Cable Constants

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1 Introduction to the Cable Constants Routines

By means of the special request word "CABLE CONSTANTS", an AUX user gains access to the Cable Constants set of routines. The Cable Constants routines calculate the resistance, inductance, conductance, and capacitance matrices for underground cables (e.g., Single-Core (SC) or Pipe-Type (PT)). These routines can also be used to generate EMTP models for these cables, both for transient and frequency scan simulations.

As in the case of the overhead line calculation module of AUX, there are two independent modules which can be accessed via keywords:

(A) Cable Model module. Keyword: "CABLE-MODEL"

(B) Cable Parameters module: Keyword: "CABLE-PARAMETERS"

The "Cable Model" module is used primarily for the generation of underground cable models (e.g., constant parameters, frequency dependent, nominal and exact pi, etc.). This module can also be used to calculate cable parameters at any given frequency, and in a variety of forms (e.g., phase, modal, or sequence parameters). This module was introduced in version 3.0, and it is not a re-written version of the CABLE CONSTANTS module available prior to version 3.0, but rather, a new program with new models, capabilities and more robust numerical algorithms. Its predecessor, is still available in the "Cable Parameters" module. The input data format has been enhanced to reflect the new modelling capabilities and it is not directly compatible with the format used prior to version 3.0. A keyword-directed conversion routine is provided.

The "Cable Parameters" module is the "old" CABLE CONSTANTS support routine (prior to version 3.0). It has some functionality and modelling capabilities which have not been added to the "Cable Model" module, namely, stratified earth modelling and overhead line modelling. Otherwise, the "Cable Parameters" is a subset of the newer "Cable Model" module.

The general structure of the input data file for running the cable constants program in 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. As shown in Table 1, a Cable Constants data case may contain more than one group of Cable-Parameters and/or Cable-Model data cards (in any order). Each such group is a separate, independent case within the Cable Constants routine. The blank card at the end of Cable-

Parameters data is the same card that marks the end of frequency cards, as described in Section 2. The blank card at the end of Cable-Model data is the same card that marks the end of optional control cards, as described in Section 2.

[1]	"BEGIN NEW DATA CASE" keyword	
[2]	"CABLE CONSTANTS" request card	
[3]	**"CABLE-PARAMETERS"**	
[3.1]		Cable-Parameters control card
[3.2]		Cable data cards
[3.3]		Frequency data cards
[3.4]		BLANK card to indicate the end of "cable parameters" data
[4]	**"CABLE-MODEL"**	
[4.1]		Cable-Model control card
[4.2]		Cable data cards
[4.3]		Frequency data cards
[4.4]		Optional Control Data Cards
[4.5]		BLANK card to indicate the end of "cable model" data
	Cards for Another Cable-Parameters or Cable-Model Data Case	
[5]	BLANK card to end "Cable Constants" requests	
[6]	BLANK card to end AUX requests	
[7]	"BEGIN NEW DATA CASE" keyword	
[8]	BLANK card to indicate end-of-run	

Table 1: General Structure of the Input Data File

2 Capabilities of the "Cable-Model" Module

This module reads physical layout and characteristics of a cable and produces cable models that will be used by the EMTP for transient, and frequency scan simulations. Single-Core as well as Pipe-Type cables are supported.

2.1 Models for Transients Simulations

FD-Model Class

The Frequency-Dependent or FD-Model class provides an accurate representation of the distributed nature of all the cable parameters: R, L, G, and C, as well as their frequency dependence in modal quantities. In this model class it is assumed that the characteristic admittance and propagation function matrices $[Y_{c,phase}]$ and $[A_{phase}]$ can be diagonalized (by a modal transformation matrix Q).

$$[Y_{c,\,phase}]^2 = [Y_{phase}][Z_{phase}]^{-1} = [G_{phase} + j\omega C_{phase}][R_{phase} + j\omega L_{phase}]^{-1} \tag{1}$$

$$[A_{phase}] = \exp(-[\gamma_{phase}]l) \tag{2}$$

$$[\gamma_{phase}]^2 = [Y_{phase}][Z_{phase}] = [G_{phase} + j\omega C_{phase}][R_{phase} + j\omega L_{phase}] \tag{3}$$

The modal transformation matrix [Q] is the eigenvector matrix that diagonalizes the product $[Y_{phase}][Z_{phase}]$; that is,

$$[Q]^{-1}[Y_{phase}][Z_{phase}][Q] = [Y_{mode}][Z_{mode}] \qquad \text{(diagonal)} \tag{4}$$

$$[Q]^{-1}[Y_{c,\,phase}][Q]^{-\tau} = [Y_{c,\,mode}] \qquad \text{(diagonal)} \tag{5}$$

$$[Q]^{\tau}[Z_{phase}][Q] = [Z_{mode}] \quad \text{and} \quad [Q]^{-1}[Y_{phase}][Q]^{-\tau} = [Y_{mode}] \qquad \text{(diagonal)} \tag{6}$$

$$[Q]^{-1}[A_{phase}][Q] = [A_{mode}] \qquad \text{(diagonal)} \tag{7}$$

The elements of $[Y_{c,mode}]$ and $[A_{mode}]$ are scalar functions of frequency and are approximated in the frequency domain with rational functions. In the time-step loop of the EMTP these rational functions become sums of exponential functions.

The modal transformation matrix Q is, in general, frequency dependent, and its elements can be approximated with rational functions (FDQ option). There are instances, however, when it is desirable to assume that the modal transformation matrix is constant and real (QREAL option). In this case, Q is calculated at a given frequency, its columns are rotated to minimize the imaginary parts of their elements, and the resulting imaginary terms are discarded. The resulting matrix Q_{real} is the used to calculate the modal parameters as shown in equations (4) to (7).

The FDQ option should be used when the highest accuracy is desired (see Reference 3). There are instances, however, when some of the elements of Q are ill-conditioned in some frequency ranges. In these cases it is preferable to use the QREAL option. There are a number of known situations where the FDQ option (as presently coded) will occasionally result in ill-conditioned Q functions. These situations are flagged by the program and an FDQ model is not produced (this automatic detection can be overridden by the user by entering "-1" in columns 22-23 of the ".dbgfit" control card). In such cases it is preferable to use the QREAL option. The situations where this ill-conditioning takes place are under investigation, and it is expected that future releases of the program will not have this limitation.

CP-Model

The CP-Model (constant-parameter model) assumes that the cable parameters R, L, and C are constant, and they are calculated at a user-supplied frequency. This model considers L and C to be distributed ("ideal cable") and R to be lumped at three places (cable ends and cable middle). The shunt conductance G is assumed to be zero.

Taking into account the frequency dependence of the cable parameters (as modelled by the FD-Model class of cable models) is an important factor for the accurate simulation of transients in the EMTP. However, the CP-Model is computationally fast and it is generally used as an alternative to model secondary lines or cables.

Note: In this implementation of AUX, the "Cable-Model" module does not generate nominal-pi circuit models. To generate nominal pi models for transient simulations, the "Cable-Parameters" module must be used.

2.2 Models for Steady-State Analysis: EXACT-PI

This model provides an exact single-frequency representation of the cable in terms 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.

The model is punched out as a Y-matrix that includes the series and shunt branches of the multiphase exact-pi circuit. This Y matrix is produced for each frequency point in a logarithmic or linear frequency interval.

It is important to realize that the exact-pi model is only a frequency domain representation of a cable at a given frequency. It is not an EMTP model in the same sense the as FDQ model. The exact-pi model can only be used in EMTP frequency scans.

To run a frequency scan in the EMTP, the special request card FREQUENCY SCAN must be included in the EMTP data deck. The format and usage of this card is described in Section 4.1.1 RuleBook 1, and summarized below.

2.3 External Parameters Data

The impedance and admittance matrices of a cable are normally computed from the physical data specified in the Cable-Model data cards. Additionally, the Cable-Model module can read these matrices directly from a separate external data file and use them to produce different cable models without the need for the physical data. The user may obtain impedance and admittance matrices in a range of frequencies from any external source (such as a program based on finite element method) and provide them to Cable-Model routine through the external data file. The format of this file is described in Section 3.6.

2.4 Cross-Bonded Cables

In order to model a cross-bonded cable accurately, each major section must be modelled in detail. This means that each minor section of the cable must be modelled (preferably with an FDQ model), and the sheath bonding and sheath grounding connections must be made explicitly using the EMTP node names.

Such a detailed representation can be computationally intensive because modelling short cable segments of the order of 400 meters or so, requires a very small time step (a fraction of the travel time of the fastest propagation mode). Furthermore, a number of these major sections must be connected to represent the entire cable. For example, a 12 km cable with 400 m minor sections, would require a total of 30 6-phase FDQ cable models. Nevertheless, this type of detailed representation is necessary when sheath currents and voltages have to be assessed (see Reference [4] and reference [5])

The detailed representation of each minor section of a cross-bonded cable is in some ways analogous to modelling a transposed overhead transmission lines by representing each transposition section explicitly, and connecting the sending and receiving node names accordingly with EMTP node names. In the case of transmission lines this situation can be approximated by assuming that the line is balanced, and using a single line where the elements of impedance and admittance matrices have been averaged to account for the effect of transposition.

A cross-bonding option is available in the Cable-Model module to provide this type of approximation. If parameter IXBD in the "Cable-type" card is set to 1, then the elements of the impedance and admittance matrices of the cable are averaged to reflect the effect of cross-bonding. The grounding of the sheaths is then controlled using the KPH parameter in the "Conductor/ Insulator" cards. Setting KPH = 0 for the sheaths, is equivalent to assuming that the sheaths are continuously grounded (at zero potential throughout the entire cable length). In this case, the sheaths can be eliminated and a three-conductor approximation of a cross-bonded cable is obtained. This three-conductor approximation compares quite favourably with the detailed modelling of each minor section of a cross-bonded cable, and it is ideally suited for switching transient studies of cross-bonded cables, because of its computational speed and accuracy.

2.5 Input Format Conversion

The data entry rules and format for "Cable-Model" and "Cable-Parameters" modules are different, mostly because of the added functionality of the "Cable-Model" module. To facilitate cross-validation of both modules, and migration from old to new formats, an automatic input data conversion option has been provided.

To enable data conversion, set either IPCH or IRUN to "1" in the appropriate fields of the "Cable-Model Control" Card (see Section 3.1). If IPCH = 1, the input data file will be converted and then stored into the standard punch file (i.e., logical unit 7). Additionally, if IRUN is set to 1, AUX will execute immediately after data conversion. Any combination of the two flags is acceptable. The direction of the format conversion is detected automatically (i.e., from "Cable-Model" to "Cable-Parameters", and vice versa).

Depending on the cable module keyword used, the program will do one of the following:

1. Keyword = "CABLE-MODEL", IPCH = IRUN = 0. Normal Cable-Model run with Cable-Model input format.

2. Keyword = "CABLE-MODEL", IPCH = 1 or IRUN = 1. AUX will try to run/convert a Cable-Model case with Cable-Parameters input format.

3. Keyword = "CABLE-PARAMETERS", IPCH = IRUN = 0. Normal Cable-Parameters run with Cable-Parameters input format.

4. Keyword = "CABLE-PARAMETERS", IPCH = 1 or IRUN = 1. AUX will try to run/ convert a Cable-Parameters case with Cable-Model input format.

When using the input format conversion option, a certain amount of caution is required because the two modules do not have the same functionality. In those cases where a one-to-one relationship between data and/or modelling requests is not possible, some assumptions and defaults have been made. These assumptions are summarized in Section 4.

3 Data Entry Rules for "Cable-Model"

The following section describes the format of a Cable-Model data case.

3.1 Cable-Model Control Card

```
          1          2          3           4          5          6          7
12345678901 234567890 1234567890  1234567890 1234567890 1234567890 123 4567890 12345 12345
```

CABLE-MODEL		Model	Q-Optn	FREQ-Q	LENGTH		Ext	IPCH	IRUN
A11		A10	E10.0	E10.0	E10.0		A7	I5	I5

CABLE-MODEL (1-11) — Keyword for "Cable-Model" module

Model (21-30) — Model keyword. It can be one of the following

"FD-MODEL" R, and L are assumed to be frequency-dependent. Modal transformation matrix may or may not be constant, depending on Q-Optn below (see Section 2.1). Produces punch file for the LMARTI or FDQ cable model.

"CP-MODEL" R, L, and the modal transformation matrix Q are assumed to be constant (see Section 2.1). Produces output for the Dommel or constant-parameter line model.

"EXACT-PI" Pi-circuits are calculated at a given number of frequencies. If Q-Optn is set to FDQ (default), the EXACT-PI becomes a correct representation of the cable at a given frequency (see Section 2.2). Produces punched for frequency scan simulations only.

	"SCAN"	Cable parameters in either phase, modal or sequence quantities computed at specified frequencies. No model is generated.
Q-Optn (31-40)	Type of modal transformation matrix Q. This keyword can be one of the following	
	"FDQ"	Q is assumed to be frequency-dependent (see Section 2.1). In the EMTP data cards for the LMARTI/FDQ model, parameter "imodel" must be set to –4.
	"QREAL"	Q is evaluated at a frequency FREQ-Q, its columns are rotated (to minimize imaginary parts), and it is also stripped of its imaginary part to make Q real and constant. In the EMTP data cards for the LMARTI/FDQ model, parameter "imodel" must be set to –3.
	"QCMPLX"	Q is evaluated at a frequency FREQ-Q, its columns are rotated (to minimize imaginary parts), and it its imaginary part is retained to make Q complex and constant. EMTP models cannot use a complex, constant modal transformation matrix. This option is meant, mostly, for research purposes.

The following table shows valid combinations of Model and Q-Optn keywords:

"FD-MODEL"	⇒	"FDQ" (default), "QREAL", "QCMPLX"
"CP-MODEL"	⇒	"QREAL" (default), "QCMPLX
"EXACT-PI"	⇒	"FDQ (default), "QREAL", "QCMPLX"
"SCAN"	⇒	"FDQ" (default), "QREAL", "QCMPLX"

FREQ-Q (41-50)	Frequency in Hz at which the constant modal transformation matrix Q is computed (default is 1000 Hz). In the case of the CP-MODEL, this is also the frequency at which R, L, and C are evaluated. This field is ignored with the "FDQ" option	
.LENGTH (51-60)	Cable length in km (default is 1.0 km)	
Ext (64-70)	Keyword for read Z and Y matrices from an external file. Normally left blank	
	[blank]	No external data. Impedance and admittance matrices are calculated by the program from physical data.
	"EXT-DAT"	external data. Impedance and admittance matrices (for a range of frequencies) are provided in a separate data file (see Section 3.5 for a detailed description of this option)

IPCH (71-75) Flag to control the storage of input data files, after input format conversion has been completed. Converted data files are stored into the standard "punch" file (i.e., logical unit 7).

= 0 Do not store converted input data file (only if IRUN = 1)

= 1 Store converted input data file into punch file.

IRUN (76-80) Flag to control program execution after input format conversion

= 0 Do not run AUX after input data file has been converted and stored into the punch file

= 1 Run AUX after data conversion is completed, whether or not storage of the converted input data file is requested. Note that if both IRUN = 1 and IPCH = 1, then any punched output which results from an AUX run (e.g., punched file for an FDQ model) will be appended to the record of the converted input data file

Note: Input data conversion between Cable-Model and Cable-Parameters formats will only take place if either IPCH or IRUN are equal to 1.

If IPCH and IRUN are zero the program will not attempt to provide any form of input format conversion, and using the wrong format rules will result in an invalid run.

3.2 Cable-Type Card

```
           1           2         3         4         5         6         7         8
123 45 67890 12345 67890123456789012345678901234567890123456789012345678901234567890
```

	TYPE	NCBL	IXBD	
	A2	I5	I5	

Type (4-5) Keyword describing cable type. Valid keywords are:

"SC" Single-Core coaxial cables.

"PT" Pipe-type cable.

NCBL (6-10)	Number of component coaxial cables (or single-phase units) which make up the SC or PT cable. For example, NCBL=3 for a three-phase SC cable.
IXBD (11-15)	Cross-bonding flag.

= 0 Not cross-bonded (default).

= 1 Sheaths (second conductor) are cross-bonded.

If IXBD = 1, parameter LENGTH corresponds to the length in km of a major section. The connection of the cross-bonded sheaths (i.e., kept separate, joined together or grounded) is determined by their Phase Numbers which are specified in the conductor data cards described in Section 3.3 for SC cables and for PT cables.

