Pole-Residue Data Format for Touchstone

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Arpad Muranyi, Senior Product Architect

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Background and motivation

The size of Touchstone files has increased dramatically in recent years

- This is due to models with more ports and more frequency points

Consequently, file size reduction is becoming an important need

- This was one of the highest priorities identified in the 2019 IBIS Touchstone Survey
- https://ibis.org/interconnect_wip/2019%20IBIS%20Touchstone%20Survey%20Report.pdf

The Pole-Residue format would serve this purpose very well

- Fitted poles or similar techniques have been used by EDA vendors for decades

We just need a tool independent standardized syntax

- The IBIS Open Forum decided to enhance Touchstone 3.0 with a Pole-Residue format
- Goals and plans were discussed in a presentation at the SPI 2022 IBIS summit
- https://www.ibis.org/summits/may22/muranyi.pdf

TSIRD 7 was submitted to the IBIS Open Forum on February 14, 2024

- The reviews uncovered a few problems, and TSIRD 7.1 is now being prepared

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Overview of TSIRD 7.1

TSIRD 7.1 proposes five new keywords for Touchstone (counting the "Begin … / End …" keyword pairs as one)

- [Begin Pole-Residue Data Source] / [End Pole-Residue Data Source]
- [Number of Pole-Residue Indices]
- [Begin Pole-Residue Data] / [End Pole-Residue Data]
- [Begin Common Poles Data] / [End Common Poles Data]
- [Begin Residues Data] / [End Residues Data]

The first two of these keywords can be considered "logistics" keywords

The pole-residue data is contained in the remaining three keywords

[Begin Pole-Residue Data] is mutually exclusive with the [Begin Common Poles Data] and [Begin Residues Data] keywords

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[Begin Pole-Residue Data Source]

The purpose of the [Begin Pole-Residue Data Source] keyword is to document the original source Touchstone file containing the network data from which the pole-residue data was generated

Subparameters:

- Source_file   (required)
- File_date   (required)
- File_revision
- File_size
- Company_name
- Source_checksum
- Min_valid_frequency
- Max_valid_frequency

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[Number of Pole-Residue Indices]

The purpose of this keyword is to provide a mechanism to check for possible typographical errors or accidental loss of data in the file

Subparameters: none

This keyword is followed by a single integer argument

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Network data matrix basics

The network data is described in a matrix format in Touchstone files

The insertion loss between each port and the return loss at each port are described by a **matrix element** in the matrix

For example, the full matrix of a four-port network would consist of a 4x4 matrix, containing 16 matrix elements

However, various shorthand notations are commonly used, such as upper or lower triangle, etc., that can help to reduce the size of the matrix

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The pole-residue equation of one matrix element

$$H(if) = \mathrm{e}^{-i2\pi fD}\left\{ H_0 + \sum_{m=1}^{M}\left[\frac{A_m - iB_m}{1 + if/(\alpha_m + i\omega_m)} + \frac{A_m + iB_m}{1 + if/(\alpha_m - i\omega_m)} \right] \right\} + ifG$$

- i represents the imaginary unit $\sqrt{(-1)}$
- f represents frequency in Hz
- e represents Euler's number, the base of the natural logarithm
- D is a delay with units of seconds
- $\mathrm{e}^{(-i*2*\pi*f*D)}$ is a delay operator in the frequency domain
- H_0 is the residue of the pole at infinite frequency (which is a real constant when delay is zero, or the magnitude of the cosine / sine functions of the delay operator when delay is non-zero)
- M is the number of pole-residue data lines defined in subparameter Number_of_data_lines
- G defines the linear asymptote, measured in 2*π*farad or siemens/Hz for Y-parameters, or in 2*π*henry or ohm/Hz for Z-parameters
- Note that delay is only allowed for S-parameters, which cannot have linear asymptotes, and linear asymptotes are only allowed for Y and Z-parameters which do not have delay operators. This means that the delay multiplier D and the asymptote G cannot be present simultaneously in the equation above

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Additional detail

$$H(if) = e^{-i2\pi fD} \left\{ H_0 + \sum_{m=1}^{M} \left[\frac{A_m - iB_m}{1 + if/(\alpha_m + i\omega_m)} + \frac{A_m + iB_m}{1 + if/(\alpha_m - i\omega_m)} \right] \right\} + ifG$$

The values ½(A_m - iB_m) and ½(A_m + iB_m) are normalized residues (divided by the pole) that correspond to the pair of complex conjugate poles. For a real pole ($B_m = 0$, $\omega_m = 0$), the corresponding summand in the equation above turns into $A_m/(1 + if/\alpha_m)$, where A_m is the coefficient of the normalized residue for the real pole. Coefficient A_m is the value that the pair of complex conjugate poles or a real pole contribute to $H_m(if)$ at DC, when $f = 0$.

