Line Constants

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1 Introduction to Line Constants Routines

The Line Constants routines evaluate the resistance, inductance, conductance, and capacitance of an arbitrary arrangement of conductors of an overhead transmission line, where one or more conductors can represent one phase (e.g., bundled phase conductors). The resulting impedance and admittance matrices can then be reduced to find the phase equivalents. The phase equivalents in turn can be transformed into modal components. With the calculated impedance and admittance data the program can generate models to represent the line for transients analysis and for steady-state solutions.

There are three main modules within this set of routines:

(A) Line Parameters Module. Keyword: "LINE-PARAMETERS"

(B) Line Model Module. Keyword: "LINE-MODEL"

(C) External Data Fitting Module. Keyword: "FIT-S"

Line Parameters Module:

The Line Parameters module reads as input the configuration of the system of conductors and produces on output the series impedance and shunt admittance matrices of the line.

The impedance and admittance matrices can be determined for the full system of physical conductors, or for the reduced system of equivalent phase conductors. The equivalent phase matrices can also be converted into symmetrical component impedance and admittance matrices (zero, positive and negative sequence quantities) of the associated perfectly transposed line (after averaging the self and mutual elements).

The Line Parameters module can also determine, at selected frequencies, the modal line parameters and wave propagation functions of the untransposed line, using eigenvalue/ eigenvector routines.

The Line Parameters module can also produce a multiphase nominal pi-circuit for a given line length. This nominal pi-circuit is an approximation that ignores the distributed nature and frequency dependence of the line parameters and is valid only for short line sections. The cards required to set up the data deck for this module are described in Section 7.

Line Model Module

The line model module reads as input the line configuration (in the same format as for the Line Parameters module) and produces, on output, line models that can be used by the EMTP for transients and steady state solutions.

The main difference between Line Parameters and Line Model Modules is that the Line Model module generates EMTP models, whereas the Line Parameters module does not (with the exception of the generation of nominal pi-circuits).

The data and control cards required to set up the data deck for this module are described in Section 8.

External Data Fitting Module:

The keyword "FIT-S" can be used to fit an externally-supplied frequency-domain function. It provides direct access to the rational function fitting routines associated with the frequency dependent line models.

2 Capabilities of the Line Model Module

The Line Model module can produce line models suitable for EMTP transients simulations. However, frequency domain models which are only suitable for steady-state analysis can also be generated.

2.1 Models for Transients Analysis

The following line models can be generated:

FD-LINE

CP-LINE

LBUILD

CONSTANT

FD-LINE

The fd-line model (frequency-dependent line model), also known as the JMARTI line model, provides an accurate representation of the distributed nature of all the line parameters: R, L, G, and C, as well as the dependence of R and L with frequency.

The model is based on the approximation by rational functions of the line characteristic impedance Z_c and propagation function A_p, namely

$$Z_c = \sqrt{((R+j\omega L)/(G+j\omega C))}$$

$$A_p = e^{-\gamma l},$$

where,

$$\gamma = \sqrt{(R+j\omega L)\cdot(G+j\omega C)}$$

and "l" is the length of the line.

The main simplification used in this model is the validity of the assumption that a constant real transformation matrix can be used to relate phase and modal quantities over an extended frequency range. This allows the approximation of Z_c and A_p as scalar quantities.

CP-LINE

The cp-line model (constant-parameter line model), also known as the Dommel line model, assumes that the line parameters R, L, and C are constant, as calculated at the requested frequency. The model considers L and C to be distributed ("ideal line") and R to be lumped at three places (line ends and line middle). The conductance G is assumed to be zero.

The frequency dependence of the line parameters (as modelled by the fd-line model) is an important factor for the accurate simulation of waveform and peak values. However, the cp-line model is very robust and simple (about 30% to 50% faster than the fd-line model) and provides a good alternative for a first approximation analysis and for the modelling of secondary lines.

LBUILD

This option provides an approximation to the line when the actual geometry is not known. The input data are the 60-Hz (or any other particular frequency) zero and positive sequence series impedance and shunt admittance of the line. From this data, an equivalent balanced-line geometry is reconstructed. This geometry is then used to generate any requested line model (including frequency dependent models) as in the normal case.

CONSTANT

This option uses as input the 60-Hz sequence impedances and admittances as in the 'lbuild' option. However, the line geometry is not reconstructed and the parameters are assumed fixed at their 60-

Hz values. Any line model can be requested but frequency dependence of the line parameters is not considered. The complexity of the models generated with this option is basically the same as the complexity of the models generated with the 'lbuild' option and, therefore, there is normally no advantage in requesting this option instead of the 'lbuild' option.

2.2 Models for Steady-State Analysis: PI-EXACT

This model provides an exact single-frequency representation of the line in the form of a multiphase pi-equivalent. The model can be read directly by the EMTP when frequency scans or single-frequency steady-state solutions are requested.

On output, this option produces a "punch file" that contains $[Z_{series}(\omega)]$ and $[Y_{shunt}(\omega)]$ at every frequency of the EMTP frequency scan calculation (see Figure 1 below), Note that the number of frequency points specified in the generation of the pi-exact model (in either a logarithmic or linear frequency intervals) must match exactly the number of frequency points in the EMTP frequency scan.

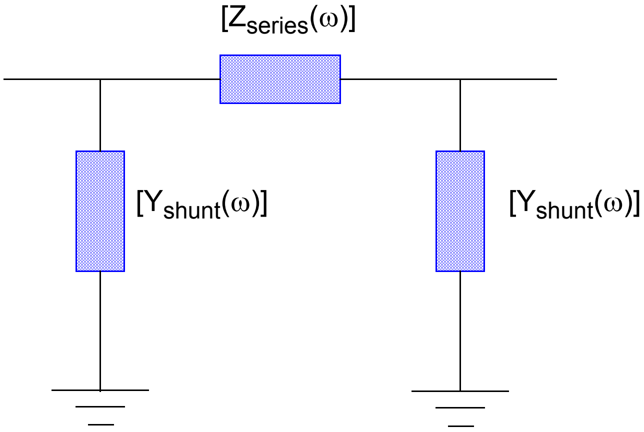


Figure 1: Circuit Representation of a PI-EXACT model

Since the parameters of the exact pi-circuit change with frequency (even for constant line parameters), the model is not valid for transients simulations.

2.3 Dimensioning Limits

Line-Model Module:	
Total Number of Conductors (including subconductors and ground wires)	177
Total Number of Phases (or Modes)	21
Number of Transposition Sections	50
Number of Poles in Rational Function Approximations	100

Line-Parameters Module:	
Total Number of Conductors (including subconductors and ground wires)	100
Total Number of Phases (or Modes)	50

2.4 Data Entry Conventions

The following terminology and conventions are used in the description of the input data file:

1. The lines in the data file are called "cards".

2. Character data entry is case insensitive (e.g., LiNe-mOdel is the same as Line-Model).

3. In the description of the card images, Fortran format convention is used to specify the data types.

4. If a data field is left blank, the default value is internally assigned by the program (assuming there is a default value for that field).

5. Control flags in I2-format fields normally have the following meaning:

   1 = on; –1 = off; blank or 0 = default value.

6. Control flags in I1-format fields normally have the following meaning:

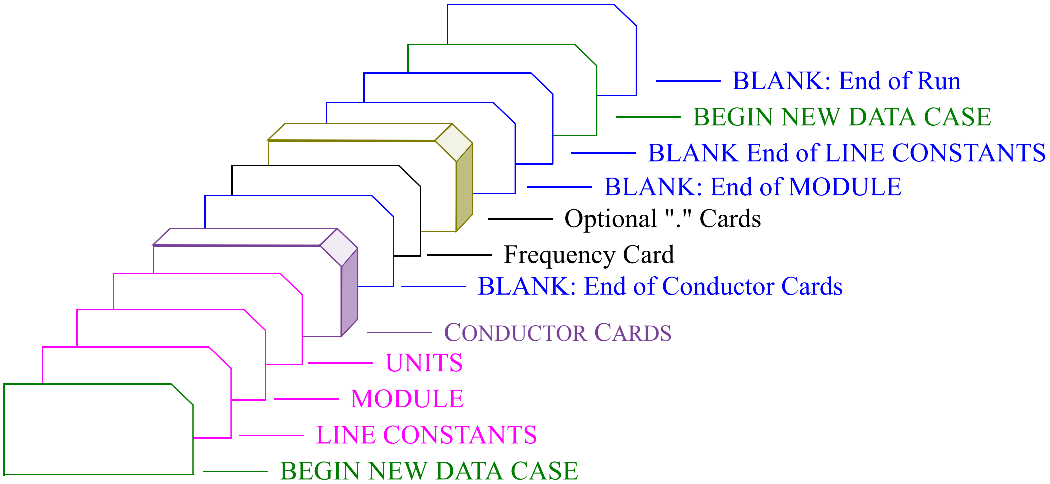
   1 = on; 0 = off.

2.5 Input/Output Units

Logical Unit	Purpose	Assignment
LU5	Input Data Deck	User
LU6	Output Listing	User
LU7	Punched Output	User
LU17	Scratch file (binary)	Internal

3 General Structure of a Line Constants Data Deck

The general structure of the input data file for running the line constants program is shown in Table 1 below. Comment lines are ignored by the program. They can be inserted anywhere in the data deck. These lines are identified by "C " or "c " (letter C or c in the first column, followed by a space in the second column). They can contain any alphanumeric characters in the rest of the line.



[1	"BEGIN NEW DATA CASE" and "LINE CONSTANTS" request card	Begin data case identifiers
[2]	MODULE	Line-Parameters, Line-Model, FIT-S
[3]]	UNITS	Metric or British
[4]	CONDUCTORS	Conductor Data Cards
	...	...
	BLANK card	BLANK card to indicate the end of conductor data cards
[5]	FREQUENCY	Earth resistivity, frequency, etc.
[6]	OPTIONAL CONTROL CARDS	Additional control for Line-Model module
[7]	BLANK to end module BLANK to end line constants BEGIN NEW DATA CASE BLANK to end run	End of Data Case Identifiers (4 cards)

Table 1: Structure of the Line Constants Program Data Deck

With reference to Table 1, the data deck consists of the following sections:

[1] BEGIN DATA CASE Identifiers

The begin data case identifiers follow general EMTP/AUX usage. Two cards are needed: a) the "BEGIN NEW DATA CASE" card, and b) the "LINE CONSTANTS" request card

[2] MODULE

This card identifies the desired type of calculation: LINE-MODEL, LINE-PARAMETERS, or FIT-S.

[3] UNITS

Selects the system of units in which the conductor data is specified, i.e., Metric or English. It also controls the input format used in the CONDUCTOR data cards

[4] CONDUCTORS

These cards specify the geometry of the system of conductors and the characteristics of the individual conductors. A marker card is used to signal the end of the group of conductor cards. The marker card can be a blank card, the word "BLANK" (left-justified), or the characters "====" (at least four, left-justified).

[5] FREQUENCY

This card contains the frequency at which to evaluate the line parameters for the LINE-PARAMETERS module, and general information about the transmission system for the LINE-PARAMETERS and LINE-MODEL modules. This general information includes the ground resistivity, the line length, and other miscellaneous information. There is only one frequency card in the LINE-MODEL module and any number of frequency cards in the LINE-PARAMETERS module.

[6] OPTIONAL CONTROL CARDS

These cards are characterized by a dot "." in the first column of the line, joined to a keyword (e.g., ".ctlfit"). These lines are optional and allow the user to supply additional control information for the processing of the line parameters and line models, and to override internally preset default values.

The internal default values have been carefully chosen and most production cases can be run without the optional control cards.

[7] END DATA CASE Identifiers

These markers follow general EMTP/AUX usage. They include the following cards: a) "BLANK", b) "BEGIN NEW DATA CASE", and c) next data case, or "BLANK" to end the run.

Default Values

The following table gives the default values for some of the parameters and control variables used by the program. Some of these values can be changed by indicating the desired new values in the corresponding data cards. Other values are fixed internally and cannot be modified.

DELF	= 100 Hz	FDC	= 1.E-15 Hz	FINF	= 1.E+08 Hz
FMAX	= 5.0 kHz	FMIN	= 0.1 Hz	GPHASE	= 0.2E-09 S/km
IBUG1	= 0	IBUGF	= 0	IFITAL	= 0
IFITZC	= 0	ICOMPF	= -1	IMONIT	= -1
IPLOT	= +1	IPRAT	= +1	IPHASE	= +1

IROT = +1
IWD1 = –1
NDEC = 8

IWAVEF = –1
IIWQ = –1
NORMAX = 25
NPDEC = 10

IQUICK = –1
IWD = –1
IXDYN = +1

4 Line-Parameters Module

The Line-Parameters module can determine the resistance, inductance, and capacitance matrices for a multiphase overhead transmission line consisting of an arbitrary configuration of conductors. The data deck for this module follows the general structure shown in Section 3, Table 1. The required cards and information are described next.

4.1 Line-Parameters Control Card [2]

```
              1         2         3         4         5         6         7         8
123456789012345 67890123456789012345678901234567890123456789012345678901234567890
```

LINE-PARAMETERS	
A15	

Enter the keyword "LINE-PARAMETERS" in columns 1-15.

4.2 Units Control Card [3]

Specify S.I. Metric or English (British) system of units for line and conductor data.

```
            1          2          3          4          5         6         7         8
12345  678 9012345678 9012345678 9012345678 9 0 1234567890123456789012345678901234567890
```

UNITS		XMIN	XMAX	DELX		INOPT	
A8		E10.0	E10.0	E10.0		I1	

I

UNITS (1-5)	= "METRIC"	The S.I. system of units is used for conductor and line data. Units of mm or cm are used for conductor diameter and bundle spacing depending on the specified input option INOPT described below:	
		Units in the CONDUCTOR cards:	
		Resistance	Ω/km
		Diameter	mm for INOPT = 1
			cm for INOPT = 2
		Height and Spacing	m
		Bundle Spacing	m for INOPT = 1
			cm for INOPT = 2
		Units in the FREQUENCY card:	
		Line length	km
	""ENGLISH" or "BRITISH"	The English system of units is used for conductor and line data.	
		Units in the CONDUCTOR cards	
		Resistance	Ω/mile
		Diameter	inches
		Height and Spacing	feet
		Bundle spacing	inches
		Units in the FREQUENCY card	
		Line length	miles

4.3 Electric Field Strength Across Right-of-Way

When fields 9 to 38 of the UNITS card are specified, the electric field strength E (in kV/m or kV/ft, according to UNITS) at ground level (assuming flat ground) on a plane perpendicular to the line are calculated. The values of E are determined at increments DELX, from XMIN to the left to XMAX to the right.