3.3 Conductor Cards for Single-Core (SC) Coaxial Cables

This subsection describes the following cards:

SC Cable: Individual Cable Card

SC Cable: Conductor/Insulator Cards

SC Cable: Phase Numbers Card

Pipe-Type Cable: Individual Cable Card

Pipe-Type Cable: Conductor/Insulator Card

Pipe-Type Cable: Phase Numbers Card

Pipe-Type Cable: Pipe-Data Cards

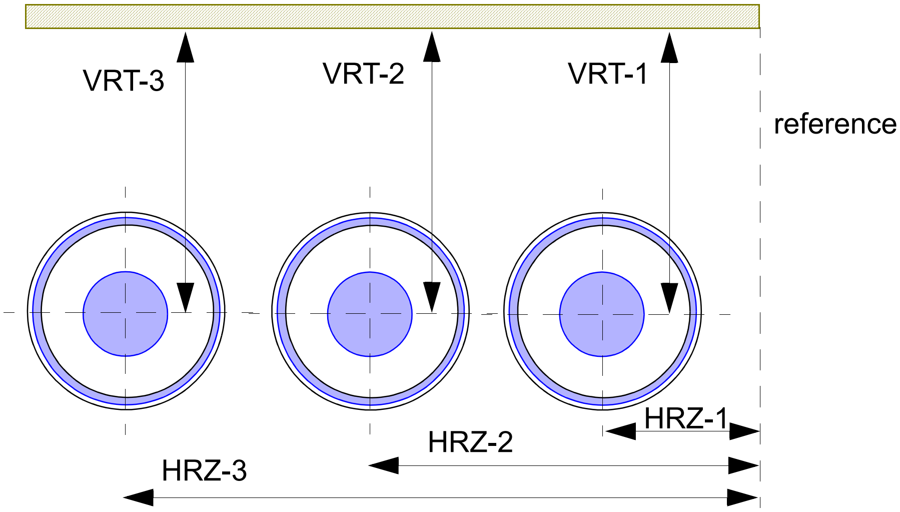
The conductor data cards required to describe a pipe-type cable are somewhat different than the conductor data cards required for an SC coaxial cable. Although many data fields are similar their description will be presented separately to facilitate readability.

SC Cable: Individual Cable Card:

This card and the following cards describe each coaxial cable. A total of NCBL Individual Cable Cards are required. No special ordering sequence is required.

12345	1 67890	2 1234567890	3 1234567890	4 1234567890	5 6 7 8 1234567890123456789012345678901234567890
NCN		VRT	HRZ	ROUT	
I5		E10.0	E10.0	E10.0	

NCN (1-5)	Number of concentric tubular conductors in this cable (or -K as described below). For example, set NCN=3 for a cable with core, sheath and armour. If NCN is positive, the Individual Cable Card must be followed by NCN Conductor/Insulator cards which describe the concentric conductors and their insulation. If NCN is negative, then –NCN=K, where K is the Kth conductor entered. This option is used to copy conductor data in the case of identical cables.
VRT (11-20)	Vertical distance (depth) measured from the of the centre of this cable to the earth's surface. This is a positive number. Units = meters



HRZ (21-30)	Horizontal distance measured from the centre of this cable to an arbitrary point of reference. Units = meters.
ROUT (31-40)	Outside radius of the insulation layer surrounding the cable. Leave blank if there is no surrounding insulation. Units = meters.

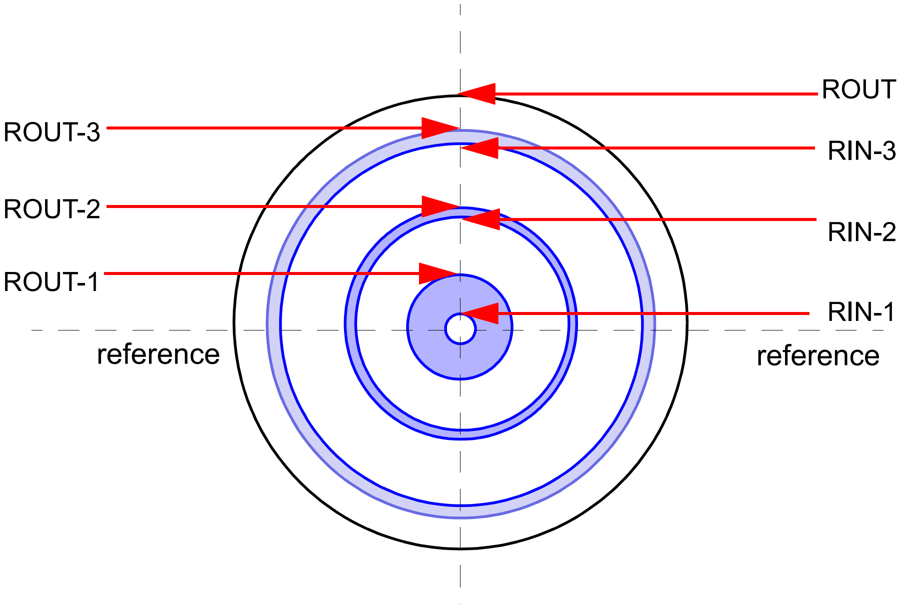
Note that if NCN is negative (data is being copied from an earlier cable) then ROUT is ignored.

SC Cable: Conductor/Insulator Cards:

When NCN in the previous card is positive, the next NCN cards describe the tubular conductors and their surrounding insulation. They must be ordered from inside out (the core conductor comes first, followed by sheath, etc.).

1 1234567890	2 1234567890	3 1234567890	4 1234567890	5 1234567890	6 1234567890	7 1234567890	12345	8 67890
RIN	ROUT	RHO	MUE	MUE-I	EPS-I	LFCT	KPH	
E10.0	E10.0	E10.0	E10.0	E10.0	E10.0	E10.0	I5	

RIN (1-10)	Inside radius of the conductor. Units = meters.
ROUT (11-20)	Outside radius of the conductor. Units = meters



RHO (21-30)	Resistivity of the conductor. Units = Ω·m.
MUE (31-40)	Relative permeability of the conductor.
MUE-I (41-50)	Relative permeability of the surrounding insulation.

EPS-I (51-60)	Relative permittivity of the surrounding insulation.
LFCT (61-70)	Loss-factor of the surrounding insulation.
KPH (71-75)	Phase-number of the conductor. Conductors of all cables must be given phase numbers starting from 1, with no gaps in phase numbering. For example, for a three-conductor cable KPH = 1, 2, 3 is a legitimate numbering arrangement, while KPH = 1, 3, 4 is not. Conductors with KPH = 0 will be grounded and all conductors with identical phase number will be bundled into a single equivalent conductor

Note: Use KPH to ground conductors which are not needed explicitly in a transient simulation. For example, if the sheaths of a submarine cable are in contact with water, they become effectively grounded. In this case set KPH = 0 for all sheaths to obtain a simpler 3-conductor model.

Note that the phase numbering sequence must start at zero and must have no gaps, but the order in which KPH appears is arbitrary. In other words, Conductor/Insulator cards do not have to be ordered according to KPH. By the same token, the order of the conductors in printed or punched output will be made according to the sequence defined by KPH.

SC Cable: Phase Numbers Card:

When NCN in the Individual Cable Card is negative, the data duplication function is enabled. Setting NCN to a negative number is equivalent to saying "make the conductor data for this cable identical to the data of cable number –NCN". For example, if all three (single-phase) cables in a three-phase cable system are identical, it is sufficient to enter the Conductor/Insulator cards for the first cable, and duplicate the rest. In this case NCN = –1 for cables 2 and 3.

Since phase number assignment is independent of the physical characteristics of the cable, it must be specified using the Phase Numbers Card.

	1		2		3 4 5 6 7 8
12345	67890	12345	67890	12345	6789012345678901234567890123456789012345678901234567890
	KPH1	KPH2	KPH3	KPH4	...
	I5	I5	I5	I5	...

KPH1 (6-10)	Phase number of the first conductor (core).
KPH2 (11-15)	Phase number of the second conductor (sheath).
KPH3 (16-20)	Phase number of the third conductor (armour).
...	...

If the cable has more than 15 conductors, the phase numbers of the next 15 conductors are read from a second card and so on.

Note: If NCN in the Individual Cable Card is positive, the it must be followed by NCN Conductor/ Insulator Cards and no Phase Numbers Card.

If NCN is negative, the Conductor/Insulator Card will be followed by a single Phase Numbers Card (unless there are more than 15 concentric conductors

Pipe-Type Cable: Individual Cable Card:

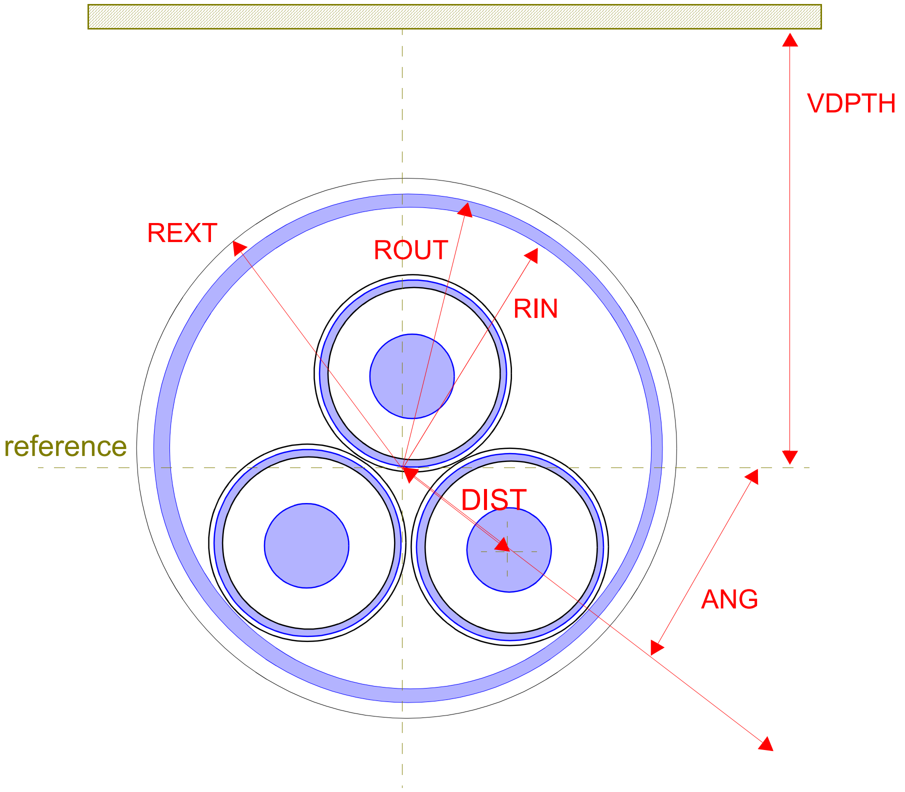
This card and the following cards describe each coaxial cable within the pipe. A total of NCBL Individual Cable Cards are required. No special ordering sequence is required.

```
          1          2          3          4          5         6         7         8
12345 67890 1234567890 1234567890 1234567890 1234567890123456789012345678901234567890
```

NCN		DST	ANG	ROUT	
I5		E10.0	E10.0	E10.0	

NCN (1-5)	Number of concentric tubular conductors in this cable (or –K as described below). For example, set NCN = 3 for a cable with core, sheath and armour.
NCN (1-5)	If NCN is positive, the Individual Cable Card must be followed by NCN Conductor/Insulator cards which describe the concentric conductors and their insulation. If NCN is negative, then –NCN = K, where K is the Kth conductor entered. This option is used to copy conductor data in the case of identical cables.

DST (11-20)	Distance measured from the of the centre of this cable to the centre of the pipe. Units = meters.



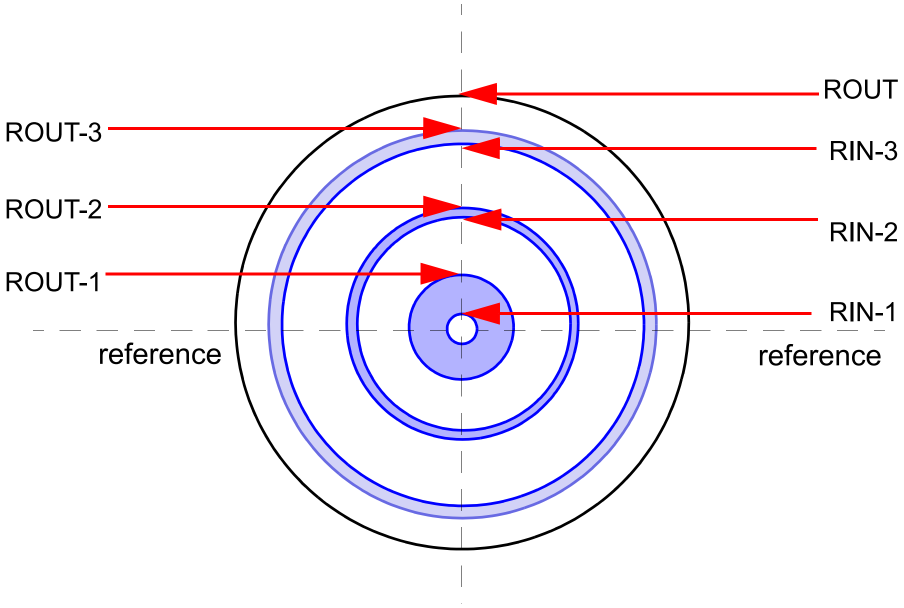
ANG (21-30)	Angle measured from the line joining the centre of this cable and the centre of the pipe, and an arbitrary reference axis. Units = degrees.
ROUT (31-40)	Outside radius of the insulation layer surrounding the pipe. Leave blank if there is no surrounding insulation. Units = meters. Note that if NCN is negative (data is being copied from an earlier cable) ROUT is ignored.

Pipe-Type Cable: Conductor/Insulator Cards:

When NCN in the previous card is positive, the next NCN cards describe the tubular conductors and their surrounding insulation. They must be ordered from inside out (the core conductor comes first, followed by sheath, etc.).

1 1234567890	2 1234567890	3 1234567890	4 1234567890	5 1234567890	6 1234567890	6 1234567890	12345	8 67890
RIN	ROUT	RHO	MUE	MUE-I	EPS-I	LFCT	KPH	
E10.0	E10.0	E10.0	E10.0	E10.0	E10.0	E10.0	I5	

RIN (1-10)	Inside radius of the conductor. Units = meters.
ROUT (11-20)	Outside radius of the conductor. Units = meters



RHO (21-30)	Resistivity of the conductor. Units = Ω·m.
MUE (31-40)	Relative permeability of the conductor.
MUE-I (41-50)	Relative permeability of the surrounding insulation.
EPS-I (51-60)	Relative permittivity of the surrounding insulation.
LFCT (61-70)	Loss-factor of the surrounding insulation.

KPH (71-75)	Conductors of all cables must be given phase numbers starting from 1, with no gaps in phase numbering. For example, for a three-conductor cable KPH = 1, 2, 3 is a legitimate numbering arrangement, while KPH = 1, 3, 4 is not. Conductors with KPH = 0 will be grounded and all conductors with identical phase number will be bundled into a single equivalent conductor

Note: .Use KPH to ground conductors which are not needed explicitly in a transient simulation. For example, if the sheaths of a pipe-type cable are in contact with the pipe, then an approximate 4-conductor system can be obtained by bundling the sheaths and the pipe together (e.g., setting KPH = 4 on sheath and pipe cards. If the pipe can also be assumed to be continuously grounded, setting KPH = 0 on sheath and pipe cards result in a 3-conductor system. For a description of the approximations involved in bundling and conductor elimination, please refer to the EMTP Theory Book.

Note that even though the phase numbering sequence must start at zero and must have no gaps, the order in which KPH appears is arbitrary. In other words, Conductor/Insulator cards do not have to be ordered according to KPH. By the same token, the order of the conductors in printed or punched output will be made according to the sequence defined by KPH.

Pipe-Type Cable: Phase Numbers Card:

When NCN in the Individual Cable Card is negative, the data duplication function is enabled. Setting NCN to a negative number is equivalent to saying "make the conductor data for this cable identical to the data of cable number –NCN". For example, if all three (single-phase) cables in a three-phase cable system are identical, it is sufficient to enter the Conductor/Insulator cards for the first cable, and duplicate the rest. In this case NCN = –1 for cables 2 and 3.

Since phase number assignment is independent of the physical characteristics of the cable, it must be specified using the Phase Numbers Card.

```
         1           2           3         4         5         6         7         8
12345 67890  12345 67890  12345 6789012345678901234567890123456789012345678901234567890
```

	KPH1	KPH2	KPH3	KPH4	...
	I5	I5	I5	I5	...

KPH1 (6-10)	Phase number of the first conductor (core).
KPH2 (11-15)	Phase number of the second conductor (sheath).
KPH3 (16-20)	Phase number of the third conductor (armour).
...	...

If the cable has more than 15 conductors, the phase numbers of the next 15 conductors are read from a second card and so on.

Note: If NCN in the Individual Cable Card is positive, the it must be followed by NCN Conductor/ Insulator Cards and no Phase Numbers Card.

If NCN is negative, the Conductor/Insulator Card will be followed by a single Phase Numbers Card (unless there are more than 15 concentric conductors in a given cable).