Duplicate real poles, or duplicate complex-conjugate pairs of complex poles are not permitted for the same matrix element, that is, in the pole-residue data provided between the [Begin Pole-Residue Data] / [End Pole-Residue Data] keyword pairs

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[Begin Pole-Residue Data]

This keyword contains the coefficients of the pole-residue representation of the network data

Subparameters:

- Delay
- Asymptote
- Constant_at_infinity
- Number_of_data_lines

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[Begin Common Poles Data]

This keyword is used when all matrix elements have the same set of poles. In this case, the [Begin Common Poles Data] keyword contains the coefficients of the common poles from the pole-residue representation of the network data, and the [Begin Residues Data] keyword(s) contain the coefficients of the (normalized) residues for each matrix element.

Subparameters:

- Number_of_data_lines

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[Begin Residues Data]

This keyword contains the coefficients of the (normalized) residues from the pole-residue representation of the network data and is used together with the coefficients of the common poles defined in the [Begin Common Poles Data] keyword

Subparameters:

- Delay
- Asymptote
- Constant_at_infinity
- Number_of_data_lines

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Statistics

Original size of an .s4p file: 8,482,201 bytes
Corresponding .pls file: 38,587 bytes
                            220x reduction

Original size of an .s4p file: 135,043 bytes
Corresponding .pls file: 18,511 bytes
                            7.3x reduction

Original size of an .s48p file: 198,304,141 bytes
Corresponding .pls file: 3,198,664 bytes
                            62x reduction

The file size reduction depends on many factors, such as the quality of original data, and the settings used in the fitter tool (fitting precision, complexity order, Q-factor for poles, etc.)

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Example of a fictitious S-parameter model

```
[Version] 3.0
# S
[Number of Ports] 4
[Number of Pole-Residue Indices] 10  ! An upper (or lower) triangle matrix only needs 10 matrix elements
[Reference] 50 50 50 0.1
[Matrix Format] Upper
!
[Begin Pole-Residue Data Source]
Company_name           NoName Corp.
Source_file            Original_matrix_formatted.s4p
File_revision          rev0.0
File_date              July 4, 2024
File_size              12345678
Source_checksum        CE114e4501d2e4E2DcEA3E17B546F339
Min_valid_frequency    0
Max_valid_frequency    10e+9
[End Pole-Residue Data Source]
!
! This example is for S-parameter models for which Asymptote is not permitted
[Begin Pole-Residue Data] (1,1) (2,2) (3,3) (4,4)
Delay = 1.234567e-09
Constant_at_infinity = 0.1234567
Number_of_data_lines = 35
  1.11997447664287e+08   3.24519226681551e+09    9.09052286272013e-05   6.49242007237459e-05
  3.45625059472302e+08   3.13202277859585e+09   -5.42268000295391e-01   2.48747631004809e-01
```

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Example (cont'd)

```
    4.87299986445282e+07    2.75489126930901e+09    1.02425334619334e-06    6.83169670830202e-06
    4.09178020913195e+08    2.63376211400015e+09   -8.21075742857057e-01    7.09421412990463e-01
    1.25803831342928e+07    2.28501210803170e+09   -6.90884078070982e-07    1.49162488028986e-06
    ...
    3.84539180679563e+08    1.63825202937485e+09    1.01930938230280e-01    1.80693045098583e+00
[End Pole-Residue Data]
!
[Begin Pole-Residue Data] (1,2) (1,3) (1,4)
(2,3) (2,4)
(3,4)
Delay = 1.654321e-09
Constant_at_infinity = 0.7654321
Number_of_data_lines = 32
    2.57657596701128e+09    7.26711892771513e+09   -1.79483212033890e+00   -4.37286249216797e-01
    2.45747062751230e+08    7.12315022893002e+09   -2.47169488917289e-02    4.52307576480460e-02
    2.24603359541219e+08    6.68617182181606e+09   -1.29395685167005e-02    7.66829440907635e-02
    2.19006983378440e+08    6.15632147553301e+09   -3.88176154021273e-02    8.26124289582556e-02
    9.67891332253463e+07    5.84109173882383e+09   -1.27899882458803e-04    1.08884971149896e-05
    ...
    1.49750555567436e+08    5.30314608166901e+09   -1.00201770683190e-03   -1.39362341960212e-03
[End Pole-Residue Data]
[End]
```

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Questions, comments?

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Thank you!

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