Input option INOPT = 1 (columns 40) must be used for the CONDUCTOR data when electric field calculations are desired. With this input option, fields 73 to 80 of the CONDUCTOR cards are used to specify the voltages between conductors and ground, in magnitude and phase angle. See Section 5 for further information on these calculations.

XMIN (9-18)	Maximum distance (in m or feet, depending on UNITS) to the left (from the vertical reference axis used in the CONDUCTOR cards) at which E is calculated. See the diagram of Figure 4 for distance measurements.
XMAX (19-28)	Maximum distance (in m or feet, depending on UNITS) to the right (from the vertical reference axis used in the CONDUCTOR cards) at which E is calculated.
DELX (28-38)	Increments from XMIN to XMAX (in the same units as XMIN and XMAX) at which E is calculated. The output is printed in the sequence E(XMIN), E(XMIN + DELX), E(XMIN + 2XDELX), ..., E(XMAX).
INOPT (40)	Input format for conductor cards (see image of CONDUCTOR data cards in Section 4.4).

= 2 This is the default option and it corresponds to the traditional EMTP format for line constants (prior to version 2.0)

= 1 This new format of the CONDUCTOR cards permits the addition of fields VOL and PHA needed for the ELECTRIC FIELD STRENGTH calculations described above.

4.4 Conductor Data Cards [4]

The conductor cards contain the geometrical data of the line and the characteristics of the individual conductors.

As indicated in the UNITS card, two input formats for the conductor data are supported. INOPT = 2 in the UNITS card (default) corresponds to the traditional EMTP format. The new format INOPT = 1 allows for two additional fields that are used for electric field at ground level calculations (Section 4.2).

Format for INOPT = 2 (Default):

		1		2	3	4	5		6	7		8
123	45678	90123456	78	90123456	78901234	56789012	34567890	12345678	90123456	789012	345678	90
IPHASE	SKIN	RESIS	IXTYPE	REACT	DIAM	HORIZ	VTOWER	VMID	SEPAR	ALPHA		NBUND
I3	E5.0	E8.0	I2	E8.0	E8.0	E8.0	E8.0	E8.0	E8.0	E6.0		I2

Format for INOPT = 1 (New Option)

		1		2	3	4		5		7		8
123	45678	90123456	78	90123456	78901234	5678901	2345678	9012345	678	789012	3456	7890
IPHASE	SKIN	RESIS	IXTYPE	REACT	DIAM	HORIZ	VTOWER	VMID	NBUND	ALPHA	VOLT	PHA
I3	E5.0	E8.0	I2	E8.0	E8.0	E7.0	E8.0	E7.0	I3	E6.0	E4.0	E4.0

There must be one conductor card for each physical conductor in the line. This includes each subconductor in a bundle and also the ground wires. There is no conductor card associated with the earth return path. Bundled conductors specified using the bundle input option SEPAR (59-66) and ALPHA (67-72) require a single conductor card.

To facilitate data entry of identical conductors, if any or all of the first six fields (IPHASE, SKIN, RESIST, IXTYPE, and REACT) is left blank, the value of the corresponding variable will be assumed to be the same as in the previous card.

In the following description, N conductors are assumed (*column numbers refer to INOPT=2 above*):

IPHASE (1-3)	The phase number to which the conductor belongs. If more than one conductor is given the same phase number, this means that the conductors are electrically connected in parallel. This is the case, for instance, of individually-specified conductors in a bundle (fields SEPAR and ALPHA left blank). It could also be used, for instance, to internally combine two parallel lines when it is not desired to preserve their individual identity. Phase numbers for conductors must follow the sequence 1, 2, 3, ..., N with no missing phases. Set IPHASE = 0 for a ground wire (ground is phase number zero, by definition).
SKIN (4-8)	Flag for skin effect correction defined as Thickness/Diameter (T/D) of an equivalent tubular conductor (see Figure 2).

> 0	Assume a tubular conductor with T/D = SKIN.
= 0.0 or BLANK	Neglect the skin effect correction (see also the description of RESIS below).
= 0.5	Assume a solid conductor.
= –1	Use Galloway-Wedepohl's formula for stranded conductors.

RESIS (9-16)	DC resistance of the conductor in units of Ω/km or Ω/mile, according to UNITS. If the skin-effect correction is to be bypassed (0.0 in field SKIN (columns 4-8), specify the conductor's AC (not DC) resistance. Recall that AC resistance is equal to DC resistance plus a skin-effect contribution which depends on frequency. Also, the internal inductance for IXTYPE = 4 will not be corrected for skin effect when SKIN = 0. is specified. For the Galloway-Wedepohl's formula ('SKIN' = -1.0), RESIS is the per unit length resistance of only one strand: one of the outer strands.
IXTYPE (17-18)	Determines the interpretation of the variable REACT below. Usually KTYPE = 4. Other alternatives are explained in Section 4.5.
REACT (19-26)	REACT Takes on different meanings depending on the value of IXTYPE. For a conductor with IXTYPE = 4, REACT is the relative permeability and it is automatically defaulted to μr = 1.0 if left blank. Section 4.5 for other alternatives.
DIAM (27-34)	Outside diameter of the conductor in units of: centimetres if UNITS = METRIC and INOPT = 2 millimetres if UNITS = METRIC and INOPT = 1 inches if UNITS = BRITISH
HORIZ (35-42)	Horizontal distance of the conductor from the reference point x = 0 (see diagram in Figure 2 below), in units of: metres if UNITS = METRIC feet if UNITS = BRITISH The reference point x = 0 can be located anywhere since distances are relative. Distances to the right of x = 0 are positive and distances to the left are negative.
VTOWER (43-50)	Vertical height of the conductor above the ground, at the tower in units of: metres if UNITS = METRIC feet if UNITS = BRITISH

When both VTOWER and VMID are specified, an average height is calculated by the program using the formula:

$$\mathrm{VMID} + \frac{\mathrm{VTOWER} - \mathrm{VMID}}{3} = \frac{2 \cdot \mathrm{VMID} + \mathrm{VTOWER}}{3}$$

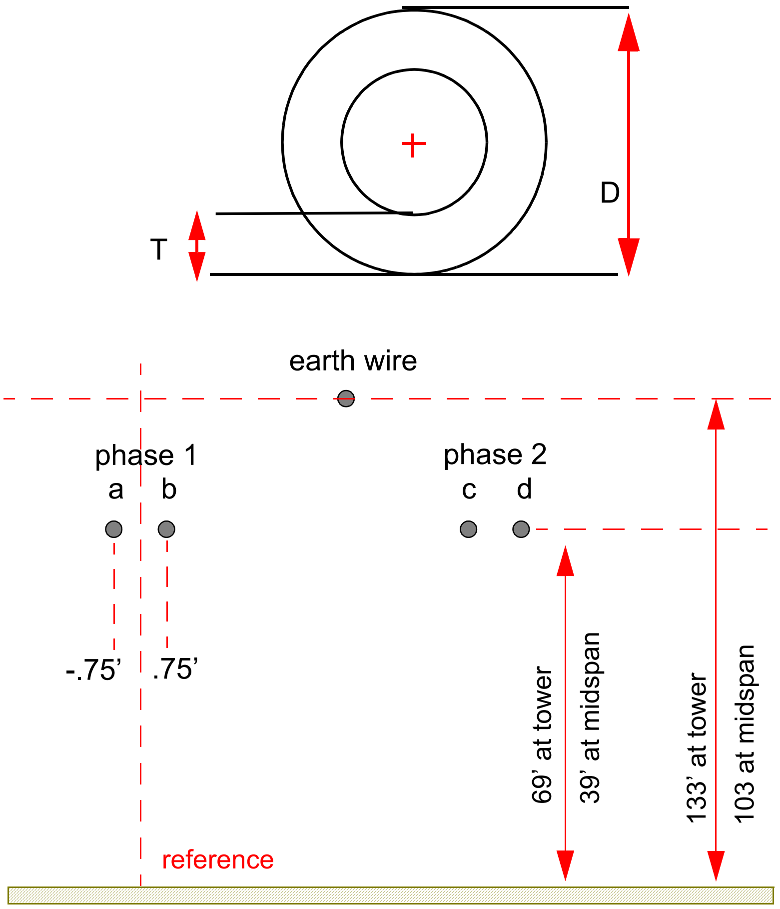
If only VTOWER is specified, then this height will be assumed uniform along the line.

VMID (51-58)	Midspan height of the conductor above the ground, at the tower in units of:

metres	if UNITS = METRIC
feet	if UNITS = BRITISH

Example of a conductor card:

```
C        1         2         3         4         5         6         7         8
C 345678901234567890123456789012345678901234567890123456789012345678901234567890
  1.3871  .03480 2   .7092   1.802    -.75    69.0    39.0
  1.3871  .03480 2   .7092   1.802     .75    69.0    39.0
  2.3871  .03480 2   .7092   1.802    40.0    69.0    39.0    18.0   0.0       2
  0  0.5    3.10 1    .484    .495    20.0   133.0
```



Conductors a, b, c, d:
R = 0.0398 Ω/mile
GMR = 0.7092"
DIAMETER = 1.802"
T/D = 0.3871

Ground wire:
R = 3.1 Ω/mile
Reactance for 1' spacing at 60 Hz = 0.484
DIAMETER = 0.495"
T/D = 0.5 (solid)

Figure 2: Example of Conductor Card (INOPT = 2)

Bundle Input Option:

Specified using parameters NBUND, SEPAR, ALPHA

Leave NBUND blank for single conductors. For a bundle with K conductors (see Figure 3 below) there are three options available to enter the bundle data:

(A) Enter a normal conductor card for each of the K conductors in the bundle, and leave NBUND blank. This may be too time-consuming for a regular symmetrical bundle, but it is the only option available for asymmetrical bundles.

(B) Convert the bundle into a single equivalent conductor using the distance averaging formulas available for this purpose and enter the equivalent conductor in a normal conductor card (leave NBUND blank). This alternative is less accurate than options (A) and (C).

(C) Specify a symmetrical bundle using the fields NBUND, SEPAR, and ALPHA. There should be only one CONDUCTOR card per bundle.

The data fields for option (C) are specified as follows:

NBUND (79-80)	Number of conductors in the bundle.
SEPAR (59-66)	Spacing between adjacent conductors in the bundle, in units of:

centimetres	UNITS = "METRIC" and INOPT = 2
millimetres	UNITS = "METRIC" and INOPT = 1
inches	UNITS = "ENGLISH"

ALPHA (67-72)	Angular position of the first conductor (or any conductor) of the bundle, in units of degrees. Positive angles are measured counter-clockwise.

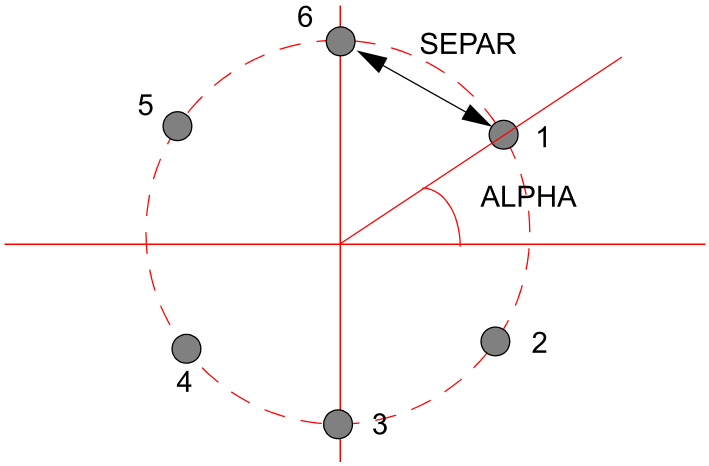


Figure 3: Sample sketch of a bundle with NBUND = 6 conductors, with angle ALPHA = 30°

Electric Field Strength At Ground Level

This option applies *only for INOPT = 1 in UNITS card*

VOLT (73-76) PHA (77-80)	These fields are used for electric field strength at ground level calculations (see also UNITS card in Section 4.2 above). Leave blank if these calculations are not desired. VOL and PHA specify the magnitude and phase angle of the voltage between the conductor and ground. The magnitude is the RMS value in kV and the phase angle is expressed in degrees. As an example, a 500 kV three-phase line with phases 1, 2, 3 could have the following voltages for normal operation:

Phase	Amplitude (RMS)	Angle(degrees)
1	289.	0.
2	289.	240.
3	289.	120.

4.5 Alternative Self-Inductance Calculation

With the default option IXTYPE = 4, the conductor internal inductance is corrected for skin effect assuming tubular conductor geometry. Alternative inductance options are possible that do not correct the conductor's internal inductance. These options are requested using the flag IXTYPE (columns 17-18). The data corresponding to the requested option is entered in field REACT (columns 19-26).

IXTYPE (17-18) Flag controlling the method used to calculate conductor inductance

= 0 Reactance for unit spacing, this reactance (not the inductance) is assumed to remain constant regardless of the frequency that may be specified in the FREQUENCY cards.

The unit spacing is:
1 meter if UNITS = "METRIC"
1 foot if UNITS = "ENGLISH"

The reactance REACT is in units of:
Ω/km if UNITS = "METRIC"
Ω/mile if UNITS = "ENGLISH"

= 1 Reactance for unit spacing (as above) at 60 Hz. As opposed to the case above where the reactance is assumed to remain constant, it is now the inductance that is assumed to remain at its 60-Hz value. If frequencies other than 60 Hz are specified in the FREQUENCY cards, the reactance will be changed proportionately.