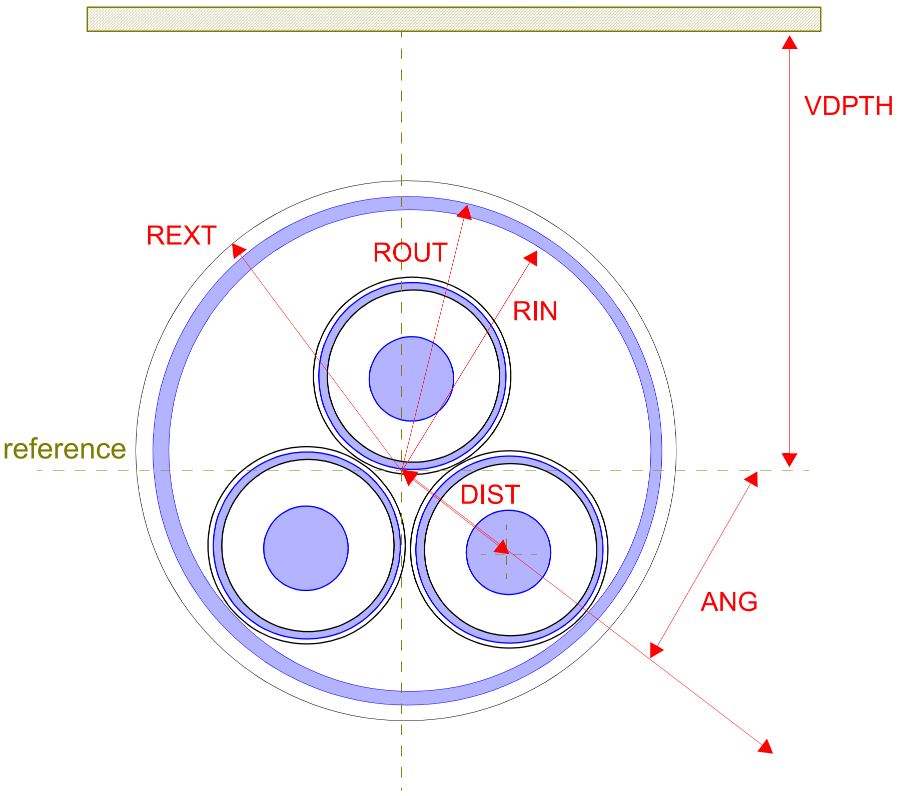
Pipe-Type Cable: Pipe-Data Cards:

For Pipe-type cables, the next two cards describe the tubular pipe and its inside and outside insulation.

First card:

1 1234567890	2 1234567890	3 1234567890	4 1234567890	12345	5 6 7 8 67890123456789012345678901234567890
RIN	ROUT	REXT	VDPTH	KPH	
E10.0	E10.0	E10.0	E10.0	I5	

RIN (1-10)	Inside radius of the PIPE. Units = meters.
ROUT (11-20)	Outside radius of the pipe. Units = meters.



REXT (21-30)	Outside radius of the tubular insulator surrounding the pipe. Units = meters.
VDPTH (31-40)	Vertical distance (depth) of the pipe's centre from the surface of the earth. Units = meters.
KPH (71-75)	Phase-number of the pipe (zero if it is grounded.

Second card:

```
         1          2          3          4          5          6          7          8
1234567890 1234567890 1234567890 1234567890 1234567890 1234567890 1234567890 1234567890
```

RHO	MUE	MUE-IN	LFTC-IN-IN	MUE-I	MUE-OUT	EPS-OUT	LFTC-OUT
E10.0	E10.0	E10.0	E10.0	E10.0	E10.0	E10.0	E10.0

RIN (1-10)	Inside radius of the conductor. Units = meters.
RHO (1-10)	Resistivity of the pipe. Units = Ω·m.
MUE-IN (21-30)	Relative permeability of the insulation inside the pipe.
EPS-IN (31-40)	Relative permittivity of the insulation inside the pipe.
LFCT-IN (41-50)	Loss-factor of the insulation inside the pipe.
MUE-OUT (51-60)	Relative permeability of the insulation surrounding the pipe.
EPS-OUT (61-70)	Relative permittivity of the insulation surrounding the pipe.
LFCT-OUT (71-80)	Loss-factor of the insulation surrounding the pipe.

Note: When REXT on the previous card is left blank (or zero), a very thin insulating layer is assumed around the pipe with MUE-OUT=1.0, EPS-OUT=1.0 and LFCT-OUT=0.0.

3.4 Earth/Frequency Card

This subsection describes the following cards:

Earth/Frequency Card: Logarithmic Scale
Earth/Frequency Card: Linear Scale
Earth/Frequency Card: User-Supplied Frequencies
Discrete-Frequency Cards

The Earth/Frequency card specifies the values for the resistivity and relative permeability of the earth. It also specifies whether the cable parameters will be calculated over a linear, logarithmic or user-defined frequency ranges. The frequency range is controlled with the keyword "F-Scl" in columns 35-40 of this card.

Earth/Frequency Card: Logarithmic Scale:

This form of frequency scaling is required for the FD-Model class of models, and it can also be used for EXACT-PI and SCAN calculations (see Section 3.1).

1	2	3		4	5		6	7	8
1234567890	1234567890	1234567890	12345	67890	1234567890	12345	67890	1234567890	1234567890
RHO-E	MUE-E	FG0		F-Scl	FMIN	NPD	NDC	FDC	
E10.0	E10.0	E10.0		A5	E10.0	I5	I5	E10.0	

RHO-E (1-10)	Earth resistivity. Units = Ω·m.
MUE-E (11-20)	Relative permeability of the earth (default is 1.0)
FG0 (21-30)	Breakpoint frequency (in Hz) of the shunt conductances for all insulating layers. For all insulators, the shunt conductance G is described with the following function of frequencyG = 2π (FG0 + Frequency) • (Loss Factor) • (Capacitance). When FG0 is left blank (not zero), a default value of 100.Hz is assumed.
F-Scl (36-40)	Set F-Scl = "LOG" for logarithmically-spaced frequencies (default). See "Earth/Frequency Card: Linear Scale", which follows, for other valid keywords
FMIN (41-50)	Minimum or starting frequency in Hz. The default value of FMIN is 0.01 Hz for logarithmic spacing, 0.001 Hz for linear spacing, and 1000 Hz for user-defined discrete frequencies.
NPD (51-55)	Number of frequency points per decade. Default is 10 for the FD-Model class, and 1 otherwise. *Logarithmic scale only.*
NDC (56-60)	Number of decades. Default is 8 for the FD-Model class, and 6 otherwise. *Logarithmic scale only.* The program automatically selects NPD•NDC+1 logarithmically spaced frequencies in the range of FMIN to FMIN•10^{-NDC}. For the FD-Model class, one point at FDC is also computed for use by the rational function fitting routine.
FDC (61-70)	Near-DC frequency in Hz. For "FD-Model" and "SCAN" options, default value of FDC is the lesser of 10^{-5} Hz and FMIN/10. Otherwise FDC is ignored. *Logarithmic scale only.*

Note: .For the FD-Model class, only LOG scale is allowed. For the CP-Model option all frequency specifications made in this card are ignored.

Earth/Frequency Card: Linear Scale:

This form of frequency scaling can be used for EXACT-PI and SCAN calculations (see Section 9.2.1). It cannot be used for the FD-Model class of models.

1 1234567890	2 1234567890	3 1234567890	12345	4 67890	5 1234567890	6 1234567890	7 1234567890	8 1234567890
RHO-E	MUE-E	FG0		F-Scl	FMIN	FDLT	FMAX	
E10.0	E10.0	E10.0		A5	E10.0	E10.0	E10.0	

RHO-E (1-10)	Earth resistivity. Units = Ω·m.
MUE-E (11-20)	Relative permeability of the earth (default is 1.0).
FG0 (21-30)	Breakpoint frequency (in Hz) of the shunt conductances for all insulating layers. For all insulators, the shunt conductance G is described with the following function of frequencyG = 2π (FG0 + Frequency) • (Loss Factor) • (Capacitance). When FG0 is left blank (not zero), a default value of 100.Hz is assumed.
F-Scl (36-40)	Set F-Scl = "LIN" for linearly-spaced frequencies (default).
FMIN (41-50)	Minimum or starting frequency in Hz. The default value of FMIN is 0.01 Hz for logarithmic spacing, 0.001 Hz for linear spacing, and 1000 Hz for user-defined discrete frequencies.
FDLT (51-60)	Frequency-increment in Hz (default is 100.0 Hz). *Linear scale only.*
FMAX (61-70)	Maximum frequency in Hz (default is 5000.0 Hz). *Linear scale only.* The program automatically selects FMIN, FMIN+FDLT, FMIN+2.FDLT, ... FMAX as the frequency points.

Note: For the CP-Model option all frequency specifications made in this card are ignored.

Earth/Frequency Card: User-Supplied Frequencies:

This form of frequency scaling can only be used SCAN calculations (see Section 3.1). This card must be followed by one or more Discrete Frequency Cards.

```
         1          2          3           4          5          6          7          8
1234567890 1234567890 1234567890  12345 67890  1234567890123456789012345678901234567890
```

RHO-E	MUE-E	FG0		F-Scl	
E10.0	E10.0	E10.0		A5	

RHO-E (1-10)	Earth resistivity. Units = Ω·m.
MUE-E (11-20)	Relative permeability of the earth (default is 1.0).
FG0 (21-30)	Breakpoint frequency (in Hz) of the shunt conductances for all insulating layers. For all insulators, the shunt conductance G is described with the following function of frequencyG = 2π (FG0 + Frequency) • (Loss Factor) • (Capacitance). When FG0 is left blank (not zero), a default value of 100.Hz is assumed.
F-Scl (36-40)	Set F-Scl = "DSC" for user-supplied frequency specification. Note that RHO-E and MUE-E are only necessary if a CP-Model is requested, or if RHOi and MUEi are left blank in the Discrete-Frequency cards below.

Discrete-Frequency Cards

When F-Scl in the previous card is set to "DSC", the user must provide one data card for each frequency, *followed by a blank card to indicate the end of the Discrete Frequency Cards.*

```
         1          2          3          4          5          6          7          8
1234567890 1234567890 1234567890 12345678901234567890123456789012345678901234567890
```

FRQi	RHOi	MUEi	
E10.0	E10.0	E10.0	

FRQi (1-10)	Frequency in Hz.
RHOi (11-20)	Earth resistivity. Units = Ω·m. Default is RHO-E of the Earth/Frequency card above.
MUEi (21-30)	Earth relative permeability at FRQi.Default is MUE-E of the Earth/ Frequency card above.

Note: The last discrete-frequency card is followed by a blank card to indicate the end of the discrete-frequency card set. Information provided by the Discrete-Frequency cards are ignored in the case of CP-Models.

3.5 Optional Control Cards

This subsection describes the following cards:

Debug Card
Printout Control Card
Node Names Card
Fitting Control Card
Fitting Printout Card
Fitting Debug Card
End Card

Optional control cards allow the user to specify additional information (e.g., node names for punched model output), 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 on the internal solution process.

These cards are optional and can appear in any sequence after the earth/frequency card (or discrete frequency cards or external data cards, as the case may be). Their presence is flagged by a dot '.' in column one joined to a keyword.

Debug Card:

This card controls debugging printouts and rotation of the Transformation matrix Q.

```
         1          2          3         4         5         6         7         8
1234567890123456789  01  23  45678901234567890123456789012345678901234567890123456789012345678901234567890
```

.DBGCBL	IDBG	IROTQ	
A19	I2	I2	

.DBGCBL (1-19) Keyword (left-justified).

IDBG (20-21) Parameter controlling the amount of printout during calculation. Higher values generate more printout (default is 0).

IROTQ (22-23) Parameter controlling the rotation of Q (does not apply to FDQ).

=1 Rotate Q so that modal capacitances $C_m = \text{diag}\,(Q^{-1}C\,Q^{-t})$ remain real (default).

=2 Rotate Q to minimize the imaginary part of its element.

Printout Control Card:

This card controls the printout of modal quantities, as well as impedance and admittance matrices at every frequency.

.

```
                  1                   2         3         4         5         6         7         8
1234567890123456789 01 23 45 678901234567890123456789012345678901234567890123456789012345678901234567890
```

.OUTCBL	I WZ	I WY	I WM	
A19	I2	I2	I2	

.OUTCBL (1-19) Keyword (left-justified).

IWZ (20-21) Parameter controlling printout of impedance matrices.

= 0 no printout (default).

= 1 printout of impedance matrix $Z = R + j\omega L$.

= 2 printout of resistance and inductance matrices R and L.

IWY (22-23) Parameter controlling printout of admittance matrices.

= 0 no printout (default).

= 1 printout of admittance matrix $Y = G + j\omega C$.

= 2 printout of conductance and capacitance matrices G and C.

IWM (24-25) Parameter controlling the printout of modal quantities.

= 0 no printout (default).

= 1 printout of modal impedances, admittances, characteristic admittances and propagation functions.

= 2 same as IWM = 1, plus the transformation matrix Q.

= 3 same as IWM = 2, with the addition of:

$$[Q^{-1} YZ\, Q - \text{diag}\, (Y_{\text{mode}} Z_{\text{mode}})] = E$$

(to verify the validity of Q). Ideally, E should be the zero matrix.

Node Names Card

This card provides node names for the sending and receiving ends of the cable. These names appear in the punched output for the models of the cable, and correspond to phase numbers 1 to N specified in KPH in the conductor/insulator cards (see Sections 9.2.3.2 and 9.2.4.2).

1 1234567890123456789	2 012345	6789	3 012345	6789	4 012345	6789	5 012345	6789	6 012345	6789	7 012345	8 67890
.NODES	SEND-1		RECV-1		SEND-2		RECV-2		SEND-3		RECV-3	
A19	A6		A6		A6		A6		A6		A6	

.NODES (1-19)	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 .NODES.

Fitting Control Card:

This card changes the value of parameters which control the fitting of modal characteristic admittances $Y_{c,mode}$, propagation functions A_{mode}, and elements of transformation matrix Q.

.

```
          1         2           3         4         5         6         7         8
1234567890123456789 01  23 45 67  89 01 234567890123456789012345678901234567890123456789
```

.CTLFIT	NORMAX	IQUICK	IXDYN	IFITYC	IFITA	IFITQ	
A19	I2	I2	I2	I2	I2	I2	

.CTLFIT (1-19)
Keyword (left-justified)

NORMAX (20-21)
Maximum number of poles in the synthesis of $Y_{c,mode}$, A_{mode} and Q (default is 25).

IQUICK (22-23)
Flag controlling the accuracy of the fit of $Y_{c,mode}$, A_{mode}, and Q (default is –1).

= 1 Much faster, but less accurate, approximation of $Y_{c,mode}$, A_{mode} and Q is produced.

= –1 Accurate fitting procedure is used.

IXDYN (24-25)
Flag controlling the approximation of A_{mode} in the low frequency range (default is 1).

= 1 Extra dynamics (extra poles and zeroes) are added to the approximation of the low frequency region of the propagation function A_{mode}. This allows a more accurate simulation of very short cable sections and of very low frequencies.

= –1 No extra dynamics are added to the approximation of A_{mode}. This results in a lower order approximation but less accurate fit for short cable sections or very low frequencies. In some cases, IXDYN = –1 can produce low frequency oscillations (e.g., 1 Hz or so) in the simulation of trapped charge.

IFITYC (26-27)
Flag controlling which modes of $Y_{c,mode}$ will be fitted.

= 0 fit all modes (default).

= N fit only mode "N" of $Y_{c,mode}$.

= –1 do not fit any mode of $Y_{c,mode}$.

IFITA (28-29)
Flag controlling which modes of A_{mode} shall be fitted.

= 0 fit all modes (default).

= N fit only mode "N" of A_{mode} .

= –1 do not fit any mode of A_{mode} .

IFITQ (30-31) Flag controlling which modes of Q will be fitted.

= 0 fit all modes (default).

= K fit only element "K" of Q. Elements of Q are numbered column-wise, so for an NxN matrix, Q (i,j) is number i+(j-1)N.

= –1 do not fit any element of Q.

Note: To produce FD-Models, the synthesis or fitting of all modes is required. This is the normal case where IFITYC, IFITA and IFITQ are 0 or blank.

Fitting Printout Card:

This card controls the amount of intermediate output information on the fitting on $Y_{c,mode}$, A_{mode} and Q.

.

```
         1          2          3         4         5         6         7         8
1234567890123456789 01 23 45 678901234567890123456789012345678901234567890123456789
```

.OUTFIT	ICOMPF	IPLOTF	IPRAT	
A19	I2	I2	I2	

.OUTFIT (1-19) Keyword (left-justified).

ICOMPF (20-21) Flag controlling the printout of a comparison table between calculated and fitted functions (default is –1).

= 1 An output table is produced comparing the data functions $Y_{c,mode}$, A_{mode} and Q as produced by the Cable-Model routine and the approximating rational functions produced by the fitting routine.

= –1 No comparison table is produced.

IPLOTF (22-23) Flag controlling the printout of a printer plot out the output file (default is 1).

= 1 A printer plot is produced comparing the calculated cable functions ($Y_{c,mode}$, A_{mode}, and Q) with their corresponding rational function approximations.

= –1 No printer plot is produced.

IPRAT (24-25) Flag controlling the printout of poles and zeros from the rational function approximations (default is 1).

= 1 Tables are produced showing the location of the poles and zeros of the rational function approximations of $Y_{c,mode}$, A_{mode} and Q. Also shown are the RC equivalent network for $Y_{c,mode}$, and the time domain exponential representation of the approximating functions.

= –1 No tables are produced.

Fitting Debug Card:

This card controls the amount of printout of internal processing information in the fitting routine.

```
         1          2           3         4         5         6         7         8
1234567890123456789 01 234567890123456789012345678901234567890123456789012345678901234567890
```

.OUTFIT	IBUGF	
A19	I2	

.OUTFIT (1-19) Keyword (left-justified).

IBUGF (20-21) Flag controlling the level of diagnostic printout. Allowed values are 0, 1, 2, or 3 (default = 0). The higher the value, the larger the amount of debugging output.

End Card:

The end-of-data card of a Cable-Model case is indicated by a blank card (or the keyword "BLANK"). Note that the end of discrete frequency cards was also indicated by a blank card. This means that in the case of discrete frequencies, and in the absence of optional control cards, there will be 2 blank cards at the end of the data case.

3.6 External Data Cards

It is possible to link the Cable Model routines to an external cable constants program as long as data are transmitted via an ASCII file in the format described below. This option would permit the creation of frequency dependent cable models using parameter calculation techniques different from those used in this module (e.g., finite elements).

