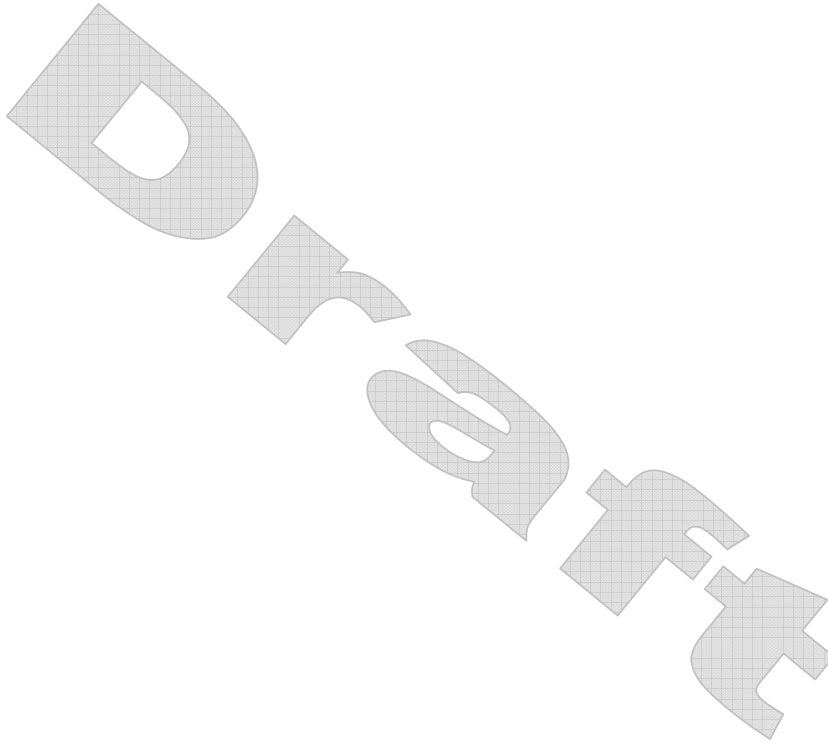


Touchstone® 2.0 File Format Specification

Rev 1.0



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Section 1I N T R O D U C T I O N
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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 de-facto standard for the transfer of frequency dependent n-port n-port parameters, up until now there has been no formal documentation of the file format or syntax. This document, based upon information from Agilent Technologies, Inc. (the originator of Touchstone), is a formal specification of the Touchstone file format, intended for use with documents and specifications produced by the GEIA/IBIS Open Forum.

Version 2.0 was created based upon the original Touchstone definition, with added features in the style of the IBIS and ICM specifications. Files written using the original syntax should be compatible with the updated specification.

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Section 2GENERAL SYNTAX RULES AND GUIDELINES
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Following are the general syntax rules and guidelines for a Touchstone file.

1. Touchstone files are case-insensitive.
2. Only ASCII characters, as defined in ANSI Standard X3.4-1986, may be used in a Touchstone file. The use of characters with codes greater than hexadecimal 07E is not allowed. In addition, ASCII control characters (those numerically less than hexadecimal 20) are not allowed, except for tabs or in a line termination sequence (carriage-return or carriage-return/line-feed combination).
Note: The use of tab characters is strongly discouraged.
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. By convention, Touchstone filenames use 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. Note that this convention may not be observed by all files. For version 2.0 and above, [Number of Ports] 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) must be enclosed in square brackets, [], and must start in column 1 of the line. No space or tab is allowed immediately after the opening bracket '[' or immediately before the closing bracket ']'. If used, only one space (' ') or underscore ('_') character separates the parts of a multi-word keyword.
8. Underscores and spaces are equivalent in keywords. Spaces are not allowed in subparameter names.

Section 3

FILE FORMAT DESCRIPTION

Introduction

Touchstone data files consist of a [Version] keyword and data, an 'option line', a [Number of Ports] keyword and data, and an optional [Reference] keyword and data, followed by one or more sets of network parameters, where each set of data is taken at a specific frequency. The [Number of Ports] keyword and data specify the number of ports represented by data in the file. 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.). The [Reference] keyword data provides the reference impedances for each port, using the same order as the port data sets. Data sets are arranged into one or more 'data lines', where the first line of n-port parameters is preceded by the frequency at which the data was taken or derived. For each frequency, data for a 1-port or 2-port network are contained on a single data line while data for 3-port and above networks are arrayed in a matrix format. The Touchstone format supports matrices of unlimited size.

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Deleted: , and a [Normalization] keyword and data

Only one option-line/data-set pair is allowed per file.

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

The [Version] keyword and data, option line, [Number of Ports] keyword and data, [Reference] keyword and data, data lines, comment line(s) and noise data are described in detail in the following sub-sections.