Note that the relationship between reactances for 1'-spacing and GMR (geometric mean radius) is given by

$$X_{1-\text{foot}}(\Omega/(\text{mile})) = \frac{f(\text{Hz}))}{100.0} \cdot 0.20223653 \cdot \log\frac{12}{\text{GMR}(\text{inches}))}$$

$$X_{1-\text{foot}}(\Omega/(\text{mile})) = (2\omega \cdot 1.609344\times 10^{-4}) \cdot \log\frac{12}{\text{GMR}(\text{inches}))}$$

= 2 GMR (geometric mean radius) of the conductor, in units of:
millimetres if UNITS = "METRIC" and INOPT = 1
centimetres if UNITS = "METRIC" and INOPT = 2
inches if UNITS = "ENGLISH"

= 3 Dimensionless ratio GMR/r, where "r" is the conductor outer radius. For solid conductors, this ratio is equal to 0.7788.

= 4 This is the standard case described before. The internal reactance is calculated from the geometry of the tubular conductor as defined by SKIN, field 'REACT' is used to enter the relative permeability μ_r of the conductor. Default value is of μ_r is 1.0.

> 5 For use with Galloway-Wedepohl's equation (SKIN=–1). REACT is used to indicate the relative permeability μ_r of the outer strands. Default value of μ_r is 1.0. IXTYPE is equal to the total number of outer strands in the conductor.

4.6 Frequency Cards [5]

There is one frequency card for each frequency at which the line parameters are to be calculated.

The FREQUENCY card contains information on the ground resistivity, electrical frequency, segmentation of the ground wires, and line length.

There is a special request flag in this card (MUTUAL, column 59) to calculate the coupling between a transmission line and a communications line.

```
         1          2           3        4          5              6          7        8
12345678 9012345678 90123456789 012345 6 789012 3 4 56789012 3 4567 8 9 012345678 90 12 34567890
```

12345678	9012345678	90123456789	012345	6	789012	3	4	56789012	3	4567	8	9	012345678	90	12	34567890
RHO	FMATRIX		ICPRN		IZPRN		ICAP	ALONG		IPIPRN	ISEG	MUTUAL		MODAL	IFILE	
E8.0	E10.0		6I1		6I1			E8.0		4I1	I1	I1		I2	I2	

RHO (1-8) — Resistivity of the ground return path in units of Ω-meter. This applies to both to "METRIC" and "ENGLISH" options in the UNITS card.

FMATRX (9-18) — Frequency used in the calculation of the line parameters in Hz.

ICPRN (30-35) — Group of 6 flags that control the printout for the capacitance matrices [C], or the susceptance matrices ω[C], or the inverse of these. Flag ICAP in column 44 controls the option of printing either the inverse or normal matrix. Six possible independent outputs can be requested by entering "1" punches in the appropriate columns:

"1" in Column No.	**Resulting printout**
30	Inverse of [C] or ω[C]
31	Inverse of $[C_E]$ or $\omega[C_E]$
32	Inverse of $[C_S]$ or $\omega[C_S]$
33	[C] or ω[C]
34	$[C_E]$ or $\omega[C_E$
35	$[C_S]$ or $\omega[C_S]$

No subscript indicates the unreduced system. Each physical conductor has a row and column in the matrix, as does each ground wire.

Subscript "E" stands for "Equivalent phase conductors". (After elimination of ground wires and bundling of subconductors with the same phase number.)

Subscript "S" stands for "Symmetrical components" of the equivalent phase conductors.

Table 2: Summary of Output Options for the Capacitance Matrix

IZPRN (37-42)

Group of 6 flags to control the printout of the series impedance matrices [Z] = [R] + jω[L], or their respective inverse. Six possible independent printed outputs can be requested by entering "1" in the appropriate columns.

"1" in Column No.	**Resulting printout**
37	[Z]
38	$[Z_E]$
39	$[Z_S]$
40	$[Z]^{-1}$
"1" in Column No.	**Resulting printout**
41	$[Z_E]^{-1}$
42	$[Z_S]^{-1}$
No subscript indicates the unreduced system. Each physical conductor has a row and column in the matrix, as does each ground wire. Subscript "E" stands for "Equivalent phase conductors". (After elimination of ground wires and bundling of subconductors with the same phase number.) Subscript "S" stands for "Symmetrical components" of the equivalent phase conductors.	

Table 3: Summary of Output Options for the series impedance matrix

ICAP (44)

Flag to control over whether it is capacitance [C] or susceptance ω[C] that will be outputted by "ICPR" requests in columns 30-35:

= 1 capacitance [C] (or its inverse).

= 0 susceptance ω[C] (or its inverse).

ALONG (45-52)

Length of the transmission line under consideration, in units of:

kilometres	if UNITS = "METRIC"
miles	if UNITS = "ENGLISH"

This field can usually be left blank in the LINE-PARAMETERS module. It is only needed if the (approximate) multiphase nominal-pi representation of the line is requested. The multiphase nominal-pi is requested with the flag IFILE (columns 71-72).

IPIPRN (54-57)
Set of 4 flags to request the output of a multiphase nominal-pi circuit for the indicated line length.

Four possible independent printouts can be requested by entering "1" in the appropriate columns:

"1" in Column No.	Output
54	[Y]
55	[Y_S]
"1" in Column No.	**Output**
56	[Z]
57	[Z_S]
Where no subscript indicates the unreduced system. Each physical conductor has a row and column in the matrix, as does each ground wire.	

Table 4: Summary of Output Options for the Nominal-pi Model

ISEG (58)
Flag indicating whether the specified ground wires are to be modelled as continuous or segmented.

= 0 continuous ground wires (default case).

= 1 segmented ground wires (split at the towers).

MUTUAL (59)
Flag to request interference calculations with a communication circuit parallel to the power circuit. (See further discussion in Section 5.2.).

= 0 no interference calculation (default case).

= 1 output of interference to a nearby communication circuit.

MODAL (69-70)
Flag to request the output of modal parameters.

= 0 or blank No output of modal parameters.

= 1 Exact modal parameters.

Modal parameters are calculated from the exact [Z] and [Y] matrices at the specified frequency. The printout includes R, X, and ωC, as well as the characteristic impedance, wave velocity and attenuation for each mode. The modal transformation matrix T_i is also listed. In these calculations, the shunt conductance G is assumed to be zero.

=–1 **Exact modal parameters with R = 0.**

The resistances are set to zero before the modal parameters are calculated. The modal parameters are then evaluated exactly as in the case of MODAL = 1. This produces a lossless approximation that differs from the more conventional one obtained with MODAL = 2 (see below). One of the differences of using this option instead of the conventional one below is that the wave velocity of the zero sequence mode will be less than the wave velocity of the aerial modes, which is closer to the actual exact case.

=2 **Lossless High-Frequency Approximation**

Resistances are ignored and modal quantities are calculated from high-frequency approximations. This approximation is often used in lightning surge studies. It implies that all modes travel with the speed of light. The self and mutual surge impedances in phase quantities become $Z_{ii} = 60 \cdot \log(2h_i/r_i)$ and

$Z_{ik} = 60 \cdot \log(D_{ik}/d_{ik})$, respectively.

=3 Modal parameters are printed for both cases: MODAL = 1 and MODAL = 2 above.

=–3 Modal parameters are printed for both cases: MODAL = –1 and MODAL = 2 above.

IFILE (71-72) Multiphase nominal-pi model of the line (short-line approximation) is punched in LU7, in a format that can be used directly by the EMTP.

The nominal-pi model is only a short-line approximation which is not valid for electrically long lines. A multiphase pi-equivalent model, which is valid for long lines at one specific frequency, can be requested in the LINE-MODEL module (see Section 6).

=0 or blank Do not generate the nominal-pi model.

≥ 1 Generate the multiphase nominal-pi model. The model is punched in LU7. The units for L and C are controlled by the specific value of IFILE.

IFILE = 1 ⇒ L in mH, C in µF

IFILE = 2 ⇒ L in mH, ωC in μS

IFILE = 3 ⇒ X in Ω, C in μF

IFILE = 4 ⇒ X in Ω, C in μS

When the nominal-pi model is requested, there is the option of specifying node names to be punched in the branch card for the model. To specify the node names, the control card .NODES must immediately follow the FREQUENCY card where the request is made.

4.7 Special Request .NODES Card

123456	1 7890123456789	2 012345	6789	3 012345	6789	4 012345	6789	5 012345	6789	6012345	6789	7 012345	8 67890
.NODES		SEND-1		RECV-1		SEND-2		RECV-2		SEND-3		RECV-3	
A6		A6		A6		A6		A6		A6			

.NODES (1-6)	Keyword (left-justified).
SEND-1 (20-25)	Name of sending end of phase number 1.
RECV-1 (30-35)	Name of receiving end of phase number 1.
SEND-2 (40-45)	Name of sending end of phase number 2.
RECV-2 (50-55)	Name of receiving end of phase number 2.
SEND-3 (60-65)	Name of sending end of phase number 3.
RECV-3 (70-75)	Name of receiving end of phase number 3.

When there are more than 3 phases, the node names for the next 3 phases are provided on the next card (with the same format, from column 20 to 75) and so on. The first 6 columns of these additional cards must be either blank or contain the keyword .NODES.

4.8 Example of Data Deck for the Line-Parameters Module

```
BEGIN NEW DATA CASE
LINE CONSTANTS
c     TEST CASE 2  (LTC2).  Line-Parameters calculation.
c .............................................................................
Files              ltc2.out            ltc2.pun
Line-Parameters
c "JOHN DAY-LOWER MONUMENTAL LINE" (222 Km). DATA AS IN BPA'S. Nov. 12, 1985.
c  New Conductors Data Format (INOPT=1)
METRIC                                 1
  1.3636  .03240 4         40.6908-6.3246 15.240
  1.3636  .03240 4         40.6908-5.8674 15.240
  2.3636  .03240 4         40.6908-0.2286 23.622
  2.3636  .03240 4         40.6908 0.2286 23.622
  3.3636  .03240 4         40.6908 5.8674 15.240
  3.3636  .03240 4         40.6908 6.3246 15.240
  0.5000  1.6216 4          9.8044-3.9319 30.023
  0.5000  1.6216 4          9.8044 3.9319 30.023
BLANK
C Frequency Card
    100.      500.           000011 101000 1    222. 10001           1 1
.nodes             k-a       m-a       k-b       m-b       k-c       m-c
    100.     1000.           011000 010000 1    222. 00101           1 0
BLANK
BLANK
BEGIN NEW DATA CASE
BLANK
```

4.9 Description of Output from the Line-Parameters Module

(A) Listing of Conductor Characteristics:

The information contained on the conductor cards of the input data deck is printed for the record more or less in its original form, with the following exceptions

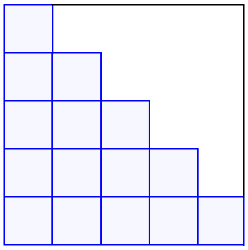
(1) In place of height at tower and midspan, the average height is listed as y-coordinate.

(2) The order of the conductor cards in the input data deck is arbitrary, while the order in the listing will always be as follows: conductors first encountered with phase numbers 1,2,3, ... , followed by conductors with already-existing phase numbers (= 2nd, 3rd, 4th, ... conductors in bundles or parallel circuits), followed by ground wires (phase number = 0).

(3) While a single conductor card may specify M conductors with the BUNDLE data option, all M conductors will be listed separately in the output.

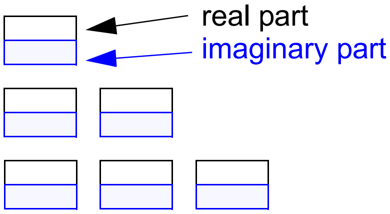
(B) Line Parameters:

Since all matrices are symmetric, only values in and below the diagonal are printed, as indicated below.



Only lower triangular matrix is printed

All matrices are complex, except the susceptance (or capacitance) matrices for the system of physical conductors and for the system of equivalent phase conductors. Real and imaginary parts are printed above each other, as indicated below.



Impedance Matrices: The matrix elements of the impedance matrices per kilometre or per mile are defined as follows:

$Z_{i,k}$ = mutual impedance between i and k,

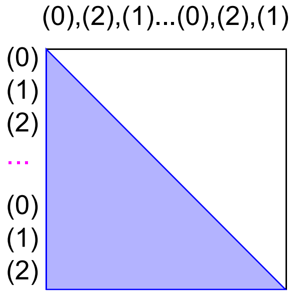
$Z_{i,i}$ = self impedance of i, with current returning through ground (and through ground wires if there are any and if they have been eliminated).

Capacitance Matrices: The matrix elements of the susceptance (or capacitance) matrices per kilometre or mile are defined as follows:

$\omega C_{i,k}$ = *negative* value of susceptance between i and k,

$\omega C_{i,i}$ = sum of all susceptances from i to all other conductors and to ground.

Symmetrical Components Matrices: Note that the matrices for symmetrical components have their rows ordered in the sequence "zero (0), positive (1), negative (2) of first three-phase circuit, (0), (1), (2) of second three-phase circuit, etc.", whereas the columns have (1) and (2) exchanged and are thus ordered "(0), (2), (1) of first circuit, (0), (2), (1) of second circuit, etc.". This trick makes these matrices symmetrical again, as indicated below.



From this modified row and column numbering, it follows that

$Z_{1,1} = Z_{2,2}$ within any three-phase circuit.

$Z_{1,0} = Z_{0,2}$ within any three-phase circuit etc., but

$Z_{1,0} = Z_{0,1}$, etc.

If there are only two equivalent phase conductors, a two-pole DC line is assumed. In this case, zero sequence refers to the operation where equal currents go into both poles and return through ground (and through ground wires if they exist and were eliminated), and positive sequence refers to the operation where the current goes into one pole and returns through the other.