External Data File Control Cards:

To use the external data option, all the cards following the Cable-Model control card are replaced by two cards. One card specifies the name of the external file:

1 2 3 4 5 6 7 8 12345678901234567890234567890123456789012345678901234567890123456789012345678901234567890
EXTERNAL FILENAME
A80

External Filename (1-80)	Name of the file containing the impedance and admittance matrices Since AUX converts all characters to uppercase, the name of this file must be in uppercase. This is important with operating systems with case-sensitive syntax

The next card provides the following information:

1 1234567890	2 1234567890	3 1234567890	 12345	4 67890	5 6 7 8 1234567890123456789012345678901234567890
NPHS	FDC	FMIN	NPD	NDC	
I10	E10.0	E10.0	I5	I5	

NPHS (1-10)	Number of phases (size of Z_{phase} and Y_{phase} matrices).
FDC (11-20)	Near-DC frequency in Hz.
FMIN (21-30)	Starting frequency in Hz.
NPD (31-34)	Number of points per decade for frequency scale.
NDC (35-40)	Number of decades for frequency scale.

Note : FDC, FMIN, NPD and NDC need to be specified only for the FD-Model class. Otherwise, they are ignored.

Also, the number of points and frequency scale (spacing) of the externally-supplied data must match FDC, FMIN, NPD and NDC exactly. The Cable-Model routine does not provide a sanity check to this effect.

External Data File Structure:

The structure of the external data must adhere to the following rules:

1. Any number of comment lines at the beginning of the file. Each line must start with "C " or "c " in columns 1 and 2. Comment lines among the data lines are not allowed.
2. First data line containing the number of phases (integer). This number must match NPHS on the external data card of Cable-Model data case.
3. One record containing the frequency F in Hz, followed by data records containing the row-wise lower triangle matrices of Z_{phase} in Ω/km and Y_{phase} in S/km at evaluated at F (real and imaginary parts). For example, if NPHS = 3, then

F

Zr(1,1)	Zi(1,1)	Zr(2,1)	Zi(2,1)	Zr(2,2)
Zi(2,2)	Zr(3,1)	Zi(3,1)	Zr(3,2)	Zi(3,2)
Zr(3,3)	Zi(3,3)			

Yr(1,1)	Yi(1,1)	Yr(2,1)	Yi(2,1)	Yr(2,2)
Yi(2,2)	Yr(3,1)	Yi(3,1)	Yr(3,2)	Yi(3,2)
Yr(3,3)	Yi(3,3)			

Z_{phase} and Y_{phase} could be in units of Ω/m and S/m, in which case the cable length must be specified in units of meters on the Cable-Model control card.

Since data are read in free format, it does not matter how many data lines are used to produce Z_{phase} and Y_{phase}, as long as the correct number of terms is used.

4. Repeat c) as many times as there are frequency points defined by FDC, FMIN, NDC, and NDC. There should be no blank lines or comment lines between valid data.

The total number of frequency points depends on the type of model to be generated. If NPHS = 1, there should be exactly NDC • NPD + 2 points, organized as follows:

```
FDC
F(1) = FMIN
F(2) = F(1) ² DELTAF
F(3) = F(2) ² DELTAF
...
```

where DELTAF = 10^{-NPD}.

If NPHS > 1, there should be exactly NDC • NPD + 3 points, organized as follows:

```
FSEED
FDC
F(1) = FMIN
F(2) = F(1) • DELTAF
F(3) = F(2) • DELTAF
...
```

where DELTAF = 10^{-NPD}.

In the case of FD models with constant modal transformation matrix Q, FSEED is the frequency at which Q constant and real will be evaluated (from Z and Y at F = FSEED). In the case if an FDQ model, FSEED is the frequency at which the seeding Q is calculated. FSEED = FMIN usually gives reasonable results.

Note: Following the second External Data File Control Card, any number of special control (i.e., dot cards) can be specified, followed by the appropriate number of End Cards (i.e., blank cards).

4 Cable-Model and Cable-Parameters Format Conversion

The format conversion option between Cable-Model and Cable-Parameters modules provided in this version of AUX, does not always produce equivalent data cases because the capabilities of both modules are different.

The recommended approach to data conversion is to set IPCH = 1, and IRUN = 0 in the Cable-Model Control Card (see Section 3.1). This has the effect of producing a punch file which contains the converted input data file without actually running the converted data case.

Nevertheless, efforts have been made to produce meaningful translations by providing defaults and built-in assumptions when necessary.

4.1 Conversion from Cable-Model to Cable-Constants

This conversion takes place when either IRUN=1 (columns 71-75) or IPCH=1 (columns 67-80) of the Cable-Model Control Card (see Section 3.1) and the "CABLE-PARAMETERS" keyword is used to request a Cable-Parameters simulation.

MODEL	Q-OPTN	F-Scl	COMMENTS
FD-MODEL	FDQ	LOG	Approximate conversion to Frequency-Dependent model with constant Q (JMARTI line model). IRUN set internally to zero.
	QREAL	LOG	Equivalent conversion to Frequency-Dependent model with constant Q (JMARTI line model). Q calculated at FREQ-Q.
CP-MODEL	QREAL	N/A	Equivalent conversion to constant-parameter model calculated at f=FREQ-Q.
	QCMPLX	N/A	Approximate conversion to constant-parameter model calculated at f=FREQ-Q. Modal transformation matrix is assumed to be real. IRUN set to zero.
SCAN	FDQ	LOG LIN DSC	Equivalent conversion. Parameters calculated at each frequency within the range specified.
EXACT-PI	FDQ	LOG LIN DSC	Approximate conversion. Cross-bonding option is used for non-cross-bonded cable, and homogeneous (Discrete) pi, depending on conductor and grounding arrangement. Discrete pi is used only if all the sheaths are connected together but not grounded. In this case, the discrete pi is used with a 1000 Ω grounding resistance. IRUN is set internally to 1.

In most cases, if a conversion option is not available, an appropriate error message is issued. For example, SCAN and EXACT-PI options with QREAL or QCMPLX are not converted.

4.2 Conversion from Cable-Constants to Cable-Model

This conversion takes place when either IRUN=1 (columns 71-75) or IPCH=1 (columns 67-80) of the Cable-Model Control Card (see Section 3.1) and the "CABLE-MODEL" keyword is used to request a Cable-Model simulation.

Option	**Comments**
Cross-bonding	Only those cases for which NCROS is not zero are converted (i.e., sheaths are not cross-bonded). In such cases, all grounding codes are ignored, and all sheaths (armours and pipe, if any) are grounded. Also, all sheaths are assumed to be connected together (ISEP ignored) and grounding resistances (ISG) are assumed to be zero.
Frequency-Dependence	FD-Model with QREAL is used. The modal transformation matrix is calculated at the frequency specified in the first frequency card. Otherwise, 1 kHz is assumed.
Constant-Parameters	SCAN option with FDQ is used. Discrete frequency scale (DSC) is used to produce output for each frequency card provided.

In most cases, if a conversion option is not available, an appropriate error message is issued, for example, cables in air, stratified earth, and overhead lines are not converted.

5 CABLE-MODEL Examples

The following examples shop a few data cases to illustrate some of the most commonly-used features of the Cable-Model module. Please note that text in italics ***(such as this)*** is used as an annotation and it is not part of the data file.

Case 1: Setting up a pipe-type cable case

```
BEGIN NEW DATA CASE
C
C ---------------------------------------------------------------------
C
C      Pipe Type cable with 3 identical, 2-conductor cables
C      Frequency dependent model.
```

```
C      Modal transformation matrix Q is frequency dependent.
C      Sheaths grounded
C
C ----------------------------------------------------------------------
CABLE CONSTANTS
C Cable-model Control Card
C --key----|       |<--model--<--Q-optn-<-freq-q--<--length-| |<--ext-<ipch<irun
cable-model         fd-model  fdq            1000.        1.               0    0
C
C Cable-type card
C  TY<NCBL<IXBD
   PT    3    0           each cable has a core and a sheath, no cross-bonding
C ------------------------------------------------------------------------------
C Data for SC cable # 1 follows
C
C PT Cable: Individual Cable Card
C NCN|  |<----DST---<----ANG--<--ROUT---
    2        0.02442       0.0    .03809
C
C PT Cable: Conductor/Insulator Card
C --RIN---<--ROUT---<---RHO---<---MUE---<--MUE-I--<--EPS-I--<--LFCT---<-KPH
    .00001    .02197  2.945E-8        1.        1.       3.5      .005    1
   .033274    .03744  1323.E-8        1.        1.       2.0      .001    0
C ------------------------------------------------------------------------------
C Data for PT cable # 2 follows (copy data from PT cable # 1)
C NCN|  |<----DST---<----ANG--<--ROUT---
   -1        0.061042     137.7          NCN=-1 to indicate copy data from cable #1
C
C PT Cable: Phase Number Card
C    <KPH1<KPH2<KPH3
         2    0                  KPH2=0 to indicate that the sheath is grounded
C ------------------------------------------------------------------------------
C Data for PT cable # 3 follows (copy data from PT cable # 1)
   -1        0.061042    -137.7
C
C PT Cable: Phase Number Card
C    <KPH1<KPH2<KPH3
         3    0
C ------------------------------------------------------------------------------
C
C 3456789 123456789 123456789 123456789 123456789 123456789 123456789 123456789
C Pipe-Data Cards
C --RIN---<--ROUT---<---REXT--<--VDPTH--<-KPH
     .1024     .1094    .10954       1.0    0      KPH=0 to ground the pipe
C --RHO---<---MUE---<-MUE-IN--<-EPS-IN--<-LFCT-IN-<-MUE-OUT-<-EPS-OUT-<-FCT-OUT-
     3281.        9.        1.       3.0      .002        1.       2.0      .002
C ------------------------------------------------------------------------------
C
C Earth/Frequency Card (log scale)
C -RHO-E--<--MUE-E--<---FG0---|   |<FScl<---FMIN--<-NPD<-NDC<---FDC---
       50.        1.        0.     LOG         .1   10    8        .1
C ------------------------------------------------------------------------------
C
C Optional cards
C ---- nodes ------<-snd1|  |<-rcv1|  |<-snd1|  |<-rcv1|  |<-snd1|  |<-rcv1|
.nodes             snd1      rcv1      snd2      rcv2      snd3      rcv3
C        1         2         3
C 3456789 123456789 123456789 1
.dbgcbl             0
.outcbl             0 0 0
```

```
.ctlfit            25-1 1 0 0 0
.outfit             1-1-1                     no printer plot or equivalent network requested
.dbgfit             0
C
C Summary of control flags:
C  Keyword      COL      FLAG
C  .dbgcbl      20-21    IDBG
C               22-23    IROTQ
C  .outcbl      20-21    IWZ
C               22-23    IWY
C               24-25    IWM
C  .nodes       20-25    send-1
C               30-35    recv-1
C               40-45    send-2
C               50-55    recv-2
C  .ctlfit      20-21    normax
C               22-23    iquick
C               24-25    ixdyn
C               26-27    ifityc
C               28-29    ifita
C               30-31    ifitq
C .outfit       20-21    icompf
C               22-23    iplotf
C               24-25    iprat
C .dbgfit       20-21    ibugf
C
BLANK CARD ENDING CABLE-MODEL DATA
BLANK CARD ENDING CABLE CONSTANT DATA CASE
BEGIN NEW DATA CASE
BLANK
```

Case 2: Setting up a Single-Core Cable

Sheaths are not grounded so we will obtain a six-conductor model. This could be used, for example, as an explicit model of a minor section of a cross-bonded cable. An FDQ model is requested.

```
BEGIN NEW DATA CASE
C ------------------------------------------------------------------------------
C      3 SC identical cables, Frequency dependent model. Modal transformation
C      matrix Q is frequency dependent. Sheath ungrounded
C ------------------------------------------------------------------------------
CABLE CONSTANTS
C Cable-model Control Card
C --key----|      |<--model--<--Q-optn-<-freq-q--<--length-| |<--ext-<ipch<irun
cable-model         fd-model  fdq                          1.              0    0
C
C Cable-type card
C  TY<NCBL<IXBD
   SC    3    0
C ------------------------------------------------------------------------------
C Data for SC cable # 1 follows
C
C SC Cable: Individual Cable Card
```

```
C NCN|  |<----VRT---<----HRZ--<--ROUT---
    2            1.1       0.0   .029335
C
C SC Cable: Conductor/Insulator Card          KPHS in this card defines EMTP phases
C --RIN---<--ROUT---<---RHO---<---MUE---<--MUE-I--<--EPS-I--<--LFCT---<-KPH
   .003175   .01254     .17D-7        1.        1.       3.5      .001    1
   .022735   .026225    .21D-6        1.        1.       2.0      .001    2
C ------------------------------------------------------------------------------
C Data for SC cable # 2 follows (copy data from SC cable # 1)
C
C SC Cable: Individual Cable Card
C NCN|  |<----VRT---<----HRZ--<--ROUT---
   -1            1.1      0.25
C
C SC Cable: Phase Number Card
C    <KPH1<KPH2<KPH3
         3    4         KPH will go from 1 to 6 to retain all conductors in the final model
C ------------------------------------------------------------------------------
C Data for SC cable # 3 follows (copy data from SC cable # 1)
C
C SC Cable: Individual Cable Card
C NCN|  |<----VRT---<----HRZ--<--ROUT---
   -1            1.1      0.50
C
C SC Cable: Phase Number Card
C    <KPH1<KPH2<KPH3
         5    6
C ------------------------------------------------------------------------------
C
C Earth/Frequency Card (log scale)
C -RHO-E--<--MUE-E--<---FG0---|   |<FScl<---FMIN--<-NPD<-NDC<---FDC---
      250.        1.         0.     log          .1   10    8        .1
C ------------------------------------------------------------------------------
C
C Optional cards
C
.dbgcbl
.outcbl            0 0 0
c ---- nodes ------<-snd1|  |<-rcv1|  |<-snd1|  |<-rcv1|  |<-snd1|  |<-rcv1|
.nodes             snd1      rcv1      snd2      rcv2      snd3      rcv3
                   snd4      rcv4      snd5      rcv5      snd6      rcv6
C        1         2         3
C 3456789 123456789 123456789 1
.ctlfit            35-1 1 0 0 0  Extra poles are requested.  default is 25.
.outfit             1 1 1        Full output request
.dbgfit             0
C
C Summary of control flags:
C  Keyword      COL      FLAG
C  .dbgcbl      20-21    idbg
C               22-23    irotq
C  .outcbl      20-21    iwz
C               22-23    iwy
C               24-25    iwm
C  .nodes       20-25    send-1
C               30-35    recv-1
C               40-45    send-2
C               50-55    recv-2
C  .ctlfit      20-21    normax
C               22-23    iquick
```

```
C                24-25    ixdyn
C                26-27    ifityc
C                28-29    ifita
C                30-31    ifitq
C .outfit         20-21    icompf
C                22-23    iplotf
C                24-25    iprat
C .dbgfit         20-21    ibugf
C
BLANK CARD ENDING CABLE-MODEL DATA
BLANK CARD ENDING CABLE CONSTANTS DATA CASE
C BEGIN NEW DATA CASE
C BLANK
C
C
C
```

Case 3: Setting up a Single-core cable with Q constant.

