blk}} = \mathbf{P_{std}}\mathbf{X_{std}} \text{ , or } \begin{bmatrix} X_3 \\ X_2 \\ X_6 \\ X_5 \\ X_4 \\ X_1 \end{bmatrix} = \begin{bmatrix} 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} X_1 \\ X_2 \\ X_3 \\ X_4 \\ X_5 \\ X_6 \end{bmatrix}.$$

The transformation matrices for voltage and current vectors are different:

$$\mathbf{T_V} = \text{diag}\{\mathbf{KM}, \mathbf{KM}, \mathbf{E_2}\} = \begin{bmatrix} 1 & -1 & 0 & 0 & 0 & 0 \\ 0.5 & 0.5 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & -1 & 0 & 0 \\ 0 & 0 & 0.5 & 0.5 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix},$$

$$\mathbf{T_I} = \text{diag}\{\mathbf{K^{-1}M}, \mathbf{K^{-1}M}, \mathbf{E_2}\} = \begin{bmatrix} 0.5 & -0.5 & 0 & 0 & 0 & 0 \\ 1 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0.5 & -0.5 & 0 & 0 \\ 0 & 0 & 1 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}.$$

Since for *Y*-parameters voltage is considered as an "input" and current as "output", in (P17) $\mathbf{T_X}$ is replaced with $\mathbf{T_V}$ and $\mathbf{T_U}$ with $\mathbf{T_I}$. Then, (P17) simplifies to

$$\mathbf{Y_{std}} = \begin{bmatrix} 0 & 0.5 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0.5 & 1 \\ 0 & 0.5 & -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0.5 & -1 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \mathbf{Y_{mm}} \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 1 \\ 0.5 & 0 & 0.5 & 0 & 0 & 0 \\ 1 & 0 & -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0.5 & 0 & 0.5 & 0 & 0 \\ 0 & 1 & 0 & -1 & 0 & 0 \end{bmatrix}$$

Finally, with given complex $\mathbf{Y_{mm}}$:

Y$_\text{std}$ =

$$\begin{bmatrix} 9.35+5.75j & 0.725-0.075j & -4.05-4.25j & -0.075+1.025j & 0.7+0.3j & 4-2.5j \\ 0.725-0.075j & 5.675-6.5j & -0.775+0.225j & -4.325+5.5j & 2.5+0.35j & 0.7-0.15j \\ -4.05-4.25j & -0.775+0.225j & 5.75+9.75j & -0.375-0.675j & -1.7-1.3j & -2+1.5j \\ -0.075+1.025j & -4.325+5.5j & -0.375-0.675j & 7.675-10.5j & -0.5-0.85j & 0.3+0.25j \\ 0.7+0.3j & 2.5+0.35j & -1.7-1.3j & -0.5-0.85 & 6.3+8j & 1+3j \\ 4-2.5j & 0.7-0.15j & -2+1.5j & 0.3+0.25j & 1+3j & 8+9j \end{bmatrix}$$

1. A. Ferrero, M. Pirola. Generalized mixed mode S-parameters, IEEE Trans. on Microwave Theory and Techniques, v.54, No.1, 2006.

2. D. Bockelman, W. Eisenstadt. Pure mode network analyzer for on-wafer measurements of mixed mode S-parameters of differential circuits, IEEE Trans. on Microwave Theory and Techniques, v.45, No.7, 1997.

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