For three or more equivalent phase conductors, only three-phase circuits are assumed, with numbers 1,2,3 forming the first circuit, numbers 4,5,6 forming the next circuit, etc. If the number of phases were 7 or 8, the last one or two phases would simply be ignored. If the number were 9, then three three-phase circuits would be assumed.

5 Special Calculation Options

5.1 Calculation of Electric Field Strength at Ground Level

The Line Parameters Module has an option to calculate electric field strength at ground level, and its usage is described in Section 4.4.

The electric field strength at ground level is difficult to evaluate if the terrain is irregular or if objects such as vehicles or buildings are close to the line. In the following, it is assumed that the terrain is perfectly flat, that the conductors are perfectly horizontal, and that there are no nearby objects.

The charges on the conductors are given by:

$$[Q] = [Q]^{-1} \cdot [V] = [C] \cdot [V] \quad \text{kC/km} \qquad (1)$$

or

$$C_j = \sum_{k=1}^{n} C_{jk} \cdot V_k \quad \text{kC/km)} \qquad (2)$$

where n is the number of conductors, C_{jk} are the elements of the capacitance matrix in F/km, and V_k is the root-mean-square phasor value of the line-to-ground voltage of conductor k in kV.

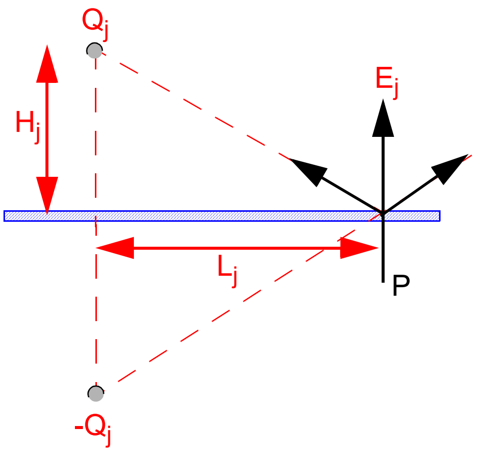


Figure 4: Contribution of Conductor j to Field Strength in P

The contribution from charge Q_j on conductor j and from charge $-Q_j$ on the image of this conductor to the field strength at point P (Figure 4 above) is

$$E_i = \frac{Q_j \cdot H_j}{\pi\varepsilon_o \cdot (H^2 + L^2)} \quad \text{kV/m} \tag{3}$$

if $\varepsilon_0 = 10^{-6}/(36\pi)$ in F/km, and H_j and L_j in m.

The magnitude of the total electric field strength at point P on the ground is

$$E_{total} = \sum_{j=1}^{n} E_j \quad \text{kV/m} \tag{4}$$

which is the value printed by the program. Note that E_{total} is a root-mean-square value since the voltages were given as root-mean-square values. The instantaneous value of the field strength would therefore be

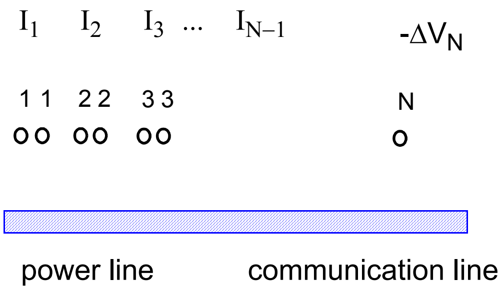
$$E_{total} = 2 \cdot E_{total} \cdot \cos(\omega t + \alpha) \tag{5}$$

with α being the angle of the phasor value

$$\sum_{j=1}^{n} E_j \tag{6}$$

5.2 Mutual Impedance with Communications Lines

When flag MUTUAL in the FREQUENCY CARD (Col. 59) is set to 1, the mutual impedances from the equivalent phase conductors 1,...N-1 to the N-th last equivalent phase conductor will be printed, as well as the impedance of the system of equivalent conductors $[Z_E]$. This is useful to study interference with communication lines, where the N-th equivalent phase conductor must represent the communication line (any type of conductor can be used for it, because the conductor type has no influence on mutual impedances). The longitudinally induced voltage in the N-th equivalent phase conductor is then,



$$-\Delta V_N = Z_{N1}\, I_1 + Z_{N2}\, I_2 + \ldots + Z_{N,N-1}\, I_{N-1} \qquad (7)$$

In addition, it is assumed that equivalent phase conductors 1,2,3 belong to three-phase circuit I; 4,5,6 to three-phase circuit II, etc. The mutual impedances are then also given for currents expressed in symmetrical components, or

$$\begin{aligned} -\Delta V N = \; & Z_{zeroI}\, I_{zeroI} + Z_{posI}\, I_{posI} + Z_{negI}\, I_{negI} \\ & + Z_{zeroII}\, I_{zeroII} + Z_{posII}\, I_{posII} \\ & + Z_{negII}\, I_{negII} + \ldots \end{aligned}$$

with I_{zeroI}, I_{posI}, I_{negI} being the zero, positive, negative sequence currents of circuit I, etc. The symmetrical components are unnormalized,

$$\begin{bmatrix} I_{zero} \\ I_{pos} \\ I_{neg} \end{bmatrix} = 1/3 \cdot \begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix} \cdot \begin{bmatrix} I_1 \\ I_2 \\ I_3 \end{bmatrix} \quad \text{with } a = e^{j120}$$

(for normalized symmetrical components, the factor in the above equation would be $1/\sqrt{3}$ instead of 1/3).

6 Line-Model Module

The Line-Model module can produce transmission line models for steady state and for transients studies. The data deck for this module follows the general structure shown in Table 1 (Section 3). The required data cards for this module are described next.

6.1 Line-Model Control Card

The Line-Model Control Card determines which model will be generated (e.g. frequency dependent, constant parameter, etc.), and which input option will be used.

The normal required information to characterize the transmission line is the geometric location of the conductors and their electrical characteristics. This information is specified in the CONDUCTOR data cards. However, when the line geometry is not known, it is still possible to generate reasonably accurate line models from the 60-Hz (or any other specific frequency) positive and zero sequence impedances. This input option, sometimes referred to as the "poor man's frequency dependent model" can be accessed by using the keyword "LBUILD" in the 'matrix' field (columns 30-39) of the LINE-MODEL control card:

The description of the fields and the specific meanings for each line model are given below as follows:

Card Format

FD-LINE

CP-LINE

PI-EXACT

SCAN

Line-Rebuild Option MATRIX = LBUILD

Fixed-Parameters Option MATRIX=CONSTANT

Card Format

1 1234567890	123456789	2 0123456789	3 0123456789	4 0123456789	5 0123456789	6 0123456789	7 0123456789	8 0
LINE-MODEL		Model	Matrix	Scale	FMIN	NPDEC/ DELF	NDEC/ FMAX	
A10		A10	A10	A10	E10.0	I10/E10.0	I10/E10.0	

Set the keyword "LINE-MODEL" in columns 1-10.

The LINE-MODEL card specifies the characteristics of the line model to be generated by the program. Output information on the processing of the model is listed in the output file. The model itself stored in the punch file in a format that can be read directly by the EMTP.

The following line models are available:

FD-LINE	Frequency dependent line model for transients simulations (also known as JMARTI line model).
CP-LINE	Constant-parameter line model for transients simulations (also known as Dommel line model).
PI-EXACT	Exact frequency domain representation of a line at a given frequency, for steady-state and frequency scan simulations.
SCAN	Generate line parameters and other information. No model is generated.

FD-LINE Model

The frequency dependent line model is used to represent the line in transients simulations with the EMTP. This model represents the true nature of a transmission line by modelling the line parameters as distributed and frequency dependent. The line resistance and inductance are evaluated as functions of frequency, as determined by skin effect and ground return conditions. The capacitance is assumed constant. A non-zero constant shunt conductance G (default value = 0.2×10^{-9} S/km) is included in the model.

The structure for the "fd-line" model request in the LINE-MODEL card is as follows:

1		2	3	4	5	6	7	8
1234567890	123456789	0123456789	0123456789	0123456789	0123456789	0123456789	0123456789	0
LINE-MODEL		Model	Matrix	Scale	FMIN	NPDEC	NDEC	
A10		A10	A10	A10	E10.0	I10/E10.0	I10/E10.0	

Keyword (1-10)	Set to "LINE-MODEL".
MODEL (20-29)	Set MODEL = FD-LINE.

MATRIX (30-39) See Section 6.8 for additional comments.

= QREAL In the general case of an untransposed line, the elements of the transformation matrix relating phase and modal quantities are complex numbers. Also, the matrix has different values at different frequencies. The fd-line model, however, makes the approximation of using a constant transformation matrix of real numbers for all frequencies in the modelling interval (default).

The optimum frequency at which to evaluate this real constant transformation matrix is determined automatically by the program (default option), or it can be specified externally by the user in the FREQUENCY control card.

After calling the eigenanalysis routines to evaluate the exact (complex) transformation matrix of the line at one frequency, the matrix is rotated and normalized. The imaginary part is then discarded and the remaining real part is taken as the "correct" transformation matrix to evaluate the line parameters and propagation functions at all frequencies. The errors due to this approximation are estimated in the Q-Error Table listed in the output file (see Section 6.8).

= BALANCED The line is modelled as perfectly transposed. The diagonal and the off-diagonal elements in the reduced Z_{phase} and Y_{phase} matrices are averaged out. The balanced-line transformation matrix used is the generalized Clarke transformation (α,β,o) for an m-phase line.

Unless the line is actually transposed, the results using this option are usually poorer than with the default "qreal" option. Check the Q-Error table in the output listing for error indicators.

= ZDOUBLE	This option applies only to double-circuit lines. The line is modelled as consisting of two separate circuits, each circuit perfectly balanced with respect to itself and to the other circuit. Under these conditions, the only coupling between the two circuits is zero sequence coupling. A special transformation matrix corresponding to this condition is used. Unless the transposition scheme of the line approaches the ideal zero coupling condition on which this option is based, better results are usually obtained with the default "qreal" option. Check the Q-Error Table in the output listing for an indication of the errors
SCALE (40-49)	The only available option is "LOG" (which is the default option). A log(f) scale is used to generate the frequency dependent functions in the model.
FMIN (50-59)	Lower limit of the frequency interval in which the line propagation function $e^{-\gamma l}$ and the line characteristic impedance Z_c are synthesized (fitting interval). Default value is FMIN=0.1Hz.
NPDEC (60-69)	Number of equally spaced points (on a log scale) in each decade of the fitting interval. NPDEC can be 10, 20, ..., up to 90 points per decade. In-between values (e.g., 15) are not permitted. Default value NPDE=10.
NDEC (70-79)	Number of decades (Default = 8). Defines the length of the fitting interval FMAX = FMIN x 10^{NDEC}.

CP-LINE Model

This option produces a constant parameters line model for transients simulations. The parameters are evaluated at the frequency specified in the FREQUENCY control card (default = 60 Hz). In this model the line is represented as a lossless, distributed LC line, with the total series resistance lumped as R/2 in the middle of the line and R/4 at each end. The shunt conductance G is taken as zero.

The data for the "cp-line" model in the LINE-MODEL card are as follows:

1 1234567890	123456789	2 0123456789	3 0123456789	4 5 6 7 8 01234567890123456789012345678901234567890
LINE-MODEL		Model	Matrix	
A10		A10	A10	

Keyword (1-10)	Set to "LINE-MODEL".	
MODEL (20-29)	Set MODEL = CP-LINE.	
MATRIX (30-39)	See Section 6.8 for additional comments.	
	= QREAL	A constant real transformation matrix, determined automatically by the program (default) or specified in the FREQUENCY card, is used for the model.
	= BALANCED	The line is modelled as balanced (perfectly transposed). The generalized Clarke (α,β,o) transformation is used for the model.
	= ZDOUBLE	Applies only to double-circuit lines. It is assumed that there is only zero-sequence coupling between the two circuits.

PI-EXACT Line Model

The "pi-exact" line model is used for STEADY-STATE or FREQUENCY SCAN solutions; it is not valid for transients simulations. This model is an exact lumped-impedance multiphase representation of the line as seen from its end points. This model is not adequate for transients simulations because, even assuming constant line parameters, the parameters of the model are different for different frequencies.

If a lumped-parameter model is desired for transients studies, it is better to use cascaded short-line sections of nominal pi-circuits. Nominal pi-circuits can be obtained as an option of the LINE-PARAMETERS module (see Section 4). In general, however, if a simple line model is desired for transients analysis, it is better to use the "CP-LINE" model (see above). This model gives much faster and much more accurate results than cascaded nominal pi-circuits.

The pi-exact equivalent is the line model that should be used for steady-state solutions and for frequency scans. The punched output for this model is given in terms of a Y-matrix representation that includes the series and shunt branches of the multiphase pi model.

The pi-exact model is produced for the frequency range specified in the LINE-MODEL card.

1		2	3	4	5	6	7	8
1234567890	123456789	0123456789	0123456789	0123456789	0123456789	0123456789	0123456789	0
LINE-MODEL		Model	Matrix	Scale	FMIN	NPDEC/ DELF	NDEC/ FMAX	
A10		A10	A10	A10	E10.0	I10/E10.0	I10/E10.0	

Keyword (1-10)	Set to LINE-MODEL.
MODEL (20-29)	Set MODEL = PI-EXACT.
MATRIX (30-39)	See Section 6.8 for additional comments.

= QCOMPLEX Since the pi-exact model is produced in phase quantities, it is not subject to the transformation matrix modelling constraints of transients line models. The exact complex transformation matrix can then be correctly used at each frequency at which the pi model is requested (default).