Also, in this case, the sheaths will be grounded to produce a 3-conductor model.

```
BEGIN NEW DATA CASE
C ------------------------------------------------------------------------------
C      3 SC identical cables, Frequency dependent model.
C      Modal transformation matrix Q is real. it is computed at 1 KHZ.
C      Sheath grounded
C ------------------------------------------------------------------------------
CABLE CONSTANTS
C Cable-model Control Card
C --key----|       |<--model--<--Q-optn-<-freq-q--<--length-| |<--ext-<ipch<irun
cable-model         fd-model  QREAL           1000        1.              0    0
C
C Cable-type card
C  TY<NCBL<IXBD
   SC    3    0
C ------------------------------------------------------------------------------
C Data for SC cable # 1 follows
C
C SC Cable: Individual Cable Card
C NCN|  |<----VRT---<----HRZ--<--ROUT---
    2            1.1       0.0   .029335
C
C SC Cable: Conductor/Insulator Card  KPH=0 on sheath specification to ground it
C --RIN---<--ROUT---<---RHO---<---MUE---<--MUE-I--<--EPS-I--<--LFCT---<-KPH
   .003175   .01254     .17D-7        1.        1.       3.5      .001    1
   .022735   .026225    .21D-6        1.        1.       2.0      .001    0
C ------------------------------------------------------------------------------
C Data for SC cable # 2 follows (copy data from SC cable # 1)
C
C SC Cable: Individual Cable Card
C NCN|  |<----VRT---<----HRZ--<--ROUT---
   -1            1.1      0.25
C
C SC Cable: Phase Number Card
C    <KPH1<KPH2<KPH3
         2    0
```

```
C ------------------------------------------------------------------------------
C Data for SC cable # 3 follows (copy data from SC cable # 1)
C
C SC Cable: Individual Cable Card
C NCN|  |<----VRT---<----HRZ--<--ROUT---
   -1            1.1      0.50
C
C SC Cable: Phase Number Card
C    <KPH1<KPH2<KPH3
         3    0
C ------------------------------------------------------------------------------
C
C Earth/Frequency Card (log scale)
C -RHO-E--<--MUE-E--<---FG0---|   |<FScl<---FMIN--<-NPD<-NDC<---FDC---
      250.        1.        0.     log          .1   10    8        .1
C ------------------------------------------------------------------------------
C
C Optional cards
C
c ---- nodes ------<-snd1|  |<-rcv1|  |<-snd1|  |<-rcv1|  |<-snd1|  |<-rcv1|
.nodes             snd1      rcv1      snd2      rcv2      snd3      rcv3
C        1         2         3
C 3456789 123456789 123456789 1
.outfit             1 1-1     Most control cards are absent: default values are assumed
C  Keyword      COL       FLAG
C .outfit       20-21    icompf
C               22-23    iplotf
C               24-25    iprat
BLANK CARD ENDING CABLE-MODEL DATA
BLANK CARD ENDING CABLE CONSTANTS DATA CASE
BEGIN NEW DATA CASE
BLANK
C
C
```

Case 4: Setting up a Single-core cable with a CP model

This case also illustrates the specification of non-identical conductors. Note that in a constant-parameters model, R and L are calculated at the same frequency as the modal transformation matrix Q.

```
BEGIN NEW DATA CASE
C ------------------------------------------------------------------------------
C      3 SC non-identical cables, Constant parameter Model computed at 1 KHZ
C       Sheath ungrounded
C ------------------------------------------------------------------------------
CABLE CONSTANTS
C Cable-model Control Card
C --key----|       |<--model--<--Q-optn-<-freq-q--<--length-| |<--ext-<ipch<irun
cable-model         cp-model  QREAL           1000        1.              0    0
C
C Cable-type card
C  TY<NCBL<IXBD
   SC    3    0
C ------------------------------------------------------------------------------
C Data for SC cable # 1 follows
C
```

```
C SC Cable: Individual Cable Card
C NCN|  |<----VRT---<----HRZ--<--ROUT---
    2            1.1       0.0    .029335
C
C SC Cable: Conductor/Insulator Card
C --RIN---<--ROUT---<---RHO---<---MUE---<--MUE-I--<--EPS-I--<--LFCT---<-KPH
   .003175   .01254     .17D-7        1.        1.       3.5      .001    1
   .022735   .026225    .21D-6        1.        1.       2.0      .001    2
C ------------------------------------------------------------------------------
C Data for SC cable # 2 follows
C
C SC Cable: Individual Cable Card
C NCN|  |<----VRT---<----HRZ--<--ROUT---
    2            1.1      0.25    .028335   NCN is positive.  Data is not copied.
C
C SC Cable: Conductor/Insulator Card
C --RIN---<--ROUT---<---RHO---<---MUE---<--MUE-I--<--EPS-I--<--LFCT---<-KPH
   .004175   .01154     .17D-7        1.        1.       3.7      .001    3
   .020735   .024225    .21D-6        1.        1.       2.5      .001    4
C ------------------------------------------------------------------------------
C Data for SC cable # 3 follows (copy data from SC cable # 1)
C
C SC Cable: Individual Cable Card
C NCN|  |<----VRT---<----HRZ--<--ROUT---
   -1            1.1      0.50           Data is copied from cable # 1 only
C
C SC Cable: Phase Number Card
C    <KPH1<KPH2<KPH3
         5    6                    KPH from 1 to 6 to indicate all condutors are retained
C ------------------------------------------------------------------------------
C
C Earth/Frequency Card (log scale)
C -RHO-E--<--MUE-E--<---FG0---|   |<FScl<---FMIN--<-NPD<-NDC<---FDC---
      250.        1.                 Anything beyond MUE-E is meaningless for a CP model
C ------------------------------------------------------------------------------
C
C Optional cards
C
c ---- nodes ------<-snd1|  |<-rcv1|  |<-snd1|  |<-rcv1|  |<-snd1|  |<-rcv1|
.nodes             snd1      rcv1      snd2      rcv2      snd3      rcv3
                   snd4      rcv4      snd5      rcv5      snd6      rcv6
.outcbl             1 1 0   Print  Y, Z in phase quantities (IWM=0)  at f = FREQ-Q.
.ctlfit            35-1 1 0 0 0
.outfit             1 1 0
C
C Summary of control flags:
C  Keyword      COL      FLAG
C  .outcbl      20-21    IWZ
C               22-23    IWY
C               24-25    IWM
C  .ctlfit      20-21    normax
C               22-23    iquick
C               24-25    ixdyn
C               26-27    ifityc
C               28-29    ifita
C               30-31    ifitq
C .outfit       20-21    icompf
C               22-23    iplotf
C               24-25    iprat
```

```
C
BLANK CARD ENDING CABLE-MODEL DATA
BLANK CARD ENDING CABLE CONSTANTS DATA CASE
BEGIN NEW DATA CASE
BLANK
C
C
```

Case 5: Setting up a Single-core cable. No model generated.

This example illustrates the calculation of cable parameters without generating a model.

```
C        1         2         3         4         5         6         7         8
C 3456789 123456789 123456789 123456789 123456789 123456789 123456789 123456789
BEGIN NEW DATA CASE
C ------------------------------------------------------------------------------
C      3 SC identical cables, to compute cable parameters (not model)
C       at specified frequencies.
C ------------------------------------------------------------------------------
CABLE CONSTANTS
C Cable-model Control Card
C --key----|       |<--model--<--Q-optn-<-freq-q--<--length-| |<--ext-<ipch<irun
cable-model         scan      fdq             1000        1.              0    0
C
C Cable-type card
C  TY<NCBL<IXBD
   SC    3    0
C ------------------------------------------------------------------------------
C Data for SC cable # 1 follows
C
C SC Cable: Individual Cable Card
C NCN|  |<----VRT---<----HRZ--<--ROUT---
    2            1.1       0.0   .029335
C
C SC Cable: Conductor/Insulator Card
C --RIN---<--ROUT---<---RHO---<---MUE---<--MUE-I--<--EPS-I--<--LFCT---<-KPH
   .003175   .01254     .17D-7        1.        1.       3.5      .001    1
   .022735   .026225    .21D-6        1.        1.       2.0      .001    2
C ------------------------------------------------------------------------------
C Data for SC cable # 2 follows (copy data from SC cable # 1)
C
C SC Cable: Individual Cable Card
C NCN|  |<----VRT---<----HRZ--<--ROUT---
   -1            1.1      0.25
C
C SC Cable: Phase Number Card
C    <KPH1<KPH2<KPH3
         3    4
C ------------------------------------------------------------------------------
C Data for SC cable # 3 follows (copy data from SC cable # 1)
C
C SC Cable: Individual Cable Card
C NCN|  |<----VRT---<----HRZ--<--ROUT---
   -1            1.1      0.50
C
C SC Cable: Phase Number Card
C    <KPH1<KPH2<KPH3
```

```
         5    6
C -------------------------------------------------------------------------------
C
C Earth/Frequency Card
C -RHO-E--<--MUE-E--<---FG0---|   |<FScl
      250.        1.        0.     dsc
C Discrete-Frequency cards
C --FRQ--<---RHO---<---MUE---
       60.                  Parameters will be printed at 10 Hz and 1 kHz
     1000.
BLANK CARD TO TERMINATE DISCRETE FREQUENCY CARDS
C -------------------------------------------------------------------------------
C
C Optional cards
C        1         2         3
C 3456789 123456789 123456789 1
.outcbl             1 1 2   IWM = 2 to request modal output
C
C Summary of control flags:
C  Keyword      COL       FLAG
C  .outcbl      20-21    IWZ
C               22-23    IWY
C               24-25    IWM
BLANK CARD ENDING CABLE-MODEL DATA
BLANK CARD ENDING CABLE CONSTANTS DATA CASE
BEGIN NEW DATA CASE
BLANK
C
C
```

Case 6: Data conversion request from Cable-Mode to Cable-Parameters

Conversion request is indicated by IPCH=1 in the Cable-Model Control Card. The direction of the conversion is determined by the fact that this is a Cable-Model data case, and it can only be converted to a Cable-Parameters data case.

```
C        1         2         3         4         5         6         7         8
C 3456789 123456789 123456789 123456789 123456789 123456789 123456789 123456789
BEGIN NEW DATA CASE
C -------------------------------------------------------------------------------
C      3 SC identical cables, Frequency dependent model. Modal transformation
C      matrix Q is constant
C      Data conversion is requested
C      Sheath ungrounded
C -------------------------------------------------------------------------------
CABLE CONSTANTS
C Cable-model Control Card
C --key----|       |<--model--<--Q-optn-<-freq-q--<--length-| |<--ext-<ipch<irun
cable-model         fd-model  qreal                       1.              1    0
C
C Cable-type card
C  TY<NCBL<IXBD
   SC    3    0
C -------------------------------------------------------------------------------
```

```
C Data for SC cable # 1 follows
C
C SC Cable: Individual Cable Card
C NCN|  |<----VRT---<----HRZ--<--ROUT---
    2            1.1       0.0   .029335
C
C SC Cable: Conductor/Insulator Card
C --RIN---<--ROUT---<---RHO---<---MUE---<--MUE-I--<--EPS-I--<--LFCT---<-KPH
   .003175   .01254     .17D-7        1.        1.       3.5      .001    1
   .022735   .026225    .21D-6        1.        1.       2.0      .001    2
C ------------------------------------------------------------------------------
C Data for SC cable # 2 follows (copy data from SC cable # 1)
C
C SC Cable: Individual Cable Card
C NCN|  |<----VRT---<----HRZ--<--ROUT---
   -1            1.1      0.50
C
C SC Cable: Phase Number Card
C    <KPH1<KPH2<KPH3
         5    6
C ------------------------------------------------------------------------------
C Data for SC cable # 3 follows (copy data from SC cable # 1)
C
C SC Cable: Individual Cable Card
C NCN|  |<----VRT---<----HRZ--<--ROUT---
   -1            1.1      0.25
C
C SC Cable: Phase Number Card
C    <KPH1<KPH2<KPH3
         3    4
C ------------------------------------------------------------------------------
C
C Earth/Frequency Card (log scale)
C -RHO-E--<--MUE-E--<---FG0---|   |<FScl<---FMIN--<-NPD<-NDC<---FDC---
      250.        1.        0.     log          .1   10    8        .1
C ------------------------------------------------------------------------------
C
C Optional cards
C
c ---- nodes ------<-snd1|  |<-rcv1|  |<-snd1|  |<-rcv1|  |<-snd1|  |<-rcv1|
.nodes             snd1      rcv1      snd2      rcv2      snd3      rcv3
                   snd4      rcv4      snd5      rcv5      snd6      rcv6
BLANK CARD ENDING CABLE-MODEL DATA
BLANK CARD ENDING CABLE CONSTANTS DATA CASE
C BEGIN NEW DATA CASE
C BLANK
C
C
C
C
```

Case 7: Data conversion from Cable-Parameters to Cable-Model

Conversion request is indicated by IPCH=1 in the Cable-Model Control Card. The direction of the conversion is determined by the fact that this is a Cable-Model data case, and it can only be converted to a Cable-Parameters data case.

```
C
C ------------------------------------------------------------------------------
C      Cable-Parameters data case (old cable constants data format)
C      Conversion requested
C      3 SC identical cables
C      Sheath ungrounded
C
CABLE CONSTANTS
C
C
C Cable-model Control Card      This data file is in "old" CABLE CONSTANTS format
C --key--------|                                                     |<ipch<irun
CABLE-PARAMETERS                                                          1
C
C 345678901234567890123456789012345678901234567890123456789012345678901234567890
C ITY ISYS  NPC IEAR KMOD IZFL IYFL  NPP NGRN
    2   -1    3    0    1   -1   -1         0
C
C NPC NPCC NPCC NPCC NPCC NPCC ...
    2    2    2
C
C CONDUCTOR
C       R1        R2        R3        R4        R5        R6        R7
C       RC        UC       UI1       EI1        RS        US       UI2       EI2
  0.003175  0.012540  0.022735  0.026225  0.029335
.17000E-07     1.000     1.000     3.500.21000E-06     1.000     1.000     2.000
C
C CONDUCTOR
C       R1        R2        R3        R4        R5        R6        R7
C       RC        UC       UI1       EI1        RS        US       UI2       EI2
  0.003175  0.012540  0.022735  0.026225  0.029335
.17000E-07     1.000     1.000     3.500.21000E-06     1.000     1.000     2.000
C
C CONDUCTOR
C       R1        R2        R3        R4        R5        R6        R7
C       RC        UC       UI1       EI1        RS        US       UI2       EI2
  0.003175  0.012540  0.022735  0.026225  0.029335
.17000E-07     1.000     1.000     3.500.21000E-06     1.000     1.000     2.000
C
C
C    VERT1    HORIZ1     VERT2    HORIZ2     VERT3    HORIZ3     . . .
     1.100     0.000     1.100     0.250     1.100     0.500
C
C        REARTH            FREQ
C        REARTH            FREQ IDEC IPNT   DIST2
   0.250000E+03   0.100000E+04
.FIT-S
   0.250000E+03   0.100000E+00    8   10  1000.0
BLANK CARD ENDING FREQUENCY CARDS
BLANK CARD ENDING CABLE CONSTANT DATA CASE
BEGIN NEW DATA CASE
BLANK
```

6 Cababilities of the CABLE-PARAMETERS Module

6.1 Introduction

The cable parameters module calculates the resistance, inductance, and capacitance matrices for an arbitrary configuration of single-core (SC) coaxial cables. A pipe-type configuration, where the aforementioned SC coaxial cables are all enclosed in a conducting pipe, is also allowed. Line constants for conventional overhead transmission lines can also be calculated using "CABLE PARAMETERS": this calculation is completely independent of the "LINE CONSTANTS" routine of Section 9.

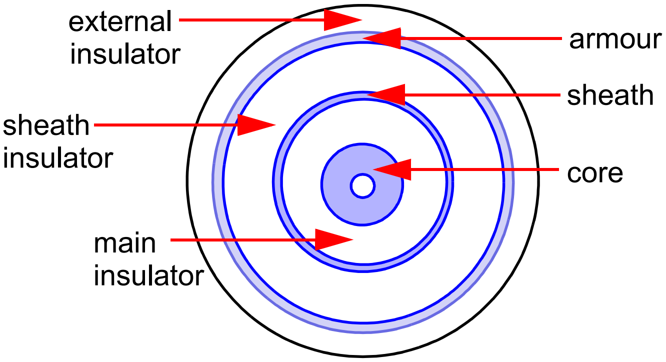


Figure 1: Cross-Section of Most General SC Coaxial Cable Geometry

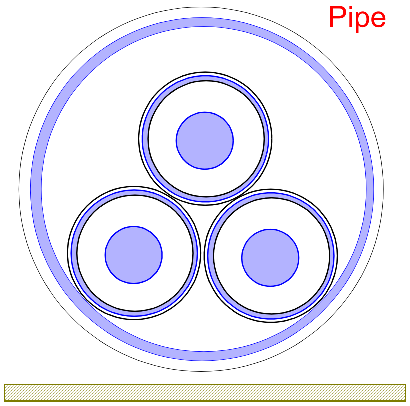


Figure 2: Illustrative Cross-Section of 0verhead Pipe-Type Cable System which contains three SC coaxial cables

The "CABLE PARAMETERS" (formerly CABLE CONSTANTS) module of the EMTP was superseded with the "CABLE-MODEL" module (version 3.0 and higher). However, since "CABLE-PARAMETERS" still has some little-used capabilities such as stratified earth modelling, it has not been removed from AUX at this point in time.

6.2 General Structure of "CABLE-PARAMETERS" Data Cards

There are classes of cables considered in the "CABLE PARAMETERS" module:

Class A	A system of single-core coaxial cables without any enclosing pipe.

Class B	A system of single-core coaxial cables within an enclosing pipe.
Class C	A system of conventional overhead conductors.

Class A Data Structure:

This is the case of a system of single-core coaxial cables that have no conducting-pipe enclosure. The input data structure for this class is as follows:

A1 First comes a "BEGIN NEW DATA CASE" card, followed by a "CABLE CONSTANTS" request card.

A2 Next comes a "CABLE PARAMETERS" request card.

A3 Next comes miscellaneous data card.

A4 Next comes one (or possibly more) cards upon which is punched the number of conductors which make up each SC coaxial cable of the system. One card will suffice for a system of up to sixteen cables; two cards are required for 17–32 cables, etc.

A5 Next come two (or possibly three) cards of geometrical and physical data for each SC coaxial cable in the system, e.g,. for three SC coaxial cables, a maximum of nine cards are required.

A6 Next comes one (or possibly more) card(s) which gives the horizontal and vertical location of the centres of all SC coaxial cables in the system. A single card can handle up to four SC coaxial cables; two cards are required for 5–8, etc.

A7 Next comes a frequency card, which specifies a new earth resistivity and frequency (or range of frequencies) for which cable constants are to be calculated.

A8 Only if the stratified earth modelling is being used for an overhead cable system, two additional cards are required, to give all parameters of this more complex earth model. If the earth is instead modelled as homogenous, no such cards exist.

A9 Repeat the data of Point A7 and Point A8 for as many different discrete frequencies or frequency ranges as desired. Signal the end of such data by means of a blank card.

A10 Repeat the data of Points A2-A9 as often as may be desired. Each of such grouping is a separate, distinct, independent data case within the "CABLE PARAMETERS" routine. Signal the end of such data by means of a blank card, which transfers control back to the main AUX module, ready to read in a new AUX data case.

Class B Data Structure

This is the case of a system of SC coaxial cables which are all enclosed by a conducting pipe. The input data structure for this class is as follows:

B1 First comes a "BEGIN NEW DATA CASE" card, followed by a "CABLE CONSTANTS" request card.