Deleted: [Normalization] keyword and data,

Note that the Touchstone format does not support direct input of mixed-mode (colloquially, "differential"), data sets (e.g., SDD11, SCD12, etc.). Differential systems may be represented in Touchstone files by collecting data for pairs of terminals as "ports" and, for S-parameters, setting reference impedances appropriately. In such cases, a Touchstone file for two-terminal system, for example, may be indistinguishable from a Touchstone file for a four-terminal system with data collected in this manner.

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[Version]

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

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

The only valid argument is "2.0".

The [Version] line is not permitted for files satisfying 1.0 syntax requirements. It is required for files using any version 2.0 syntax.

Option Line

Each Touchstone data file must contain an option line (additional option lines after the first one will 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 GHz, MHz, KHz, Hz. 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 ($dB = 20 \cdot \log_{10} |magnitude|$)
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 document). 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] line, 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 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/G/H] [MA/DB/RI] [R n]
For 2-port files: # [HZ/KHZ/MHZ/GHZ] [S/Y/Z/G/H] [MA/DB/RI] [R n]
```

For n-port files: # [HZ/KHZ/MHZ/GHZ] [S/Y/Z/G/H] [MA/DB/RI] [R n]

where the square brackets ([]) indicate optional information;
.../.../.../ means select one of the choices; and n is replaced by a
positive number.

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

For version 1.0 files, the reference resistance defines the system
reference for the S-parameter data sets and the normalization used on
G-, H-, Y- and Z-parameter data sets.

For version 2.0 files, the reference resistance defines the system
reference for the S-parameter data sets 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 sets in version 2.0 files.

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Option Line Examples:

Minimum required option line examples (using all default values) are
shown below. Note these examples assume version 1.0 syntax.

#

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

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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
1 ohm:
Hz Z MA R 1

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

Frequency in Hz, G-parameters in magnitude-angle, format normalized to
1 ohm:
Hz G MA R 1

For version 1.0 files, the Options line must immediately precede any
data lines and must be the first non-comment line in the file. For
version 2.0 files, the Options line must precede the [Number of Ports]
line.

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Note that the reference
impedance specified here
applies for all ports
described in the data lines,
if [Reference] is not
present.¶

[Number of Ports]

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Each Touchstone 2.0 file must contain one and only one [Number of
Ports] keyword and entry. The [Number of Ports] keyword and associated
data define the number of ports represented by data in the file.

The [Number of Ports] line must begin with the keyword [Number of Ports], in brackets as shown. This keyword is followed by a single positive integer argument, separated from the keyword by whitespace.

The [Number of Ports] line is required for version 2.0 files and must appear immediately after the option line and before any data sets (or the optional [Reference] keyword).

Deleted: and [Normalization]

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The [Number of Ports] keyword is not permitted in version 1.0 files.

Example 1:

```
! 4-port S-parameter data
! Note that this data can be also represented using 1.0 rules
[Version] 2.0
# GHZ S MA R 50
[Number of Ports] 4
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
```

[Reference]

The [Reference] keyword and associated data provide a per-port definition of the reference environment used for the S-parameter measurements in the data sets. It may appear only once in the file.

The [Reference] line must 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 lines may not be shared with data for any other keyword in the file

Each of the entries is a real-valued impedance and is assumed to be ordered per port exactly as the data lines later in the file.

The units of the [Reference] impedances are ohms.

The [Reference] line may only appear after the [Number of Ports] keyword and before any data sets.

Deleted: the optional [Normalization] keyword and

Note that complex and imaginary impedance values are not supported.

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

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

The [Reference] keyword is not permitted in version 1.0 files.

Example 2:

```
! 4-port S-parameter data
! The default impedance is overridden by the [Reference] line
! Due to mixed reference impedances, this data cannot be represented
! using 1.0 syntax.
[Version] 2.0
# GHZ S MA R 50
[Number of Ports] 4
[Reference] 50 75 0.01 0.01
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
```

Data Lines

Following the option line and/or [Reference] are the data sets. Data sets contain the data for the network parameters (S-parameter, Z-parameter, etc.) specified by the option line. 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 above are arranged on multiple data lines in a matrix format. Each set of n-port parameters is preceded by a frequency value (i.e. the first entry in the first or only data line of a data set is a frequency value), and the n-port parameters itself is formatted as pairs of values (magnitude-angle, dB-angle or real-imaginary).

There are three general rules for formatting data lines and data sets:

1. In version 1.0 files, no more than four pairs of n-port parameters are allowed per data line. No restriction exists on the number of data points on a line in version 2.0 files.
2. Individual entries in a data lines are separated by whitespace
3. A data line is terminated by a newline character (CR or CR/LF combination).
4. All data sets must be arranged in increasing order of frequency.
5. Frequency values must appear at the beginning of lines, after the newline character.

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

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.

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.

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[Normalization]¶

The [Normalization] keyword and associated data define the reference environment used for normalizing the Z, Y, H, G and noise data in the data sets. For example, a data point corresponding to 50 ohms would appear as the value "2" if the data file is normalized to an impedance of 25 ohms.

[Normalization] may appear only once in the file.¶

¶

The [Normalization] line must begin with the keyword [Normalization], in brackets as shown. This keyword is followed by a single positive integer or floating-point number, separated from the keyword by whitespace. ¶

¶

The unit of the [Normalization] impedance is ohms.¶

¶

The [Normalization] line may only appear after the [Reference] keyword and before any data sets.¶

¶

Note that complex and imaginary impedance values are not supported. ¶

¶

[Normalization] is required if the [Reference] keyword is used. Otherwise, it is optional. If the [Normalization] line is not present, the normalization impedance for the data sets is assumed to be defined by the reference impedance on the option line. ¶

¶

The [Normalization] keyword is not permitted in version 1.0 files. ¶

¶

[Normalization] does not apply to S-parameter data sets.¶

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

2-port data set (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 N11, N21, etc. represent pairs of data values

Network parameter data points will 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, while for 2-port networks all four combinations are required.

Note the order in which 2-port n-port parameters is entered - '21' data precedes '12' data.

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 (sets) are allowed but, as mentioned above, they must be arranged in increasing order of frequency.

Following are some examples of Touchstone files for 1-port and 2-port networks. Lines beginning with a bang (!) symbol are comments.

Example 3 (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 4 (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.

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Example 5 (version 1.0):

```
!2-port H-parameter file, single frequency point
# KHz H MA R 1
! 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, with a reference impedance of 1 ohm.

Example 6 (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

The network parameter data for a 3-port or 4-port network is arranged in a matrix format, 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 4x4 matrix). As required by the general rules, the first data line of each network parameter data set is preceded by the frequency value at which the data was taken.

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

```
4-port 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 points, where *Nij* represent pairs of data values.

As usual, network parameter data points are 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). Multiple data sets are allowed, but as

mentioned above, they must be arranged in increasing order of frequency.

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

Example 7:

```
! 4-port S-parameter data, taken at three frequency points
# 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.

5-port and above Networks

The n-port parameters for 5-port and above networks are also arranged in a matrix format. Version 1.0 files are limited to a maximum of 4 network parameter data points per line, additional entries beyond the first four in the matrix row must be continued on the following line(s). Version 2.0 files may continue data on the same line, or across multiple lines. Each row of the matrix must start on a new line. As usual, the first entry in the first data line of a data set is the frequency value. These rules are illustrated by showing the format for a 6-port network:

```
6-port 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>
```

Where

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

N11, N12, etc. network parameter data points, where N_{ij} represent pairs 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 data matrix for a 10-port network. The Y-parameter data is in magnitude-angle format, and is for a single frequency.

Example 8:

```
# 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
```

Comment Lines

Touchstone data files may include comments. Comment lines are text preceded with the exclamation mark (!). A comment may be the only entry on a line or may follow the data on any line.

Adding Noise Parameters

Noise parameters may be included in Touchstone data files. However, they may only be included in 2-port network descriptions. Noise data follows the G-, H-, S-, Y-, or Z-parameter data for all frequency points.

Each line of a noise parameter data set has the following five entries:
`<x1> <x2> <x3> <x4> <x5>`

where

- x1 Frequency in units. The first point of noise data must have a frequency less than the frequency of the last S-parameter frequency.
- x2 Minimum noise figure in dB.
- x3 Source reflection coefficient to realize minimum noise figure (MA). For version 1.0 files, this is normalized to 50 ohms if no impedance is specified on the options line. No normalization is assumed for version 2.0 files.
- x4 Phase in degrees of the reflection coefficient (MA).
- x5 Normalized 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 50 ohms if no impedance is specified on the options line. No normalization is assumed for version 2.0 files.

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Note that the frequencies for noise parameters and network parameters need not match. The only requirement is that the lowest noise-parameter frequency be less than or equal to the highest network-parameter frequency. This allows the file processor to determine where network parameters end and noise parameters begin.

The [Reference] keyword does not apply to noise parameter data.

Deleted: ¶
 If [Normalization] is not present, the source reflection coefficient and effective noise resistance are normalized to the same resistance as specified in the option line for the network parameters.¶
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Example 9:

```
!2-port network, S-parameter and noise data
[Version] 2.0
# GHZ S MA R 50
[Number of Ports] 2
[Reference] 50 25.0
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
```