	= QREAL	In the general case of an untransposed line, the elements of the transformation matrix relating phase and modal quantities are complex numbers. Also, the matrix has different values at different frequencies. The fd-line model, however, makes the approximation of using a constant transformation matrix of real numbers for all frequencies in the modelling interval.
		The optimum frequency at which to evaluate this real constant transformation matrix is determined automatically by the program (default option), or it can be specified externally by the user in the FREQUENCY control card.
		After calling the eigenanalysis routines to evaluate the exact (complex) transformation matrix of the line at one frequency, the matrix is rotated and normalized. The imaginary part is then discarded and the remaining real part is taken as the "correct" transformation matrix to evaluate the line parameters and propagation functions at all frequencies. The errors due to this approximation are estimated in the Q-Error Table listed in the output file (see Section 6.8).
	= BALANCED	The line is assumed perfectly transposed. The line series impedances and shunt admittances, as determined from the line geometry, are averaged out.
	= ZDOUBLE	For double circuit lines. The line is assumed zero-sequence coupled only.
SCALE (40-49)	= LIN	The pi-exact matrices are generated over a linear frequency range defined by the interval [FMIN, FMAX] at discrete increments DELF.
	= LOG	The pi-exact matrices are produced over a logarithmic frequency range in the interval [FMIN, FMAX], where FMAX = FMIN x 10NDEC, and NPDEC is the number of points per decade. (See below for the specification of FMIN, NPDEC, and NDEC.)
FMIN (50-59)	SCALE = LIN	Initial frequency of frequency range in Hz. The built-in default value is 0.0 Hz.
		If FMIN < 0 then only one pi-exact equivalent, at frequency |FMIN|, is generated. This option is useful for steady-state solutions at one frequency (when this option is requested, the fields 'scale', NPDEC/DELF, and NDEC/FMAX are ignored).

	SCALE = LOG	Initial frequency of the frequency range in Hz. The built-in default value is 0.1 Hz. If FMIN < 0 then only one pi-exact equivalent, at frequency |FMIN|, is generated. This option is useful for steady-state solutions at one frequency (when this option is requested, the fields 'scale', NPDEC/DELF, and NDEC/FMAX are ignored).
NPDEC/ DELF (60-69)	SCALE = LIN	DELF: Frequency increment in Hz. The built-in default value is 100.0 Hz.
	SCALE = LOG	NPDEC: Number of equally spaced points in each decade of the logarithmic frequency range. Use multiples of 10. The built-in default value is 10, maximum value is 90.
NDEC/FMAX (70-79)	SCALE = LIN	FMAX: Last frequency in the frequency range in Hz. The built-in default value is 5000.0 Hz.
	SCALE = LOG	Number of decades (Default = 6). Defines the length of the frequency range as: FMAX = FMIN x 10^{NDEC}.

Parameter SCAN Option

The parameters scan option is requested with the keyword "scan" in the 'MODEL' field of the LINE-MODEL card. This option generates an output listing showing the transformation matrices, line parameters, and wave functions over the requested frequency range. No line model is generated.

```
         1         2          3          4          5         6         7         8
1234567890  123456789 0123456789 0123456789 01234567890123456789012345678901234567890
```

LINE-MODEL		Model	Matrix	
A10		A10	A10	

Keyword (1-10)	Set to "LINE-MODEL"	
MODEL (20-29)	MODEL = SCAN	
MATRIX (30-39)	= QREAL	Real transformation matrix from Q exact at one frequency.

= QCOMPLEX	Complex transformation matrix, evaluated exactly at each frequency.
= BALANCED	Clarke transformation for balanced lines.
= BALPAR	Same as "balanced" but more compact output listing.
= ZDOUBLE	Transformation matrix for double circuit lines with only zero-sequence coupling

SCALE (40-49)	The only available option is "LOG" which is the default option. The line parameters and wave functions are generated over a logarithmic frequency range.
FMIN (50-59)	Lower limit of the frequency interval in which the line propagation function $e^{-\gamma l}$ and the line characteristic impedance Z_c are synthesized (fitting interval). Default value is FMIN=0.1Hz.
NPDEC (60-69)	Number of equally spaced points (on a log scale) in each decade of the fitting interval. NPDEC can be 10, 20, ..., up to 90 points per decade. In-between values (e.g., 15) are not permitted. Default value NPDE=10.
NDEC (70-79)	Number of decades (Default = 8). Defines the length of the fitting interval FMAX = FMIN x 10^{NDEC}.

Line-Rebuild Option MATRIX = LBUILD

The line-rebuild option is requested with the keyword "LBUILD" in the 'matrix' field of the LINE-MODEL card. *This is a data input option that can be used with any of the available line models.*

1 1234567890	123456789	2 0123456789	3 0123456789	4 5 6 7 8 01234567890123456789012345678901234567890
LINE-MODEL		Model	Matrix	
A10		A10	A10	

Keyword (1-10)	Set to "LINE-MODEL"
MODEL (20-29)	Set MODEL to any of the available line models described above.

MATRIX (30-39) = LBUILD

The CONDUCTOR data cards for this option do not contain the line geometry as in the standard case, but the 60 Hz (or any other specific frequency) values of the zero and positive sequence impedances: R_0, L_0, G_0, C_0, and R_1, L_1, G_1, C_1. Optionally, for extra accuracy, the conductor's DC resistance can be supplied. The format of the CONDUCTOR cards is described in Section 6.4.

From the 60 Hz parameter information, the program builds an equivalent balanced arrangement of phase conductors that matches the specified 60 Hz sequence parameters. It also estimates the skin effect characteristics of the conductors. (this estimate is better if the conductor's DC resistance is specified.)

After rebuilding the line geometry and conductor characteristics, the requested line model is processed as in the ordinary case. Since the reconstructed line is assumed to be balanced, the transformation matrix is the same one used for balanced lines (generalized Clarke).

Fixed-Parameters Option MATRIX = CONSTANT

The fixed-parameters option is requested with the keyword "CONSTANT" in the 'matrix' field of the LINE-MODEL card. As in the "LBUILD" case, this option can be used with any of the available line models.

1 1234567890	123456789	2 0123456789	3 0123456789	4 5 6 7 8 01234567890123456789012345678901234567890
LINE-MODEL		Model	Matrix	
A10		A10	A10	

Keyword (1-10) Set to "LINE-MODEL".

MODEL (20-29) Set MODEL to any of the available line models described above.

MATRIX (30-39)	= CONSTANT	As in the case of the line-rebuild option (subsection 8.8.1.5) the line data is specified in terms of the 60 Hz (or any other frequency) zero and positive sequence parameters, except that no DC resistance is used in this case. The CONDUCTOR cards for this option are described in Section 6.5. As opposed to the line-rebuild option that rebuilds the line geometry in order to be able to consider the frequency dependence of the line parameters, the fixed-parameters option assumes that the line parameters R, L, G, and C remain constant as the frequency changes. This option can be used in combination with the fd-line model to create what is mathematically equivalent to a BALANCED cp-line model where R is truly distributed rather than lumped in three places. In general, the line-rebuild option gives much better results than the fixed-parameters option, and is the recommended model when only one-frequency data (e.g., 60 Hz) is available.

6.2 Units Control Card [3]

Specifies whether the S.I. metric or the English (British) system of units is used for the conductors and line data.

12345678	1 2 3 9012345678901234567890123456789	4 0	5 6 7 8 1234567890123456789012345678901234567890
UNITS		INOPT	
A8		I1	

UNITS
(1-8)

Flag identifying units used for conductor and line data.

= METRIC	The S.I. system of units is used for conductor and line data (mm or cm are used for conductor diameter and bundle spacing depending on the specified data input option INOPT (described below)).

Units in conductor cards	
Resistance	Ω/km
Diameter	mm if INOPT = 1 cm if INOPT = 2
Height & spacing	m
Bundle spacing	mm if INOPT = 1 cm if INOPT = 2
Units in the frequency card	
Line length	km

= ENGLISH or BRITISH — The English system of units is used for conductor and line data.

Units in conductor cards	
Resistance	Ω/mile
Diameter	inches
Height & spacing	feet
Bundle spacing	feet
Units in the frequency card	
Line length	miles

INOPT (40) — Default indicating option is used in the input format.

= 2 (default) — This option corresponds to the traditional EMTP format for line constants.

= 1 — This new format allows for electric field strength calculations in the LINE-PARAMETERS module.

6.3 Conductor Data Cards [4]

The conductor cards contain the geometrical data of the line and the characteristics of the individual conductors.

The meaning of the different fields in the CONDUCTOR cards is basically the same as explained in Section 4 for the LINE-PARAMETERS module. A summary of the required information and the differences in the present module are presented next.

As indicated in the UNITS card, two input formats are supported for the conductors data. The option INOPT = 2 (default) corresponds to the traditional EMTP format. The new format INOPT = 1 allows for two additional fields (columns 73-80) which are used for electric field calculations in the LINE-PARAMETERS module.

In the LINE-MODEL module, frequency dependence due to skin effect is always calculated. The approximation for tubular conductors is used for these calculations. Flag IXTYPE (columns 17-18) is assumed to be 4 by default and variable SKIN (columns 4-8) must be positive. The voltage specification fields for electric field calculations, columns 73-80 for INOPT = 1, are not used in this module.

Format for INOPT = 2 (Default):

		1		2	3	4	5		6	7		8
123	45678	90123456	78	90123456	78901234	56789012	34567890	12345678	90123456	789012	345678	90
IPHASE	SKIN	RESIS	IXTYPE	REACT	DIAM	HORIZ	VTOWER	VMID	SEPAR	ALPHA		NBUND
I3	E5.0	E8.0	I2	E8.0	E8.0	E8.0	E8.0	E8.0	E8.0	E6.0		I2

Format for INOPT = 1 (New Option)

		1		2	3	4		5		7	8
123	45678	90123456	78	90123456	78901234	5678901	2345678	9012345	678	789012	34567890
IPHASE	SKIN	RESIS	IXTYPE	REACT	DIAM	HORIZ	VTOWER	VMID	NBUND	ALPHA	
I3	E5.0	E8.0	I2	E8.0	E8.0	E7.0	78.0	E7.0	I3	E6.0	

There must be one conductor card for each physical conductor in the line. This includes each subconductor in a bundle and also the ground wires. There is no conductor card associated with the earth return path. Bundled conductors specified using the bundle input option SEPAR (59-66) and ALPHA (67-72) use a single conductor card.

To facilitate data entry of identical conductors, if any or all of the first six fields (IPHASE, SKIN, RESIST, IXTYPE, and REACT) is left blank, the value of the corresponding variable will be assumed to be the same as in the previous card.

In the following description, N conductors are assumed (*column numbers refer to INOPT=2 above*):

IPHASE (1-3)	The phase number to which the conductor belongs. If more than one conductor is given the same phase number, this means that the conductors are electrically connected (connected in parallel). This is the case, for instance, of individually specified conductors in a bundle (fields SEPAR and ALPHA left blank). It could also be used, for instance, to internally combine two parallel lines when it is not desired to preserve their individual identity. Phase numbers for conductors must follow the sequence 1, 2, 3, ..., N with no missing phases. Set IPHASE = 0 for a ground wire (ground is phase number zero, by definition).	
SKIN (4-8)	Flag for skin effect correction defined as Thickness/Diameter (T/D) of an equivalent tubular conductor (see Figure 5 below)	
	> 0	Assume a tubular conductor with T/D = SKIN.
	= 0.0 or BLANK	Neglect the skin effect correction (see also the description of RESIS below).
	= 0.5	Assume a solid conductor.
RESIS (9-16)	DC resistance of the conductor in units of Ω/km or Ω/mile, according to UNITS.	
KTYPE (17-18)	KTYPE = 4 or blank. Internal reactance is corrected for skin effect from the geometry of the tubular conductor defined by SKIN.	
REACT (19-26)	REACT is the relative permeability and it is automatically defaulted to $\mu_r = 1.0$ if left blank.	
DIAM (27-34)	Outside diameter of the conductor in units of:	
	centimetres	if UNITS = METRIC and INOPT = 2
	millimetres	if UNITS = METRIC and INOPT = 1
	inches	if UNITS = BRITISH
HORIZ (35-42)	Horizontal distance of the conductor from the reference point x = 0 (see diagram in Figure 5 below)), in units of:	
	metres	if UNITS = METRIC
	feet	if UNITS = BRITISH

The reference point x = 0 can be located anywhere since distances are relative. Distances to the right of x = 0 are positive and distances to the left are negative.

VTOWER
(43-50)

Vertical height of the conductor above the ground, at the tower in units of:

metres if UNITS = METRIC

feet if UNITS = BRITISH

When both VTOWER and VMID are specified, an average height is calculated by the program using the formula:

$$\mathrm{VMID} + \frac{\mathrm{VTOWER} - \mathrm{VMID}}{3} = \frac{2 \cdot \mathrm{VMID} + \mathrm{VTOWER}}{3}$$

If only VTOWER is specified, then this height will be assumed uniform along the line.