B2 Next comes a "CABLE PARAMETERS" request card.

B3 Next comes a miscellaneous data card.

B4 Next will come one card which gives parameters of the pipe.

B5 Next will come one (or possibly more) card(s) which specifies the location of each SC coaxial cable within the pipe. One card will suffice for up to four SC coaxial cables, two will be required for 5–8 SC coaxial cables, etc.

B6 Next comes one (or possibly more) card(s) upon which is punched the number of conductors which make up each SC coaxial cable of the system. One card will suffice for a system of up to sixteen cables; two cards are required for 17–32 cables, etc.

B7 Next come two (or possibly more) card(s) of geometrical and physical data for each SC coaxial cable in the system, e.g., for three SC coaxial cables, a maximum of nine cards are required.

B8 Next comes one card which gives the horizontal and vertical location of the centre of the pipe.

B9 Next comes a frequency card, which specifies a new earth resistivity and frequency (or range of frequencies) for which cable constants are to be calculated.

B10 Only if the stratified earth modelling is being used for an overhead cable system, two additional cards are required, to give all parameters of this more complex earth model. If the earth is instead modelled as homogeneous, no such cards exist.

B11 Repeat the data of Point B9 and Point B10, for as many different discrete frequencies or frequency ranges as desired. Signal the end of such data by means of a blank card.

B12 Repeat the data of Points B2-B9 as often as may be desired. Each of such grouping is a separate, distinct, independent data case within the "CABLE PARAMETERS" routine. Signal the end of such data by means of a blank card, which transfers control back to the main AUX module, ready to read a new AUX data case.

Class C Data Structure

This is the case of a system of conventional overhead conductors, as is usually solved using the "LINE CONSTANTS" routine of Section 9. The input data structure for this class is as follows:

C1 First comes a "BEGIN NEW DATA CASE" card, followed by a "CABLE CONSTANTS" request card

C2 Next comes a "CABLE PARAMETERS" request card.

C3 Next comes a miscellaneous data card.

C4 Next come three cards for each circuit which belongs to the overhead conductor system. Parameters specified include the number of phases, the number of ground wires, the number of conductors in a bundle, geometrical data, conductor resistivity, etc., e.g., considering a system which consists of a single-circuit 500-kV transmission line and a double-circuit 230-kV transmission line all on the same right-of-way, nine data cards would be involved.

C5 Next comes one (or possibly more) data card(s) which gives the height, sag, and horizontal location for the centre of each bundle of each circuit of the system. One card will suffice for 1 or 2 bundles, two cards are required for 3 or 4 bundles, etc., e.g., two coupled single circuits, each of which is supported by its own towers and has a single ground wire, would require four cards (because there are eight bundles total -- four for each circuit).

C6 Next comes a frequency card, which specifies a new earth resistivity and frequency (or range of frequencies) for which line constants are to be calculated.

C7 Only if the 3−layer Nakagawa stratified earth model is being used, two additional cards are required, to complete the parameters of this more complex model of the earth. If the earth should instead be modelled as homogeneous, no such cards exist.

C8 Repeat the data of Point C6 and C7 for as many different discrete frequencies or frequency ranges as may be desired. Signal the end of such data by means of a blank card.

C9 Repeat the data of Points C2-C9 as often as may be desired. Each of such grouping is a separate, distinct, independent data case within the "CABLE PARAMETERS" routine. Signal the end of such data by means of a blank card, which serves to transfer control back to the main AUX module, ready to ready a new AUX data case.

7 Data Entry Rules for CABLE-PARAMETERS

The preceding section outlined the structure of a "CABLE PARAMETERS" data case in general terms. The format and meaning of the associated data cards are now described in detail. Unscaled MKS units are consistently used throughout, it may be noted (e.g., distance in meters, voltage in volts, capacitance in farads, etc.).

7.1 Format for "A2", "B2", and "C2" Data

The data cards of Points A1-A2, B1-B2 and C1-C2 have the following format:

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
BEGIN NEW DATA CASE
```

Followed by

```
         1          2         3         4         5         6           7         8
123456789012345  67890123456789012345678901234567890123456789012  34  5678901234567890
```

CABLE CONSTANTS		N	
A15		I2	

N (63-64) = –1 Transmission line (C2 data).

= 0 Excluding pipe, the majority of cables have two or less conductors (B2 or A2 data).

= +1 Excluding pipe, the majority of cables have more than 2 conductors (B2 or A2 data).

```
         1          2         3         4         5         6         7          8
12345678901234567  8901234567890123456789012345678901234567890  12345  67890
```

CABLE-PARAMETERS		IPCH	IRUN
A17		I5	I5

CABLE-PARAMETERS (1-17)	Keyword.	
IPCH (71-75)	Flag to control the storage of input data files, after input format conversion has been completed. Converted data files are stored into the standard "punch" file.	
	= 0	Do not store converted input data file (only if IRUN = 1).
	= 1	Store converted input data file into punch file IRUN.
IRUN (76-80)	Flag to control program execution after input format conversion.	
	= 0	Do not run AUX after input data file has been converted and stored into the punch file.
	= 1	Run AUX after data conversion is completed, whether or not storage of the converted input data file is requested. *Note that if both IRUN = 1 and IPCH = 1, then any punched output which results from an AUX run (e.g., punched file for an FDQ model) will be appended to the record of the converted input data file.*

7.2 Format for "A3", "B3", and "C3" Data

The miscellaneous data card of Points A3, B3 and C3 has the following format:

12345	1 67890	12345	2 67890	12345	3 67890	12345	4 67890	12345	5 6 7 8 67890123456789012345678901234567890
ITYPEC	ISYST	NPC	IEARH	KMODE	IZFLAG	IYFLAF	NPP	NGRND	
I5	I5	I5	I5	I5	I5	I5	I5	I5	

ITYPEC (1-5)	Flag which indicates the class of data case which is presently being created.	
IPCH (71-75)	CLASS A:	ITYPE = 2, which implies a system of SC coaxial cables without any surrounding pipe.
	CLASS B:	ITYPE = 3, which implies a system of SC coaxial cables which are enclosed within a conducting pipe.

CLASS C: ITYPE = 1, which implies a system of conventional overhead conductors.

ISYST (6-10) For CLASS A and CLASS B cases "ISYST" indicates whether the cable system is underground or in the air.

= –1 Underground (buried) cable system.

= 0 Cable system is in the air, but is touching the earth's surface. See further comment elsewhere.

= +1 Cable system is in the air, above the surface of the earth.

For CLASS C cases, "ISYST" indicates possible transposition:

= 0 Untransposed overhead line.

= 2 Continuously-transposed overhead line.

NPC (11-15) CLASSES A and B Number of SC coaxial cables which make up the system of interest.

CLASS C The number of transmission circuits which make up the overhead system of interest, e.g., the most common case will have just NPC=1 circuit, which consists of three phase-conductor bundles (for a 3-phase line) and possibly one or more ground-wire bundles

IEARTH (16-20) Flag indicating which model for the earth is to be used:

= 0 for homogeneous (Carson) earth model.

= 99 for 3-layer stratified (Nakagawa) earth model. This is allowed only for overhead systems (miscellaneous data parameter "ISYST" equal to 0 or 1).

KMODE (21-25) Flag used to request the calculation and output of various modal quantities of interest, as described later.

= 0 No modal calculation or output.

= 1 Modal quantities will be calculated and printed during the calculation at individual frequencies. If the automatic looping is requested (see Section 7.10). These quantities are calculated but not printed.

= 2 Print modal quantities during automatic frequency looping.

IZFLAG (26-30) Flag which indicates the format of series-impedance output (inductance or reactance or both) in the phase domain.

= –1 Don't print anything.

= 0 Print matrices [R] and [L].

	= 1	Print matrices [R] and ω[L].
	= 2	Print both of the above.

The diagonal elements are self-impedances of the conductors and the off-diagonal elements are the mutual impedances. For overhead lines, the order of the printout is the same as that of the phase conductors entered. For SC coaxial cables, the printout starts from the inner-most conductor of each cable in the order of input, then continues to the next outer layer of the conductor of each cable, etc. For a pipe-type cable system, the last series-impedance in the printout is for the pipe.

IYFLAG (31-35) Flag which indicates the format of shunt-admittance output (capacitance, or susceptance, or both) in the phase domain.

	= –1	Don't print anything.
	= 0	Print matrices [G] and [C].
	= 1	Print matrices [G] and ω[C].
	= 2	Print both of the above.

The order of this printout is same as that for the series-impedance.

NPP (36-40)	CLASSES A & C	Unused (leave blank).
	CLASS B	
	= 1	finite pipe thickness.
	= 2	pipe of infinite thickness. Miscellaneous data parameter "ISYST" must also be zero, in this case.

NGRND (41-45) This parameter describes the grounding conditions of the cable system, i.e., for data in Class A and Class B.

	CLASS A	
	= 0 or 1	None of the conductors is grounding.
	= 2	All armours, if any, are grounded.
	= 3	sheaths and armours, if any are grounded.
	= 4	See note below.
	CLASS B	
	= 0	None of the conductors is grounded.
	= 1	The pipe is grounded.
	= 2	All armours and pipe are grounded.

= 3 All armours and all sheaths, if any, and pipe are grounded.

= 4 See note below.

CLASS C Leave blank.

Note: If the grounding conditions are different for different cables in the system, or not all the outer conductors of the cables are grounded, set NGRND = 4 and add one extra data card with the format: 2X,78I1 right before the frequency card(s). (See Section 7.10.)

Input an integer code number (I1), based on the following rules, for each of the cables according to their input ordering; and enter the pipe, if any, in the very last entry.

For all cables excluding pipe:

ngrnd = 0 None of the conductors of the cable is grounded.

= 1 The core of cable is grounded.

= 2 The sheath of the cable is grounded

= 3 The armour of the cable is grounded.

= 4 The sheath and the armour of the cable are grounded.

= 5 The core and the sheath of the cable are grounded.

= 6 The core and the armour of the cable are grounded.

= 7 The core, the sheath, and the armour of the cable are grounded.

For pipes only:

NGRND = 0 Not grounded.

= 1 Grounded.

7.3 Format for "A4" and "B6" Data

For cable systems (either Class A or Class B), the number of conductors which make up each SC coaxial cable of the system must be indicated; the following format is used:

```
          1           2           3           4          5         6         7         8
12345 67890 12345 67890 12345 67890 12345 67890 1234567890123456789012345678901234567890
```

NCPP1	NCPP2	NCPP3	NCPP4	NCPP5	NCPP6	NCPP7	NCPP8	• • •
I5	I5	I5	I5	I5	I5	I5	I5	

$NCPP_K$ The k-th SC coaxial cable of the system has this many conductors in it:

= 3 For the SC coaxial cable which has all three conductors: core, sheath and armour.

= 2 for the SC coaxial cable which has only two conductors: core and sheath.

= 1 for the situation of a core only.

For purposes of this input, it may be noted that the SC coaxial cables have been numbered between "1" and "NPC". Such numbering is arbitrary, except that the string of $NCPP_k$ must be non-increasing (that is, all 3-conductor SC coaxial cables must precede any 20-conductor cables and all 2–conductor cables must precede any core-only cables). This ordering, once established, is applied to the rest of the data case.

7.4 Format for "B4" Data

Point B4 data consists of a single card, upon which the user is to punch various parameters of the pipe. The following format applies:

```
                    2          3          4          5          6          7          8
1234567890 1234567890 1234567890 1234567890 1234567890 1234567890 1234567890 1234567890
```

RP1	RP2	RP3	ρ	μr	ε1	ε2	
E10.1	E10.1	E10.1	E10.1	E10.1	E10.1	E10.1	

RP_1 (1-10)	Inner radius of the pipe, in units of meters.
RP_2 (11-20)	Outer radius of the pipe, in units of meters.
RP_3 (21-30)	Outer radius of the tubular insulator which surrounds the pipe, in units of meters.
ρ (31-40)	Resistivity of the pipe, in units of ohm-meters.
μ_r (41-50)	Relative permeability of the pipe. This is a dimensionless number: the ratio of the permeability of the pipe to the permeability of free space.

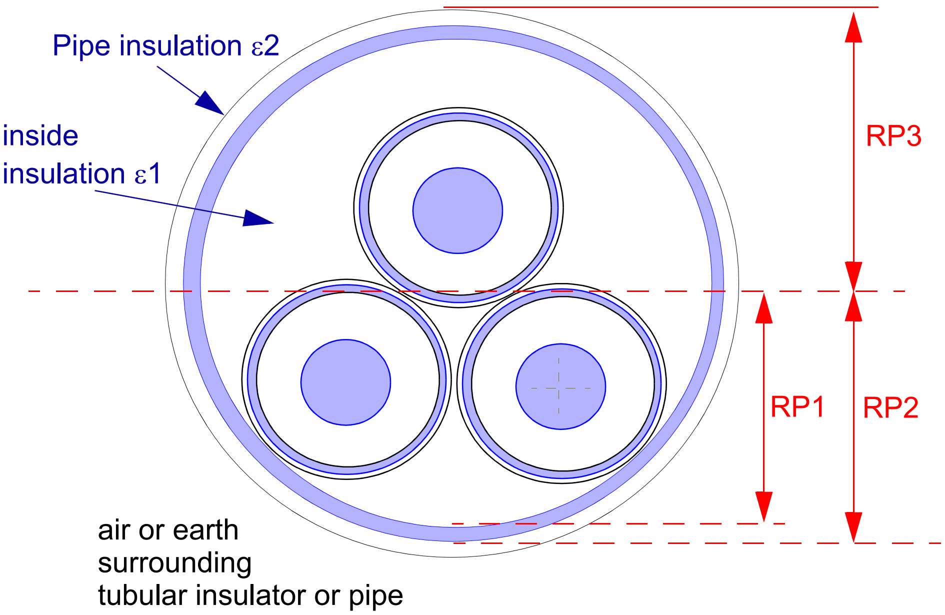


Figure 3: Cross-Section of a Pipe-Type Cable

ε_1 (51-60)	Relative permittivity of the insulating medium which is inside the pipe (between the pipe and SC coaxial cables which are contained). This is a dimensionless quantity: the ratio of the permittivity of the inner insulating medium to the permittivity of free space.
ε_2 (61-70)	Relative permittivity of the insulating tube which surrounds the pipe. This is a dimensionless quantity.

7.5 Format for "C4" Data

For each circuit of the system of conventional overhead conductors which is being studied, three data cards of the following format are to be punched.