VMID
(51-58)

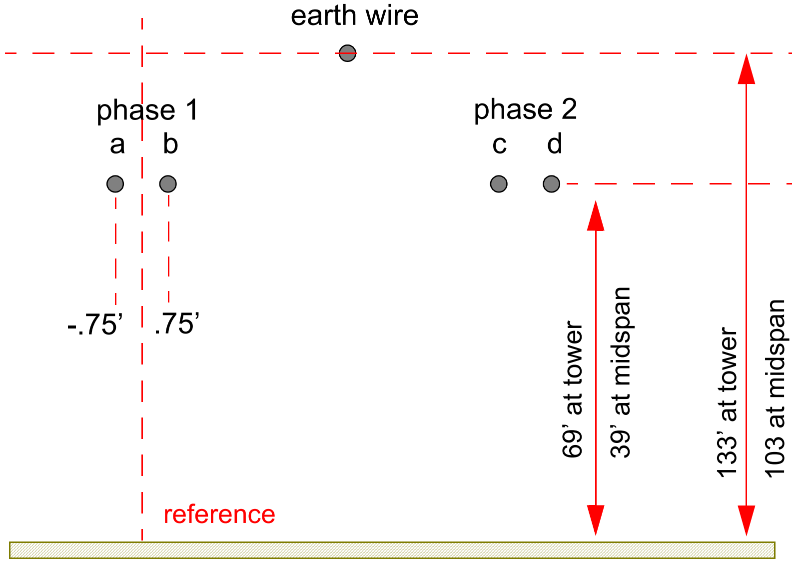
Midspan height of the conductor above the ground, at the tower in units of:

metres if UNITS = METRIC

feet if UNITS = BRITISH

Example of a conductor card:

```
C        1         2         3         4         5         6         7         8
C 345678901234567890123456789012345678901234567890123456789012345678901234567890
  1.3871  .03480 2   .7092   1.802    -.75    69.0    39.0
  1.3871  .03480 2   .7092   1.802     .75    69.0    39.0
  2.3871  .03480 2   .7092   1.802     40.0   69.0    39.0    18.0   0.0       2
  0  0.5    3.10 1    .484    .495     20.0  133.0
```



Conductors a, b, c, d:

R = 0.0398 Ω/mile

GMR = 0.7092"

DIAMETER = 1.802"

T/D = 0.3871

Ground wire

R = 3.1 Ω/mile

Reactance for 1’ spacing at 60 Hz = 0.484

DIAMETER = 0.495"

T/D = 0.5 (solid)

Figure 5: Example of Conductor Card (INOPT = 2)

Bundle Input Option:

Specified using parameters NBUND, SEPAR, ALPHA

Leave NBUND blank for single conductors. For a bundle with K conductors (see Figure 6 below) there are three options available to enter the bundle data:

(A) Enter a normal conductor card for each of the K conductors in the bundle, and leave NBUND blank. This may be too time-consuming for a regular symmetrical bundle, but it is the only option available for asymmetrical bundles.

(B) Convert the bundle into a single equivalent conductor using the distance averaging formulas available for this purpose and enter the equivalent conductor in a normal conductor card (leave NBUND blank). This alternative is less accurate than options (A) and (C).

(C) Specify a symmetrical bundle using the fields NBUND, SEPAR, and ALPHA. There should be only one CONDUCTOR card per bundle.

The bundle fields for option (C) are specified as follows:

NBUND (79-80)	Number of conductors in the bundle.	
SEPAR (59-66)	Spacing between adjacent conductors in the bundle, in units of:	
	centimetres	UNITS = "METRIC" and INOPT = 2
	millimetres	UNITS = "METRIC" and INOPT = 1
	inches	UNITS = "ENGLISH"
ALPHA (67-72)	Angular position of the first conductor (or any conductor) of the bundle, in units of degrees. Positive angles are measured counter-clockwise.	

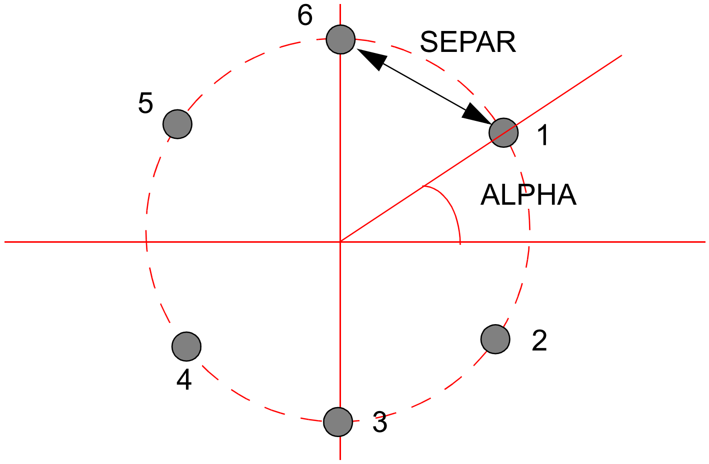


Figure 6: Sample sketch of a bundle with NBUND = 6 conductors, with angle ALPHA = 30^{o}

6.4 Conductor Cards for the Line-Rebuild Option

The Line-Rebuild option is described in Section 6.1. The format for the conductor cards is indicated next.

```
           1          2           3          4          5           6          7          8
12 3456789 0123456789 0123456789  0123456789 0123456789 0123456789  0123456789 01234567890
```

KCIRCT		FPARAM	RZERO	LZERO	GZERO	CZERO	RDC	
I2		E10.0	E10.0	E10.0	E10.0	10.0	E10.0	

KCIRCT (1-2)		Number of phases.
FPARAM (10-19)		Frequency in Hz at which the sequence parameters are given. The built-in default value is 60 Hz.
RZERO (20-29)		Zero sequence resistance in Ω/km, for UNITS = METRIC, or Ω/mile for UNITS = ENGLISH.
LZERO (30-39)		Zero sequence inductance in mH/km, for UNITS = METRIC, or mH/mile for UNITS = ENGLISH.
GZERO (40-49)		Zero sequence conductance in S/km, for UNITS = METRIC, or S/mile for UNITS = ENGLISH.
CZERO (50-59)		Zero sequence capacitance in µF/km, for UNITS = METRIC, or µF/mile for UNITS = ENGLISH.
RDC (60-69)	= 0	DC resistance of the conductors in Ω/km or Ω/mile (according to UNITS) will be estimated by the program.
	> 0	DC resistance of the conductors in Ω/km or Ω/mile (according to UNITS). This parameter is optional for greater accuracy. If not given, it will be estimated by the program.

```
                    2          3          4          5           6          7        8
1234567890123456789 0123456789 0123456789 0123456789 0123456789  012345678901234567890
```

	RPOS	LPOS	GPOS	CPOS	
	E10.0	E10.0	E10.0	10.0	

RPOS (20-29)	Positive sequence resistance in Ω/km, for UNITS = METRIC, or Ω/mile for UNITS = ENGLISH.

LPOS (30-39)	Positive sequence inductance in mH/km, for UNITS = METRIC, or mH/mile for UNITS = ENGLISH.
GPOS (40-49)	Positive sequence conductance in S/km, for UNITS = METRIC, or S/mile for UNITS = ENGLISH.
CPOS (50-59)	Positive sequence capacitance in μF/km, for UNITS = METRIC, or μF/mile for UNITS = ENGLISH.

6.5 Conductor Cards for the Fixed-Parameters Option

The Fixed-Parameters option is described in Section 6.1. The format for the conductor cards is indicated next.

12	3456789	1 0123456789	2 0123456789	3 0123456789	4 0123456789	5 0123456789	6 7 8 012345678901234567890
KCIRCT		FPARAM	RZERO	LZERO	GZERO	CZERO	
I2		E10.0	E10.0	E10.0	E10.0	10.0	

KCIRCT (1-2)	Number of phases.
FPARAM (10-19)	Frequency in Hz at which the sequence parameters. The built-in default value is 60 Hz.
RZERO (20-29)	Zero sequence resistance in Ω/km, for UNITS = METRIC, or Ω/mile for UNITS = ENGLISH.
LZERO (30-39)	Zero sequence inductance in mH/km, for UNITS = METRIC, or mH/mile for UNITS = ENGLISH.
GZERO (40-49)	Zero sequence conductance in S/km, for UNITS = METRIC, or S/mile for UNITS = ENGLISH.
CZERO (50-59)	Zero sequence capacitance in μF/km, for UNITS = METRIC, or μF/mile for UNITS = ENGLISH.

1234567890123456789	2 0123456789	3 0123456789	4 0123456789	5 0123456789	6 7 8 012345678901234567890
	RPOS	LPOS	GPOS	CPOS	
	E10.0	E10.0	E10.0	10.0	

RPOS (20-29)	Positive sequence resistance in Ω/km, for UNITS = METRIC, or Ω/mile for UNITS = ENGLISH.
LPOS (30-39)	Positive sequence inductance in mH/km, for UNITS = METRIC, or mH/mile for UNITS = ENGLISH.
GPOS (40-49)	Positive sequence conductance in S/km, for UNITS = METRIC, or S/mile for UNITS = ENGLISH.
CPOS (50-59)	Positive sequence capacitance in µF/km, for UNITS = METRIC, or µF/mile for UNITS = ENGLISH.

6.6 Frequency Card [5]

12345678	1 9012345678	2 3 4 90123456789012345678901234	5 56789012	34567	8	6 7 8 9012345678901234567890
RHO	FMATRX		ALONG		ISEG	
E8.0	E10.0		E8.0		I1	

RHO (1-8)	Ground return resistivity in ohm-m.
FMATRX (9-18)	Frequency, in Hz, at which to evaluate the transformation matrix. Default = Internally determined by the program for the fd-line model. 60 Hz for the cp-line model. Frequency at which to evaluate the transformation matrix T_i in line models with 'matrix' = "qreal" option.

For the frequency dependence line model (fd-line), the program will automatically select an optimum value of FMATRX for the range of switching transients. This value is based on asymptotic conditions for the particular line under consideration. Typical values are in the range from 500 Hz to 5 kHz with a mean around 1000 Hz. The selection of an optimum value is based on constancy of T_i within the typical frequency range for switching transients. For studies involving other frequency ranges (e.g., lightning studies), FMATRX should be supplied externally.

For the constant parameters line model (cp-line), the default value for FMATRX is 60 Hz. If FMATRX < 0 is specified for this model, the program will determine FMATRX internally, using the same procedure as for the fd-line model.

ALONG (45-52)	Line length in km, for UNITS = METRIC, or miles for UNITS = ENGLISH.	
ISEG (58)	= 0	Ground wires are not segmented (default).
	= 1	Ground wires are segmented.

6.7 Optional Control Cards [6]

Optional control cards allow the user to specify additional information on the transmission system (e.g. node names and transposition scheme) and to have a greater degree of control over internal processes (e.g. rational functions fitting). They can also be used to request additional output and debugging information.

These cards are optional and can appear in any order after the FREQUENCY card. Their presence is signalled by a dot '.' in column one joined to a key word.

The following optional control cards are available:

(A) Associated with the processing of the line parameters and functions:

.dbgline
.phase
.imbal
.nodes
.outline
.transp

(B) Associated with the rational functions fitting for frequency dependence line models:

.ctlfit
.dbgfit
.outfit

Unless otherwise indicated, control flags are either on or off, where 1 = on and –1 = off.

(A) Line Processing Control Cards

.NODES (Node Names)

Allows input of node names at the sending and receiving ends of each phase. The node names will be printed in the line model branches of the punch file.

	1	2		3		4		5		6		7	8
123456	7890123456789	012345	6789	012345	6789	012345	6789	012345	6789	012345	6789	012345	67890
.nodes		k-a		m-a		k-b		m-b		k-c		m-c	
A6		A6		A6		A6		A6		A6		A6	

1	2		3		4		5		6		7	8
1234567890123456789	012345	6789	012345	6789	012345	6789	012345	6789	012345	6789	012345	67890
	k-d		m-d		k-e		m-e		k-f		m-f	
	A6		A6		A6		A6		A6		A6	

Node names are assigned in sending-receiving end pairs. Additional cards can be used for node specification of more than three phases.

.TRANSP (Transposition Option)

This option produces a line model for transposed lines based on the averaging of the series impedance and shunt admittance matrices. This procedure is only an approximation to the correct solution of modelling each transposition segment explicitly and then specifying the appropriate node connections in the EMTP. Averaging is valid only when the length of the transposition sections is several times smaller than the wavelength of the propagating signals.

Span Length Cards

	1		2	3	4				8
123456789	01	23456789	0123456789	0123456789	0123456789	0123456789	0123456789	0123456789	0
.TRANSP	NSPAN		spanl1	spanl2	spanl3	spanl4	spanl5	spanl6	
A9	I2		E10.0	E10.0	E10.0	E10.0	E10.0	E10.0	

```
         1         2         3         4                                       8
1234567890123456789 0123456789 0123456789 0123456789 0123456789 0123456789 0123456789 0
```

	spanl7	spanl8	spanl9	spanl10	spanl11	spanl12	
	E10.0	E10.0	E10.0	E10.0	E10.0	E10.0	

.transp (1-9)	Keyword to flag the transposition option.
nspan (10-11)	Number of transposition sections.
spanl-j	Span length, sections 1 to 6 for the first card, and 7 to 12 for the second card. Length in km (METRIC) or miles (ENGLISH). Additional cards can be added for more that 12 transposition sections. *The sum of the lengths of all the transposition sections must equal the total length of the line as specified in the FREQUENCY card to an accuracy of three digits.* This provides a check on the correct specification of the transposition sections. There is no check, however, on the specification of the phase sequence.

Phase Sequence in Transposition Section:

```
         1         2                   3         4         5         6         7         8
1234567890123456789 01  23   45   67  89  01   234567890123456789012345678901234567890
```

	n^1_1	n^1_2	n^1_3	n^1_4	n^1_5	n^1_6	...
	I2	I2	I2	I2	I2	I2	...

```
         1         2                   3         4         5         6         7         8
1234567890123456789 01  23   45   67  89  01   234567890123456789012345678901234567890
```

	n^2_1	n^2_2	n^2_3	n^2_4	n^2_5	n^2_6	...
	I2	I2	I2	I2	I2	I2	...

Phase sequence in section 1 is specified in Card 1 (20-79), namely:

$n_1^1, n_2^1, n_3^1, n_4^1, n_5^1, n_6^1, \ldots, n_n^1$ = phase number as specified in 'iphase' in the CONDUCTOR cards (see Section 6.3)

$n_1^2, n_2^2, n_3^2, n_4^2, n_5^2, n_6^2, \ldots, n_n^2$ = phase number as specified in 'iphase' in the CONDUCTOR cards (see Section 6.3)

At least one additional card is needed for each additional transposition section.

.Gphase (Phase Shunt Conductance)

This option allows the specification of values for the line shunt conductance G other than the internal default value of 0.2×10^{-9} S/km (for those line models that assume nonzero G). The values specified in these cards are the diagonal elements of the reduced (not the full conductors matrix) G_{phase} matrix. The off-diagonal elements of G_{phase} are assumed to be zero.

1234567	1 890123456789	2 0123456789	3 0123456789	4 0123456789	0123456789	0123456789	0123456789	8 0
.GPHASE		G_{aa}	G_{bb}	G_{cc}	G_{dd}	G_{ee}	G_{ff}	
A7		E10.0	E10.0	E10.0	E10.0	E10.0	E10.0	

1 1234567890123456789	2 0123456789	3 0123456789	4 0123456789	5 0123456789	6 0123456789	7 0123456789	8 0
	G_{gg}	G_{hh}	G_{ii}	G_{jj}	G_{kk}	G_{ll}	
	E10.0	E10.0	E10.0	E10.0	E10.0	E10.0	

.GPHASE (1-7)	Keyword to flag the shunt conductance option.
G_{xx} (20-79)	Phase conductances (G_{aa} G_{bb} ... G_{ff} in the first card and G_{gg} ... G_{ll} for the second card) in S/km for UNITS = METRIC or S/mile for UNITS = BRITISH. These are the conductances from conductors to ground. Additional cards can be used as required. **Note:** A value of zero or blank for a given entry will be taken as $G_{ii} = 0.$ and not as the default value of 0.2×10^{-9} S/km, which is assumed when the .gphase option is not specified.

.OUTLINE (Output from Line Processing)

12345678	1 90123456789	2 01	23	3 4 5 6 7 8 456789012345678901234567890123456789012345678901234567890
.OUTLINE		IWAVEF	IMONIT	
A8		I2	I2	

.OUTLINE
(1-8)
Keyword to flag the output information option.

IWAVEF
(20-21)
Flag controlling the printout status of $Z_c = \sqrt{Z/Y}$ and

$A_p = e^{-(\sqrt{ZY} \cdot l)}$.

= 1 The wave functions Z_c and A_p are printed on the output file for each line mode over the frequency range specified in the LINE-MODEL card.

= -1 No output of the line wave functions (default value).

IMONIT
(22-23)
Flag controlling the monitoring of frequency being processed.

= 1 The frequency being processed is indicated during the evaluation of the line wave functions. (This is useful during slow system processing.)

= –1 No frequency monitoring (default value).

.DBGLINE (Debug Line)

12345678	1 90123456789	2 01	23	45	67	89	3 4 5 6 7 8 456789012345678901234567890123456789012345678901234567890
.DBGLINE		IBUG1	IROT	IWQ	IWD	IWD1	
A8		I2	I2	I2	I2	I2	

.DBGLINE (1-8) Keyword to flag line processing debugging and control.

IBUG1 (20-21) Flag controlling the amount of printout during line parameter calculations. Valid range is 0,1,2, or 3 (default = 0).

IROT (22-23) Flag controlling the rotation of the modal transformation matrix Q or T_I. Default value is 1.

= 1 Rotate the transformation matrix T_i to satisfy the condition: modal shunt conductance matrix $G_m = 0$ when phase shunt conductance matrix $G_{ph} = 0$.

= 2 Rotate the transformation matrix T_i to minimize the imaginary part of its elements.

The following flags are valid when MODEL = SCAN and Transformation Matrix = qcomplex in the LINE-MODEL control card:

IWQ (24-25) Flag to control the printing of the modal transformation matrix Q or T_I.

= 1 Print the transformation matrix Q-complex at each frequency of the frequency loop.

= –1 Do not print.

IWD (26-27) Flag controlling the printout of the product $[Y_{mode} \cdot Z_{mode}]$. Default value is –1 (no printout).

= 1 Print the product $[Y_{mode} \cdot Z_{mode}]$ at each frequency of the frequency loop. Ideally, for T_i-exact, [Ymode . Zmode] = diagonal matrix.

= –1 Do not print.

IWD1 (28-29) Similar to IWD, above. Default value is –1 (no printout).

= 1 Same as above, but with the elements of $[Y_{mode} \cdot Z_{mode}]$ normalized so that the largest real part of any element equals one.

= –1 Do not normalize.

.IMBAL (Test Sources for Q-error Indicators)

Value of the voltage sources for the open-circuit/short-circuit Q-Error tests. In the open circuit test, all the phases at the receiving end of the line are open. In the short circuit test, all the phases at the receiving end of the line are short circuited.

```
         1          2          3          4          5          6          7          8
12345678 90123456789 0123456789 0123456789 0123456789 0123456789 0123456789 0123456789 0
```

.IMBAL		VOLT-A	PHASE-A	VOLT-B	PHASE-B	VOLT-C	PHASE-C	
A8		E10.0	E10.0	E10.0	E10.0	E10.0	E10.0	

.IMBAL (1-8)	Flag to request the override of the test sources for the Q-error indicators.
VOLT-J (20-29) ...	Voltages at the sending end. Magnitude of the voltage source V_J connected from phase J to ground at the sending end of the line. (A short circuit at the sending end can be simulated by making VOLT-J = 0.)
PHASE-J (30-39) ...	Phase angle (in degrees) of voltage source V_J.

Additional cards can be added as required for additional phases. The internal default values (if the .IMBAL option is not used) are as follows:

$$V_a = 1\ /0^{o} \qquad V_b = 1\ /0^{o} \qquad V_c = 1\ /120^{o}$$

$$V_d = 1\ /0^{o} \qquad V_e = 1\ /0^{o} \qquad V_f = 1\ /120^{o}$$

(B) Fitting Control Cards

.CTLFIT (FIT-S Control)

Allows for additional user control over the fitting of the line wave functions Z_c and $A_p = e^{-\gamma l}$. Additional output information can also be requested.

	1	2					3 4 5 6 7 8
1234567	890123456789	01	23	45	67	89	45678901234567890123456789012345678901234567890123456789
.CTLFIT		NORMAX	IQUICK	IXDYN	IFITZC	IFITAL	
A7		I2	I2	i2	i2	i2	

.CTLFIT (1-7)	Keyword to control the fitting process of fd-line models.	
NORMAX (20-21)	Maximum number of poles in the synthesis of the line wave functions Z_c and A_p. Default value is 25.	
IQUICK (22-23)	Flag controlling the accuracy of the fit of Z_c and A_p. Default value is –1.	
	= 1	Much faster (fewer iterations) approximation of Z_c and A_p is produced. Some accuracy is sacrificed with respect to the normal procedure.
	= –1	Normal iteration procedure is used.
IXDYN (24-25)	Flag controlling the low frequency approximation of A_p. Default value is 1.	
	= 1	Extra dynamics (extra poles and zeroes) are added to the approximation of the low frequency region of the propagation function A_p. This allows a more accurate simulation of very short line sections (e.g., for breaker re-ignition studies) and of very low frequencies (e.g., for trapped charge conditions).
	= –1	No extra dynamics are added to the approximation of A_p. This results in a lower order approximation but less reliable for short line sections or very low frequencies.
IFITZC (26-27)	Flag controlling the fitting of Z_c in different modes.	
	= N	Only one mode "N" of the Z_c function is fitted. Mostly for testing purposes.
	= 0	Fit all modes (Default).
IFITA1 (28-29)	Flag controlling the fitting of A_p in different modes.	

= N Only one mode "N" of the A_p function is fitted. Mostly for testing purposes.

= 0 Fit all modes (Default).

To produce the fd-line model, synthesis of all modes is required. This is the normal case with the default flags IFITZC = 0 or blank and ifital = 0 or blank.

.OUTFIT (FIT-S Output)

Controls the amount of output information on the fitting of the line functions.

```
              1           2           3         4         5         6         7         8
1234567 890123456789 01 23 45 678901234567890123456789012345678901234567890123456789012345678901234567890
```

.OUTFIT		ICOMPF	IPLOTF	IPRAT	
A7		I2	I2	I2	

.OUTFIT (1-7) Keyword to control the amount of output generated during the fitting process of fd-line models.

ICOMPF (20-21) Flag controlling the printout of a comparison table. Default value is -1 (no printout).

= 1 An output table is produced comparing the data functions Z_c and A_p as produced by the line constants routines and the approximating rational functions produced by FIT-S.

= –1 No comparison table is produced.

IPLOTF (24-25) Flag controlling the printout of a printer plot.
Default value is 1 (print).

= 1 A printer plot is produced comparing the data functions and the approximations.

= –1 No printer plot is produced.

IPRAT (26-27) Flag controlling the printout of poles and zeros tables. Default value is 1 (print).

= 1	Tables are produced showing the location of the poles and zeros of the rational function approximations of Z_c and A_p. Also shown are the RC equivalent network for Z_c and the time domain exponential representation of the approximating functions.
= –1	No tables are produced.

.DBGFIT (FIT-S Debug)

Controls the amount of internal processing output from FIT-S.

```
           1           2            3           4           5           6           7           8
1234567  890123456789 01  23456789012345678901234567890123456789012345678901234567890
```

.DBGFIT		IBUGF	
A7		I2	

.DBGFIT (1-7)	Keyword to request debug information during the fitting process of fd-line models.
IBUGF (20-21)	Flag controlling the level of diagnostic printout. Valid range is 1-3 (default = 0). The higher the number, the larger the amount of debugging output from FIT-S.

6.8 Transformation Matrices and Q-Error Indicators

For a perfectly balanced line, the modal transformation matrices to relate modal and phase quantities do not change with frequency (constant transformation matrices) and can be chosen to be real (e.g. generalized Clarke, as used by the program).

In the general case of the untransposed line, however, the transformation matrices change with frequency. The line currents transformation matrix T_i is the matrix that diagonalizes the product $Y_{phase} \cdot Z_{phase}$ where Y_{phase} is the shunt admittance matrix in phase quantities and Zphase is the series impedance matrix in phase quantities. The resulting Q or T_i matrix, determined by the eigenanalysis routines, is complex. To standardize the results, T_i is normalized, using the Euclidean Norm (whereby each column j is divided by $k_j = \sqrt{\sum Q^2_{ij}}$. The voltages transformation matrix T_v (which diagonalizes the reverse product $Z_{phase}.Y_{phase}$) is not determined by the eigenanalysis routines but calculated directly from the relationship $T_v = T_i^{-t}$ (where the superscript means inverse transposed).

Processing of the transients line models in the EMTP requires real transformation matrices T_i and T_v. To obtain approximate T_i and T_v matrices, the columns of T_i-complex can be rotated to make the imaginary parts of its elements small and then retain only the real parts.

In the case of the pi-exact model, the final form of the model is expressed in terms of self and mutual phase quantities, and there is no impediment in using exact complex transformation matrices at each frequency at which the model is produced. This model, however, is a one-frequency model, valid for steady-state solutions but not for transients simulations.

The cp-line model does not take into account the frequency dependence of the line parameters. The model is formulated in terms of modal quantities, with the modal parameters R, L, and C calculated exactly at only one frequency using the exact complex transformation matrix at that frequency. Since the model assumes zero modal conductances ($G_m = 0$), the columns of the transformation matrix T_i are rotated to satisfy this condition. As a result of this rotation, the imaginary parts of the elements of T_i usually become very small. Since the EMTP requires T_i to be purely real, only the real part of T_i (after the indicated rotation) is retained in the model (the punch files has T_i = real).

The fd-line model takes into account the frequency dependence of the line parameters and the distributed nature of the losses (including a finite inductance G). As in the case of the cp-line model, however, the fd-line model is formulated in terms of modal quantities, and also has the constraint of requiring a real constant transformation matrix T_i. Even though the fd-line model does not assume zero modal conductances, the recommended criterion to rotate T_i is the same as for the cp-line model, that is, T_i is rotated to satisfy the condition $G_{mode} = 0.$ for $G_{phase} = 0.$ This default rotation can be overridden with the optional control card .DBGLINE (field 'irot'). Since G is normally very small, the results obtained with both rotation criteria are very similar. It is nonetheless believed that the default rotation gives more physically consistent results.

Q-error Indicators

A Q-Error table is printed out by the Line-Model module. This table gives an indication of the possible errors when using a constant real transformation matrix Q or T_i instead of the exact complex one at each frequency. A constant real T_i is used in the fd-line and in the cp-line models. (An exact complex T_i at each frequency is used in the pi-exact model.)

The errors shown in the Q-Error table correspond to single-frequency steady-state comparisons for unbalanced combinations of open and short circuit conditions. In these tests, all phases at the receiving end of the line are open or all phases are shorted. Unbalanced sources are connected at the sending end of the line (see Section 6.7 on the .IMBAL optional control card for the values of these sources).

The percent errors shown in the Q-Error table for a given frequency correspond to the phase voltage or current that has the largest error.

The Q-Error table is a *qualitative guide* and does not include all possible factors. As the frequency goes higher than about 1000 Hz, the resonant peaks in the open and short circuit response curves are relatively sharp and small phase errors can result in relatively larger magnitude differences. Another factor that must be considered in these evaluations is that small open circuit currents can be in relatively large error under unbalanced conditions. To give qualitatively meaningful results, the error comparisons in the Q-Error table do not include currents or voltages smaller than 5% of the largest values.

6.9 Examples of Data Decks for the Line-Model Module

The following benchmark example generates a frequency dependent line model with default options.

```
BEGIN NEW DATA CASE
LINE CONSTANTS
c     TEST CASE 1A  (LTC1A).  Frequency Dependence Line-Model
c     NORMAL DATA DECK WITH ALL DEFAULT OPTIONS
c .............................................................................
FILES              ltc1a.out           ltc1a.pun
Line-Model         FD-LINE
c .............................................................................
C BPA'S 500 KV, 174-MILE, COULEE-RAVER DOUBLE CIRCUIT LINE
C (Original Deck of 12/10/73)
c .............................................................................
BRITISH
  1.3636 .05215  4         1.602  -17.1875 49.06   49.06
  1.3636 .05215  4         1.602  -18.25   48.0    48.0
  1.3636 .05215  4         1.602  -19.3125 49.06   49.06
  2.3636 .05215  4         1.602  -27.1875 85.06   85.06
  2.3636 .05215  4         1.602  -28.25   84.0    84.0
  2.3636 .05215  4         1.602  -29.3125 85.06   85.06
  3.3636 .05215  4         1.602  -17.1875 121.06  121.06
  3.3636 .05215  4         1.602  -18.25   120.0   120.0
  3.3636 .05215  4         1.602  -19.3125 121.06  121.06
  4.3636 .05215  4         1.602   17.1875 121.06  121.06
  4.3636 .05215  4         1.602   18.25   120.0   120.0
  4.3636 .05215  4         1.602   19.3125 121.06  121.06
  5.3636 .05215  4         1.602   27.1875  85.06   85.06
  5.3636 .05215  4         1.602   28.25    84.0    84.0
  5.3636 .05215  4         1.602   29.3125  85.06   85.06
  6.3636 .05215  4         1.602   17.1875  49.06   49.06
  6.3636 .05215  4         1.602   18.25    48.0    48.0
  6.3636 .05215  4         1.602   19.3125  49.06   49.06
  0.5    2.61    4          .386  -9.0     163.96  163.96
  0.5    2.61    4          .386   9.0     163.96  163.96
BLANK
C  FREQUENCY CARD
C   rho                                       length   iseg
```

```
    100.                                        174.     1
.nodes             k-a       m-a       k-b       m-b       k-c       m-c
BLANK
BLANK
BLANK
BEGIN NEW DATA CASE
BLANK
```

The following example is for a pi-exact model for steady-state frequency scans

```
BEGIN NEW DATA CASE
LINE CONSTANTS
c     TEST CASE 3  (LTC3).  Pi-Exact steady-state line model.
c ..............................................................................
Files              ltc3.out            ltc3.pun
Line-Model         Pi-Exact            log       0.1                1        10
c "JOHN DAY-LOWER MONUMENTAL LINE" (222 Km).
c  New Conductors Data Format (INOPT=1)
METRIC                                 1
  1.3636  .03240 4         40.6908-6.3246 15.240
  1.3636  .03240 4         40.6908-5.8674 15.240
  2.3636  .03240 4         40.6908-0.2286 23.622
  2.3636  .03240 4         40.6908 0.2286 23.622
  3.3636  .03240 4         40.6908 5.8674 15.240
  3.3636  .03240 4         40.6908 6.3246 15.240
  0.5000  1.6216 4          9.8044-3.9319 30.023
  0.5000  1.6216 4          9.8044 3.9319 30.023
BLANK
C Frequency Card
c rho                                       length       iseg
100.                                        222.         1
BLANK
BLANK
BEGIN NEW DATA CASE
BLANK
```

The following example .id for the LBUILD line reconstruction option

```
BEGIN NEW DATA CASE
LINE CONSTANTS
c     TEST CASE 6  (LTC6). REBUILT LINE GEOMETRY
c     "John Day - Lower Monumental Line"
c ..............................................................................
FILES              ltc6.out            ltc6.pun
Line-Model         fd-line   lbuild
c ..............................................................................
METRIC
c .......f.........R.........L.........G.........C.........Rdc..................
 3       60.       0.18736   3.6012    0.        0.007524  0.0162
                   0.017413  0.96731   0.        0.012027
BLANK
C  Frequency Card (Only rho and length used in this option)
c rho                                       length
100.                                        222.
C .outline: iwavef,imonit
```

```
C .outfit:  icompf,iplotf,iprat
C .ctlfit:  normax,iquick,ixdyn,ifitzc,ifita1
.outline            1-1
.outfit             1 1-1
.ctlfit                     1
BLANK
BLANK
BEGIN NEW DATA CASE
BLANK
```

7 FIT-S Module

The FIT-S module provides access to the fitting routines FIT-S as a separate program to generate rational function approximations of user-supplied frequency domain transfer functions.

This option is invoked by the keyword "FIT-S" in the MODULE card of the Line Constants Program data deck (see Table 1 in Section 3).

The function to be approximated is read in as a table containing magnitude and phase angle as a function of frequency on a logarithmic scale (see FIT-S control card below). The rational function approximation is given in the output file in frequency domain form (poles and zeros) and in time domain form (k's and poles and time coefficients in a sum of exponential representation). An equivalent circuit representation can also be obtained, upon request, through the 'ipnet' flag in the .outfit control card.

7.1 FIT-S Control Card

12345	1 67890123456789	2 3 01234567890123456789	4 5 6 7 8 01234567890123456789012345678901234567890
FIT-S		PARFILE	TFORM
A5		A20	A40

The required input data is the magnitude and, optionally, the phase angle of the frequency domain function to be synthesized. The name of the file containing the data curve is specified "FIT.DAT".

The names for the output and punch files are specified in the FILES card, or assigned externally. The output and punch files have the same form as the ones for the fd-line model (see Section 6.1). The punch file will contain the time domain form of the approximation in terms of a sum of exponential functions. The output file contains the approximating function in both frequency and time domain forms, including, for non-delay functions, the value of the elements in an RC synthesis network.

FIT-S (1-5)	Keyword to request the external curve fitting option FIT-S.
PARFILE (20-39)	Name of file with the function data (Default - "FIT.DAT"). File containing the function data, as described in Section 7.2.
TFORM (40-80)	Fortran READ format statement. This field must contain the Fortran format specifier (including the external parentheses) for the program to read the data function from file 'parfile'.

The data function is read point by point as follows:

```
READ (LU4,TFORM) FREQ, AMAG, APHASE
```

where:

TFORM	Is the FORMAT specified in columns 40 to 80 of the FIT-S control card.
LU4	The data curve is read from file 'parfile' which is internally connected to LU4.
FREQ	frequency point in Hz. The data frequency points must be logarithmically spaced.
AMAG	Magnitude of the data function.
APHASE	Phase angle in degrees (for radians use .ctlfit card).

7.2 Data Function File

The data curve file 'parfile' (attached to LU4) has the following structure:

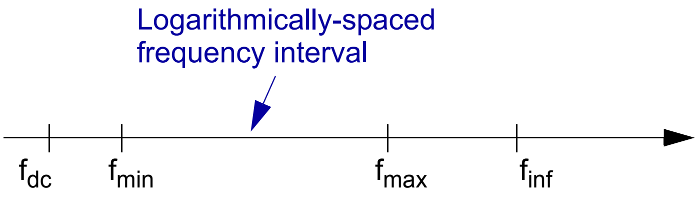
(A) It can contain any number of comment lines (identified by 'C ' or 'c ' in the first two columns), as long as these lines are placed before the block of data points. No comment lines are allowed in between data points.

(B) Data points. These points will be read according to TFORM.

(C) "END" (columns 1-3) at the end of the data points.

7.3 Data Function Format

The data points must be given on a logarithmic frequency scale as indicated in the following diagram:



f_{dc}	DC frequency point in Hz (e.g., 10^{-15} Hz). This frequency must be less than or equal to f_{min}. The data at this point is used by the program to match the asymptotic behaviour when f=0.
f_{inf}	Infinite frequency in Hz (e.g., 10^{8} Hz). This frequency must be greater than or equal to f_{max}. The data at this point is only used for comparison (output) purposes (it is not used in the processing of the approximation).

The data points between f_{min} and f_{max} must be logarithmically spaced and there must be 10 or a multiple of 10 (up to 90) points per decade.

7.4 Type Of Fit

Unless otherwise specified in the .CTLFIT card (Section 7.5 below), the rational function synthesis assumes that the data function is minimum phase shift with no time delay. Both magnitude and phase angle are used in the approximation process.

7.5 Optional Control Cards

As in the case of the fd-line model in the LINE-MODEL module, optional control cards are allowed in order to change the internally set default conditions. These cards are:

.ctlfit

.dbgfit

.outfit

.CTLFIT (FIT-S Control)

Allows for additional control over the fitting of the data function. Fields NORMAX, IQUICK, and IXDYN in this card have the same meaning as for the fd-line model (Section 6.1). Fields IDELAY and IPHASE are new in this module.

```
          1          2                    3         4         5         6         7         8
1234567 890123456789 01 23 45 67 89 4567890123456789012345678901234567890123456789012345678901234567890
```

.CTLFIT		NORMAX	IQUICK	IXDYN	IDELAY	IPHASE	
A7		I2	I2	I2	I2	I2	

.CTLFIT (1-7)
Keyword to control the fitting process of fd-line models.

NORMAX (20-21)
Maximum number of poles in the synthesis of the line wave functions Z_c and A_p. Default value is 25.

IQUICK (22-23)
Flag controlling the accuracy of the fit of Z_c and A_p. Default value is –1.

= 1 Much faster (fewer iterations) approximation of Z_c and A_p is produced. Some accuracy is sacrificed with respect to the normal procedure.

= –1 Normal iteration procedure is used.

IXDYN (24-25)
Flag controlling the low frequency approximation of A_p. Default value is 1.

= 1 Extra dynamics (extra poles and zeroes) are added to the approximation of the low frequency region of the IDELAY = 1 functions (see below). Extra dynamics (extra poles and zeros) are added to the approximation of the low frequency region.

= –1 No extra dynamics are added.

IDELAY (26-27)
Flag indicating the type of the data function. Default value is 0.

= 0 Corresponds to a data function with no time delay (e.g., the Z_c function in the fd-line model).

= 1	Corresponds to a data function with a pure time delay t (e.g., the propagation function $A_p = e^{-\gamma l}$ in the fd-line model). When this option is specified, flag IPHASE (below) is ignored.

IPHASE (28-29)	(only for 'idelay'=0)	
	> 0	(Default) Both magnitude and phase data are used in the fitting procedure.
	< 0	The phase angle of the data function is ignored. A minimum-phase shift approximation based only on the magnitude of the data function is performed.
	= 2 or –2	Phase angle of the data function is in radians (otherwise it is assumed to be in degrees).

.DBGFIT (FIT-S Debug)

Controls the amount of internal processing output from FIT-S.

```
          1           2          3         4         5         6         7         8
1234567  890123456789 01  2345678901234567890123456789012345678901234567890123456789 0
```

.DBGFIT		IBUGF	
A7		I2	

.DBGFIT (1-7)	Keyword to request debug information during the fitting process of fd-line models.
IBUGF (20-21)	Flag controlling the level of diagnostic printout. Valid range is 1-3 (default = 0). The higher the number, the larger the amount of debugging output from FIT-S.

.OUTFIT (FIT-S Output)

Controls the amount of output information on the fitting process. Fields ICOMPF, and IPLOTF in this card have the same meaning as for the fd-line model (Section 6.1).

	1	2			3 4 5 6 7 8
1234567	890123456789	01	23	45	6789012345678901234567890123456789012345678901234567890
.OUTFIT		ICOMPF	IPLOTF	IPNET	
A7		I2	I2	I2	

.OUTFIT (1-7)	Keyword to control the amount of output generated during the fitting process of fd-line models.
ICOMPF (20-21)	Flag controlling the printout of a comparison table. Default value is –1 (no printout).

= 1 An output table is produced comparing the data functions Z_c and A_p as produced by the line constants routines and the approximating rational functions produced by FIT-S.

= –1 No comparison table is produced.

IPLOTF (22-23)	Flag controlling the printout of a printer plot. Default value is 1 (print).

= 1 A printer plot is produced comparing the data functions and the approximations.

= –1 No printer plot is produced.

IPNET (24-25)	Flag indicating the type of equivalent network representing the approximating function. This applies only to 'idelay'=0 functions.

= 0 (Default) No equivalent network is produced.

= 1 Series R//C blocks equivalent.

= 2 Parallel R+C branches equivalent.

= 3 Series R//L blocks equivalent.

7.6 Examples of Data Deck for the FIT-S Module

Sample data deck for FIT-S option follows.

```
BEGIN NEW DATA CASE
LINE CONSTANTS
c  ** New Line Constants Program **  June 1987.
c     TEST CASE 9 (LTC9).
```

```
c     EXTERNAL DATA-CURVE OPTION
c ..................................................................
FILES                ltc9.out             ltc9.pun
FIT-S                ltc9.par             (1X,E11.0,44X,2E11.0)
c ..................................................................
C  OPTIONAL CONTROL CARDS
C .outfit:  icompf,iplotf,iprat,idata
.outfit               0 1 0 1
BLANK
BLANK
BEGIN NEW DATA CASE
BLANK
```

Sample Data-Curve file follows

```
c  ** New Line Constants Program **  June 1987.
c     TEST CASE 9 (LTC9). EXTERNAL DATA-CURVE OPTION
c     Data-Curve File. Columns Zc and Phase(dg) will be used.
c
c    FREQ        R          L          G          C          Zc       Phase
  1.0000E-15 1.6195E-02 1.6993E+01 3.0009E-12 7.5248E-03 7.3463E+04-4.5117E-10
  1.0000E-01 1.6491E-02 5.4988E+00 2.0006E-10 7.5248E-03 1.8870E+03-3.7872E+01
  1.2589E-01 1.6568E-02 5.4299E+00 2.0006E-10 7.5248E-03 1.6953E+03-3.6771E+01
  1.5849E-01 1.6664E-02 5.3609E+00 2.0006E-10 7.5248E-03 1.5279E+03-3.5354E+01
  1.9953E-01 1.6785E-02 5.2920E+00 2.0006E-10 7.5248E-03 1.3830E+03-3.3609E+01
  2.5119E-01 1.6937E-02 5.2231E+00 2.0006E-10 7.5248E-03 1.2593E+03-3.1541E+01
  3.1623E-01 1.7129E-02 5.1542E+00 2.0006E-10 7.5248E-03 1.1553E+03-2.9180E+01
.
.
.
  3.9811E+06 9.6203E+02 1.7091E+00 2.0006E-10 7.5248E-03 4.7664E+02-6.4456E-01
  5.0119E+06 1.0872E+03 1.7046E+00 2.0006E-10 7.5248E-03 4.7601E+02-5.8013E-01
  6.3096E+06 1.2277E+03 1.7007E+00 2.0006E-10 7.5248E-03 4.7544E+02-5.2159E-01
  7.9433E+06 1.3854E+03 1.6971E+00 2.0006E-10 7.5248E-03 4.7494E+02-4.6851E-01
  1.0000E+07 1.5623E+03 1.6940E+00 2.0006E-10 7.5248E-03 4.7449E+02-4.2048E-01
  1.0000E+08 5.0833E+03 1.6763E+00 2.0006E-10 7.5248E-03 4.7199E+02-1.3826E-01
END
```