```
         1         2         3         4         5         6         7         8
1234567890 1234567890 1234567890 1234567890 1234567890123456789012345678901234567890
```

NP	NG	KBP	KBG	
I5	I5	I5	I5	

NP (1-5)	The number of phase-wire bundles which belong to the circuit in question, e.g., for a 3–phase circuit, "NP" will equal three.
NG (6-10)	The number of ground-wire bundles which belong to the circuit in question.
KBP (11-15)	The number of individual physical conductors which compose each phase-wire bundle of the circuit in question. If there is no bundling of phase wires, "KBP" will equal unity.
KBG (16-20)	The number of individual physical conductors which compose each ground-wire bundle of the circuit in question. If there is no bundling of ground wires, "KBG" will equal unity.

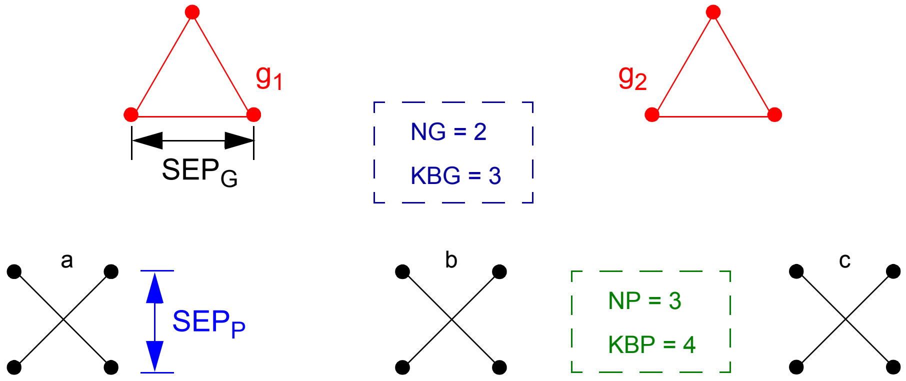
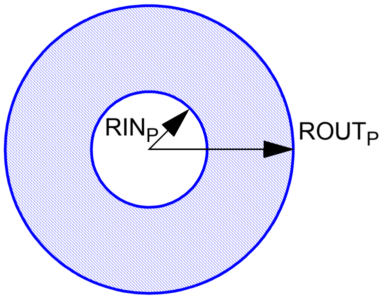


Figure 4: Illustrative single-circuit 3-phase overhead transmission line (as seen in cross-section). The three phase-wire bundles are of four conductors each; there are two ground-wire bundles, of three conductors each.

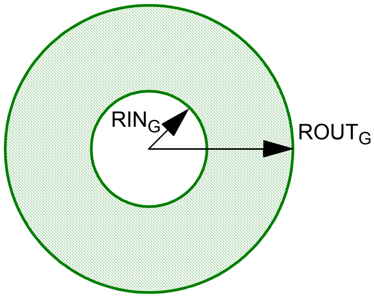
```
         1          2          3          4          5          6          7         8
1234567890 1234567890 1234567890 1234567890 1234567890 1234567890 12345678901234567890
```

ROUTP	RINP	ROUTG	RING	SEPP	SEPG	
E10.1	E10.1	E10.1	E10.1	E10.1	E10.1	

ROUT$_p$ (1-10)	Outer radius of the tubular conductors which are used for each phase-wire bundle of the circuit in question. Units are meters.



RIN$_p$ (11-20)	Inner radius of the tubular conductors which are used for each phase-wire bundle of the circuit in question. Units are meters.
ROUT$_G$ (21-30)	Outer radius of the tubular conductors which are used for each ground-wire bundle of the circuit in question. Units are meters.



RIN$_G$ (31-40)	Inner radius of the tubular conductors which are used for each ground-wire bundle of the circuit in question. Units are meters.
SEP$_P$ (41-50)	Separation between centres of two adjacent conductors of any one of the phase-wire bundles. Units are meters. The "KBP" conductors of the bundle are assumed to be uniformly spaced around the circumference of a circle.

SEP_G
(51-60)
Separation between centres of two adjacent conductors of any one of the ground-wire bundles. Units are meters. The "KBG" conductors of the bundle are assumed to be uniformly spaced around the circumference of a circle.

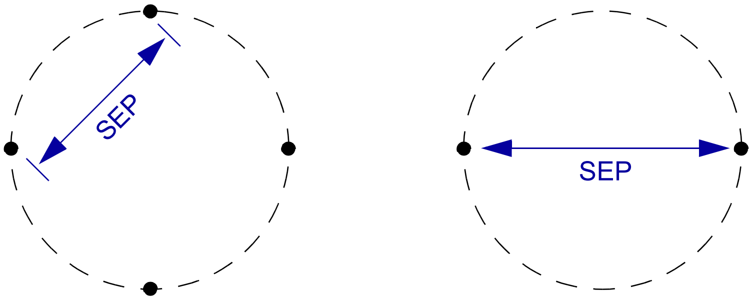


Figure 5: Illustration of two different bundles; that on the left has four conductors, while the bundle on the right has only two. Note the uniform spacing.

ρ_p
(1-10)
Resistivity of the material used in each tubular conductor of each phase-wire bundle of the circuit under consideration. Units are ohm-meters.

1 1234567890	2 1234567890	3 1234567890	4 1234567890	5 6 7 8 1234567890123456789012345678901234567890
ρp	μp	ρg	μg	
E10.1	E10.1	E10.1	E10.1	

ρ_p
(1-10)
Resistivity of the material used in each tubular conductor of each phase-wire bundle of the circuit under consideration. Units are ohm-meters.

μ_p
(11-20)
Relative permeability of the material used in each tubular conductor of each phase-wire bundle of the circuit under consideration. This is a dimensionless quantity.

ρ_G
(21-30)
Resistivity of the material which is used in each tubular conductor of each ground-wire bundle of the circuit under consideration. Units are ohm-meters.

μ_G (31-40)	Relative permeability of the material which is used in each tabular conductor of each ground-wire bundle of the circuit under consideration. This is a dimensionless quantity.

7.6 Format for "A5" and "B7" Data

For each SC coaxial cable of the system, a maximum of three data cards are to be punched according to the following format. Such cards are to be stacked in the circuit order which was defined for Point "A4" data.

```
         1         2         3         4         5         6         7         8
1234567890 1234567890 1234567890 1234567890 1234567890 1234567890 1234567890 1234567890
```

r1	r2	r3	r4	r5	r6	r7	
E10.1	E10.1	E10.1	E10.1	E10.1	E10.1	E10.1	

r_1 (1-10)	Inner radius of the tubular core, for the SC coaxial cable under consideration. Units are meters.
r_2 (11-20)	Outer radius of the tubular core (equal to the inner radius of the first insulating layer), for the SC coaxial cable under consideration. Units are meters.
r_3 (21-30)	Inner radius of the sheath (equal to the outer radius of the first insulating layer), for the SC coaxial cable under consideration. Units are meters.
r_4 (31-40)	Outer radius of the sheath (equal to the inner radius of the second insulating layer), for the SC coaxial cable under consideration. Units are meters.
r_5 (41-50)	Inner radius of the armour (equal to the outer radius of the second insulating layer), for the SC coaxial cable under consideration. Units are meters.
r_6 (51-60)	Outer radius of the armour (equal to the inner radius of the third insulating layer), for the SC coaxial cable under consideration. Units are meters.
r_7 (61-70)	Outer radius of the third (outer-most) layer of insulation, for the SC coaxial cable under consideration. Units are meters.

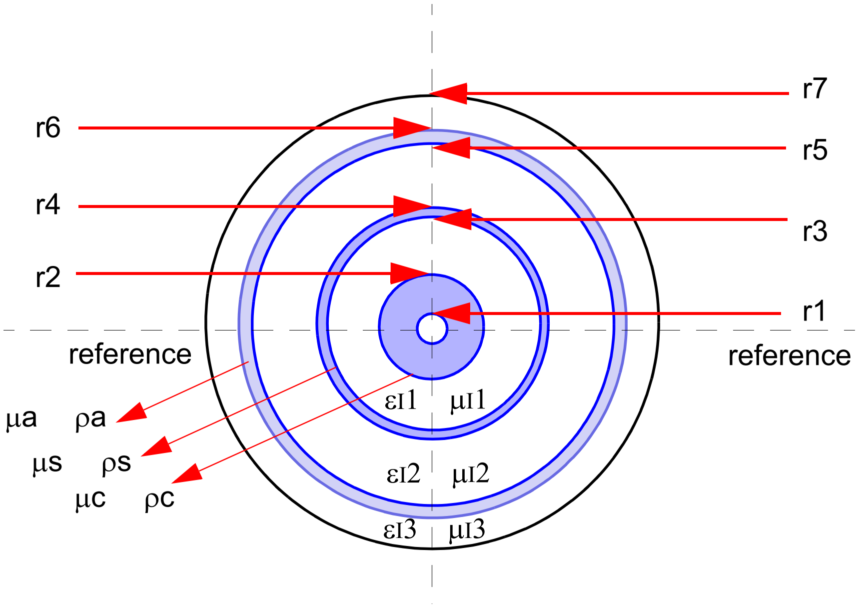


Figure 6: Cross-Section of an SC Coaxial Cable

1 1234567890	2 1234567890	3 1234567890	4 1234567890	5 1234567890	6 1234567890	7 1234567890	8 1234567890
ρc	μc	μi1	εi1	ρs	μs	μi2	εi2
E10.1	E10.1	E10.1	E10.1	E10.1	E10.1	E10.1	E10.0

ρ_c (1-10)	Resistivity of the tubular core, for the SC coaxial cable under consideration. Units are ohm-meters.
μ_c (11-20)	Relative permeability of the tubular core, for the SC coaxial cable under consideration. This is a dimensionless quantity.
μ_{I1} (21-30)	Relative permeability of the first insulating layer. This is a dimensionless quantity.
ε_{I1} (31-40)	Relative permittivity of the first insulating layer. This is a dimensionless quantity.
ρ_s (41-50)	Resistivity of the tubular sheath, for the SC coaxial cable under consideration. Units are ohm-meters.

μ_S (51-60)	Relative permeability of the tubular sheath. This is a dimensionless quantity.
μ_{I2} (61-70)	Relative permeability of the second insulating layer. This is a dimensionless quantity.
ε_{I2} (71-80)	Relative permittivity of the second insulating layer. This is a dimensionless quantity.

```
         1         2         3         4         5         6         7         8
1234567890 1234567890 1234567890 1234567890 1234567890123456789012345678901234567890
```

ρa	μa	μi3	εi3	
E10.1	E10.1	E10.1	E10.1	

ρ_a (1-10)	Resistivity of the tubular armour, for the SC coaxial cable under consideration. Units are ohm-meters.
μ_a (11-20)	Relatively permeability of the tubular armour. This is a dimensionless quantity.
μ_{I3} (21-30)	Relative permeability of the third insulating layer. This is a dimensionless quantity.
ε_{I3} (31-40)	Relative permittivity of the third insulating layer. This is a dimensionless quantity.

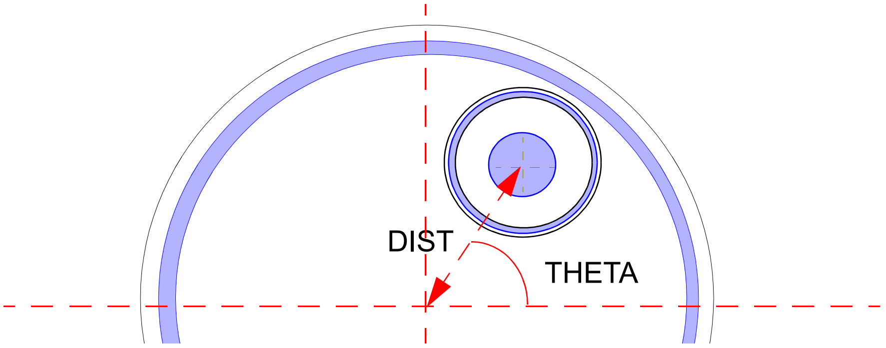
7.7 Format for "B5" Data

The location of each of the "NPC" SC coaxial cables within the surrounding conducting pipe is specified by one (or possibly more) card of the following format:

```
         1         2         3         4         5         6         7         8
1234567890 1234567890 1234567890 1234567890 1234567890 1234567890 1234567890 1234567890
```

DIST1	THETA1	DIST2	THETA2	DIST3	THETA3	DIST4	THETA4
E10.1	E10.1	E10.1	E10.1	E10.1	E10.1	E10.1	E10.1

$DIST_k$	Distance between the centre of the pipe and the centre of the k–th SC coaxial cable, in units of meters.
$THETA_k$	Angular position of the k-th SC coaxial cable, in units of degrees.



7.8 Format for "C5" Data

For each bundle of the overhead conductor system, a triplet of numbers giving the horizontal and vertical location is to be supplied, according to the following format:

1	2	3	4	5	6	7 8
1234567890	1234567890	1234567890	1234567890	1234567890	1234567890	12345678901234567890
VTOWER1	VMID1	HORIZ1	VTOWER2	VMID2	HORIZ2	
E10.1	E10.1	E10.1	E10.1	E10.1	E10.1	

$VTOWER_k$	Height above the earth's surface of the centre of the k-th bundle; this is height in meters, at the tower (the maximum height).
$VMID_k$	Height above the earth's surface of the centre of the k-th bundle; this is height in meters, at mid-span (the minimum height).
$HORIZ_k$	The centre of the k-th bundle is this far to the right of an arbitrarily chosen reference line.

With regard to the ordering of the bundles which belong to the system under study (i.e., index "k"), two rules must be observed:

Rule 1: First come all phase-wire bundles of the system, in order of the circuit number to which they belong (as established by Point C4 data), i.e., start with all phase-wire bundles of circuit number two, etc.

Rule 2: Then come all (if there are any) ground-wire bundles of the system, in order of the circuit number to which they belong (as established by Point C4 data), i.e., start with all ground-wire bundles of circuit number one, if any; then consider all of the ground-wire bundles of circuit number two, etc.

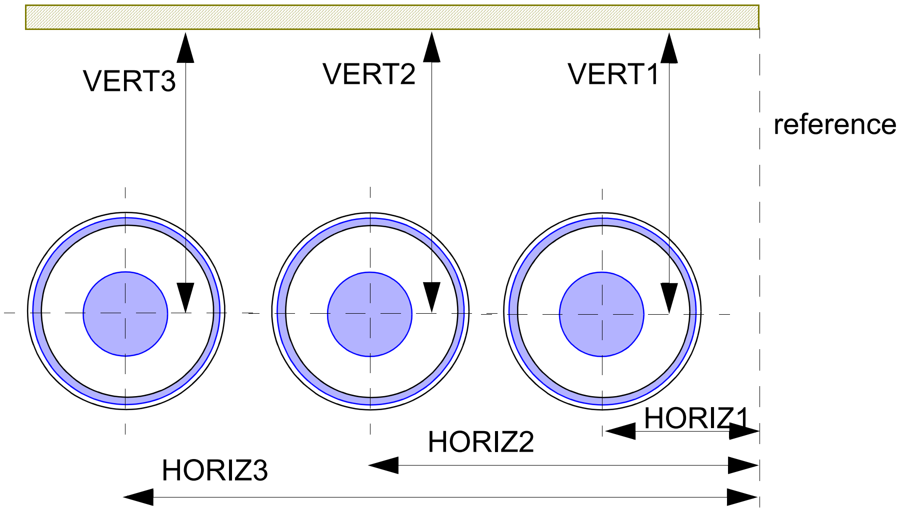
Within any one circuit, ordering of the phase-wire bundles and the ground-wire bundles is arbitrary. Rows of the resulting line constants matrices [R], [L] and [C] will be based on this ordering, however, it might be noted.

7.9 Format for "A6" Data

For each of the "NPC" SC coaxial cables of the system, horizontal and vertical coordinates which locate the centre must be specified, as follows:

1 1234567890	2 1234567890	3 1234567890	4 1234567890	5 1234567890	6 1234567890	7 1234567890	8 1234567890
VERT1	HORIZ1	VERT2	HORIZ2	VERT3	HORIZ3	VERT4	HORIZ4
E10.1	E10.1	E10.1	E10.1	E10.1	E10.1	E10.1	E10.1

VERT$_k$	Vertical separation between the centre of the k-th SC coaxial cable and the surface of the earth, in units of meters. This is always a positive number, whether the system of SC coaxial cables is below the ground or not.
HORIZ$_k$	The centre of the k-th SC coaxial cable is this far (in meters) to the right of an arbitrary reference line.



Here the ordering of the SC cables (i.e., index "k") is as established in Section 7.3.

7.10 Format for "C6", "A7", and "B9" Data

Parameters can be calculated at discrete frequencies or over automatic loops over a certain frequency range.

Discrete frequencies:

The "frequency card" of all three classes of data has the same format:

1 123456789012345	2 3 678901234567890	4 5 6 7 8 12345678901234567890123456789012345678901234567890
RHO	FREQ	
E10.1	E10.1	

RHO (1-15)	Resistivity of the top (i.e., surface) layer of the earth, in units of ohm-meters. If the earth is assumed to be homogeneous (parameter "IEARTH" equal to zero; see Section 7.2), "RHO" is the resistivity of the entire uniform earth.

FREQ (16-30)	Frequency in Hertz at which cable constants (for "A7" or "B9" data) or line constants (for "C6' data) are to be calculated, should only one frequency be desired. A blank or zero field will be defaulted to the synchronous power system frequency (generally 50 Hz or 60 Hz).

Frequency Looping:

For the automatic looping over logarithmically-spaced frequencies three cards are needed.

Card1:

1 123456789012345	2 3 678901234567890	4 5 6 7 8 12345678901234567890123456789012345678901234567890
RHO	FREQ	
E15.6	E15.6	

RHO (1-15)	Resistivity of the top (i.e., surface) layer of the earth, in units of ohm-meters. If the earth is assumed to be homogeneous (parameter "IEARTH" equal to zero; see Section 7.2), "RHO" is the resistivity of the entire uniform earth.
FREQ (16-30)	Frequency in Hz at which the transformation matrix is to be calculated.

Card 2:

Enter the keyword ".FIT-S" in columns 1-6. This will cause the transfer of control to the fitting routines of LINE CONSTANTS (see Section 9). Optionally, the user can also add the .NODES cards of LINE CONSTANTS (see Section 9).

123456	2 3 4 5 6 7 8 678901234567890123456789012345678901234567890123456789012345678901234567890
.FITS	
A6	

Card 3:

1 123456789012345	2 3 678901234567890	 12345	4 67890	 12345678	5 6 7 8 90123456789012345678901234567890
RHO	FREQ	IDEC	IPNT	DIST	
E15.6	E15.6				

RHO (1-15)	Resistivity of the top (i.e., surface) layer of the earth, in units of ohm-meters. If the earth is assumed to be homogeneous (parameter "IEARTH" equal to zero; see Section 7.2), "RHO" is the resistivity of the entire uniform earth.
FREQ (16-30)	Beginning frequency of the scan (frequency looping) Hz.
IDEC (31-35)	Number of decades of frequency space which are to be spanned during the automatic frequency looping.
IPNT (36-40)	Number of points per decade of frequency space at which [R], [L], and [C] are to be calculated. There must be 10 or a multiple of 10 (up to 90) points per decade.
DIST (41-48)	Length of transmission circuit under consideration in units of meters.

Note: The fitting of the frequency-dependent characteristic is presently available only for the untransposed circuit configuration.

7.11 Format for "C7", "A8", and "B10" Data

If the 3-layer stratified (Nakagawa) earth modelling is being used, then the just-described "frequency card" is to be immediately followed by two cards of the following format:

1 1234567890	2 1234567890	3 1234567890	4 1234567890	5 6 7 8 1234567890123456789012345678901234567890
DEP12	DEP23	RHO2	RHO3	
E10.1	E10.1	E10.1	E10.1	

1 1234567890	2 1234567890	3 1234567890	4 1234567890	5 1234567890	6 1234567890	7 8 12345678901234567890
μ_1	μ_2	μ_3	ε_1	ε_2	ε_3	
E10.1	E10.1	E10.1	E10.1	E10.1	E10.1	

DEP_{12} (1-10)	Distance below the surface of the earth at which layer number 1 ends and layer number 2 begins. Units are in meters. See sketch below.
DEP_{23} (11-20)	Distance below the surface of the earth at which layer number 2 ends and layer number 3 begins. Units are meters. Recall the layer number 3 is infinitely deep.
RHO_2 (21-30)	Resistivities of layer number 2of the earth,. Units are ohm-meters. Recall that "RHO" of the frequency card is used to specify the resistivity of layer number 1.
RHO_3 (31-40)	Resistivities of layer number 3 of the earth,. Units are ohm-meters. Recall that "RHO" of the frequency card is used to specify the resistivity of layer number 1.
μ_1 (1-10)	Relative permeability of layer number 1 of the earth. This is a dimensionless quantity.
μ_2 (11-20)	Relative permeability of layer number 2 of the earth. This is a dimensionless quantity.
μ_3 (21-30)	Relative permeability of layer number 3 of the earth,. This is a dimensionless quantity.
ε_1 (31-40)	Relative permittivity of layer number 1 of the earth. This is a dimensionless quantity.
ε_2 (41-50)	Relative permittivity of layer number 2 of the earth. This is a dimensionless quantity.
ε_3 (51-60)	Relative permittivity of layer number 3 of the earthy. This is a dimensionless quantity.

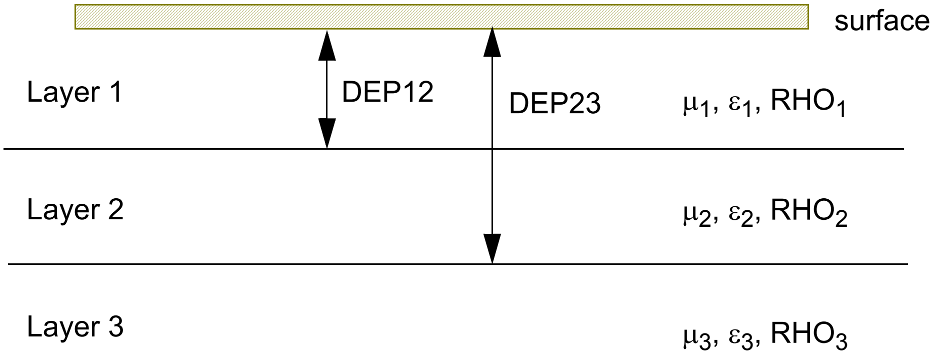


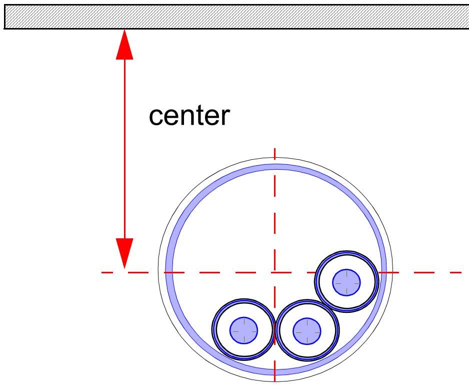
Figure 7: Stratofoed Earth Model

7.12 Format for "B8" Data

The vertical distance between the centre of the pipe (which enclosed the SC coaxial cables) is to be punched according to the following format:

1 1234567890	2 3 4 5 6 7 8 1234567890123456789012345678901234567890123456789012345678901234567890
CENTER	
E10.1	

CENTRE is always positive, whether the pipe is below the ground or not. Units are meters.



8 Degenerate Configurations and Special Cases

It is the purpose of the present section to describe how the user of "CABLE-PARAMETERS" can handle special configurations which are less general than those described in Section 7. The topics covered are as follows:

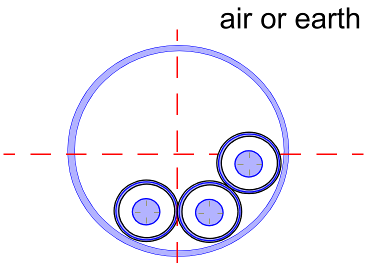
Pipe Without Tubular Insulator Around It
Infinitely-Thick Pipe
Solid Core for SC Coaxial Cable
Solid Overhead-Line Conductors
No Bundling of Conductors
SC Coaxial Cable Without Outer Insulator
SC Coaxial Cable with No Armour and Outer Insulator
SC Coaxial Cable With No Armour and No Outer Insulators
SC Coaxial Cable with No Sheath and No Outer Insulators
SC Coaxial Cable Having Core 0nly (all three insulators, armour and sheath missing)

Pipe Without Tubular Insulator Around It

Suppose that a pipe-type (Class B) configuration is involved, but without any insulating tube around the outside of the conducting pipe. Then Point B4 data is to be treated as follows:

1. Leave RP$_3$ (columns 21-30) blank.

2. Leave the data field for E$_2$ (columns 61-70) blank



Infinitely-Thick Pipe

While physically unrealizable, a pipe of infinite thickness is nonetheless useful in certain situations as a modelling approximation. This is a special case of the Class B situation. By definition, there is no earth for this case, and all zero-sequence current of the enclosed SC coaxial cables must return through the pipe. Data requirements for this special case are as follows:

1. On the Point B3 miscellaneous data card, two parameters are to be punched unusually:

   "ISYST" of columns 6–10 is to be punched zero;

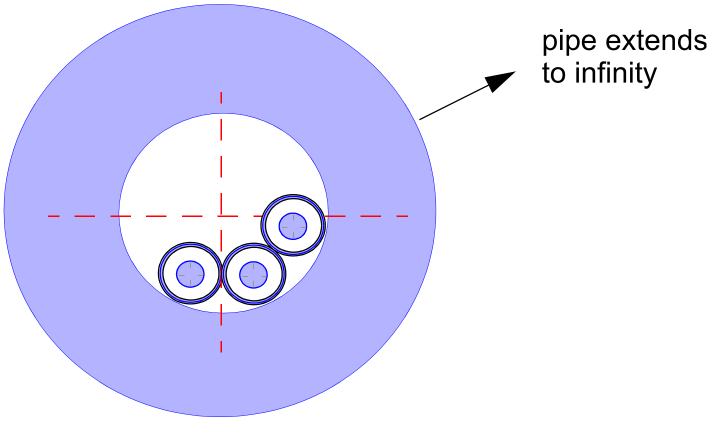
   "NPP" of columns 46-40 is to be punched zero (rather than the usual value of unity).

2. On the Point B4 data card, three data fields can be left blank:

   "RP_2" of columns 11-20 and "RP_3" of columns 21-30 --- since the outer radii of the pipe and the surrounding insulator are not even finite.

   "ε_2" of columns 61-70 --- since the surrounding insulator does not even exist (or if it does, it is infinitely far away!).

   On the "frequency card" of Point B9 data, field "RHO" of columns 16–30 can be left blank, since the earth no longer exists.



Solid Core for SC Coaxial Cable

For either Class A or Class B cable systems, the core of any SC coaxial cable can be made solid rather than tubular, if so desired. The first of two Point A5 or Point B7 data cards has columns 1-10 used for punching the inner radius r_1 of the tabular core. Simply set this parameter to zero, to produce a solid core.

Solid Overhead-Line Conductors

For a conventional overhead transmission line of Class C, the conductors of either the phase-wire bundles or the ground-wire bundles can be made solid, rather than tubular, if so desired. Recall that the second of the Point C4 data cards is punched with an inner radius RIN_p for phase-wire conductors, and RIN_G for ground-wire conductors.

1. Set RIN_p of columns 11-20 equal to zero, in order to obtain solid conductors for the phase wires.

2. Set RIN_G of columns 31-40 equal to zero, in order to obtain solid conductors for the ground wires.

No Bundling of Conductors

For a conventional overhead transmission line of Class C, it is Point C4 data which specifies whether phase-wire or ground-wire conductors are to be bundled.

1. If a phase-wire bundle only consists of a single tubular conductor (i.e., if there is no bundling of phase conductors), the "KBP" of columns 11-15 of the first Point C4 data card will be punched equal to unity, by definition. Field SEP_p of columns 41-50 of the second Point C4 data card can then be left blank -- since interconductor separation within a phase-wire bundle does not exist.

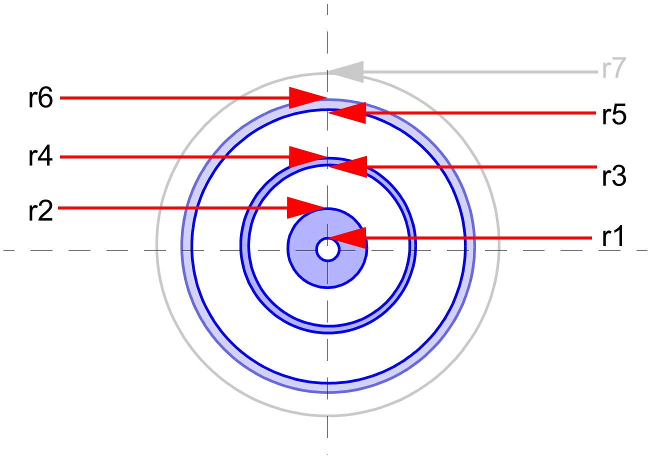
2. If a ground-wire bundle only consists of a single tubular conductor (i.e., if there is no bundling of ground conductors), then "KBG" of columns 16-20 of the first Point C4 data card will be punched equal to unity, be definition. Field SEP_G of columns 51-60 of the second Point C4 data card can then be left blank -- since interconductor separation within a ground-wire bundle does not exist.

SC Coaxial Cable Without Outer Insulator

For a Class A or Class B data case, the outer (or third) layer of insulation of any SC coaxial cable can be omitted. In this case, the three Point A5 or Point B7 data cards are handled as follows:

1. Leave r_7 (columns 61-70 of the first data card) blank.

2. Leave data fields m_{I3} and e_{I3} (columns 31-40 of the third card) blank -- since such parameters do not exist.

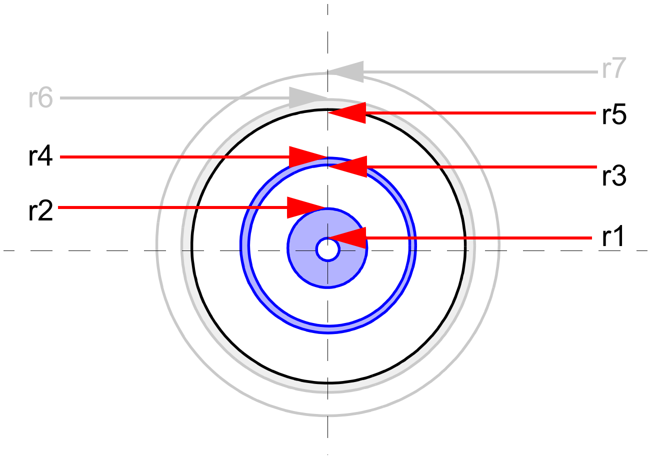


SC Coaxial Cable with No Armour and Outer Insulator

For a Class A or Class B data case, both the armour and the outer (or third) layer of insulation of any SC coaxial cable can be omitted. In this case, the three Point A5 or Point B7 data cards are handled as follows:

1. Leave r_7 and r_6 (columns 51-70 of the first card) blank.

2. Omit the third data card because of the nonexistence of r_a, mm_a, m_{I3}, and e_{I3}.

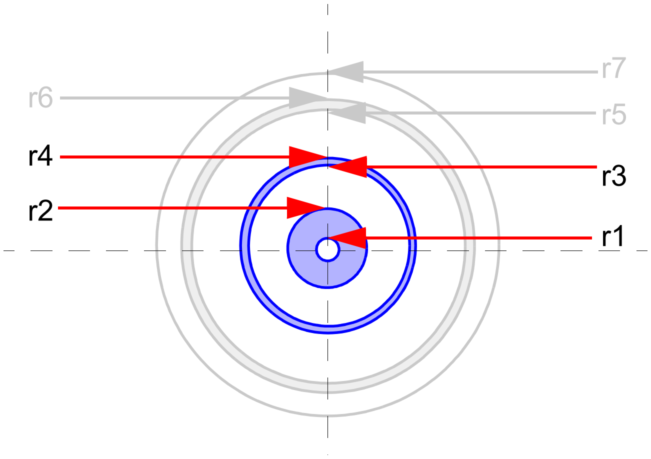


SC Coaxial Cable With No Armour and No Outer Insulators

For a Class A or Class B data case, the outer (second and third) layers of insulation and armour of any SC coaxial cable can be omitted. In this case, the three Point A5 or Point B7 data cards are handled as follows:

1. Leave r_7, r_6 and r_5 (columns 41-70 of the first card) blank.

2. Leave data fields m_{I2} and e_{I2} (columns 61-80 of the second card) blank and omit the third card -- since such parameters do not exist.



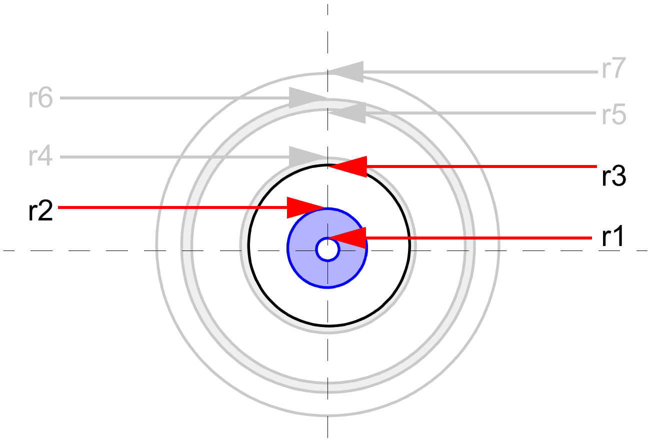
SC Coaxial Cable with No Sheath and No Outer Insulators

For a Class A or Class B data case, both the sheath, armour and the outer (second and third) layers of insulation of any SC coaxial cable can be omitted. In this case, the three Point A5 or Point B7 data cards are handled as follows:

1. Leave r_7, r_6, r_5 and r_4 (columns 31-70 of the first card) blank.

2. Leave blank all other data fields which are used for parameters of the nonexistent sheath and outer insulator. In particular, there are four: r_s, m_s, m_{I2}, and e_{I2} (columns 41-80 of the second card).

3. Omit the third card -- since parameters for armour and its outer insulator do not exist.



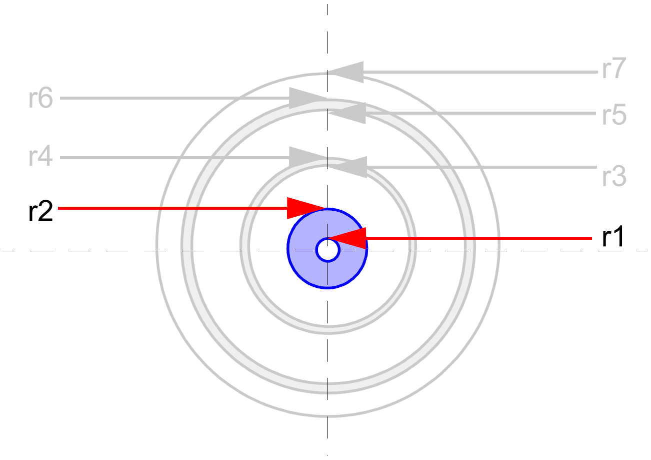
SC Coaxial Cable Having Core 0nly (all three insulators, armour and sheath missing)

For a Class A or Class B data case, the armour, sheath and all three layers of insulation of any SC coaxial cable can be omitted, leaving just the tubular conductor core. In this case, the three Point A5 or Point B7 data cards are handled as follows:

1. Leave r_7, r_6, r_5, r_4 and r_3 (columns 21-70 of the first card) blank.

2. Leave blank all other data fields which are used for parameters of the nonexistent sheath and layers of insulation. In particular, there are six: m_{I1}, e_{I1}, r_s, m_s, m_{I2}, and e_{I2} (columns 21-80 of the second card).

3. Omit the third card -- since the parameters for armour and its outer insulator do not exist.



9 Approximation Used for the Bundling of Overhead Conductors

It is important for the user to be aware that "CABLE PARAMETERS" treats bundled conductors of conventional overhead transmission lines quite differently than does "LINE CONSTANTS" of Section 9. The reader may already have realized this, since the Point C4 data is not sufficient to uniquely specify the geometry of a bundle. No angular position of any one conductor of the bundle is specified, it will be noted.

The "LINE CONSTANTS" code of Section 9 calculates line constants for the system of physical conductors first. This is then reduced, as conductors are paralleled (the bundling operation). On the other hand, "CABLE PARAMETERS" does the bundling at data-input time. The geometric mean radius of the bundle is immediately calculated, and then a single approximately equivalent conductor is used to represent each bundle for the calculation of line constants. There never is any set of line constants for the system of physical conductors, then, when using "CABLE PARAMETERS".

Needless to say, this bundling of conductors at data-input time simplifies the calculation considerably, and speeds it up. But an approximation is involved.

10 Crossbonded Cables

10.1 Introduction

It is common practice to crossbond a three-phase PV or CV cable, i.e., to wrap around single-core coaxial cable with a polyethelene or oil-immersed paper insulation, so that the circulating current within the sheaths is reduced. A schematic diagram of a crossbonded cables is given in Figure 8, below. This cable consists of 3 or more cascaded major sections. One major section consists of three minor sections as illustrated in Figure 8.

The sheaths are crossbonded at the ends of the first and second minor sections. As a common practice, the length of one minor section is between 300m and 500m, thus the length of one major section is about 1 km to 1.5 km. The sheaths of the three phases are short-circuited and grounded at the junction of each major section. Because of the existence of a resistance at the grounding point due to a poor conductivity of soil, it appears as if the sheaths are grounded through the resistance of Rs as shown in Figure 10.8.

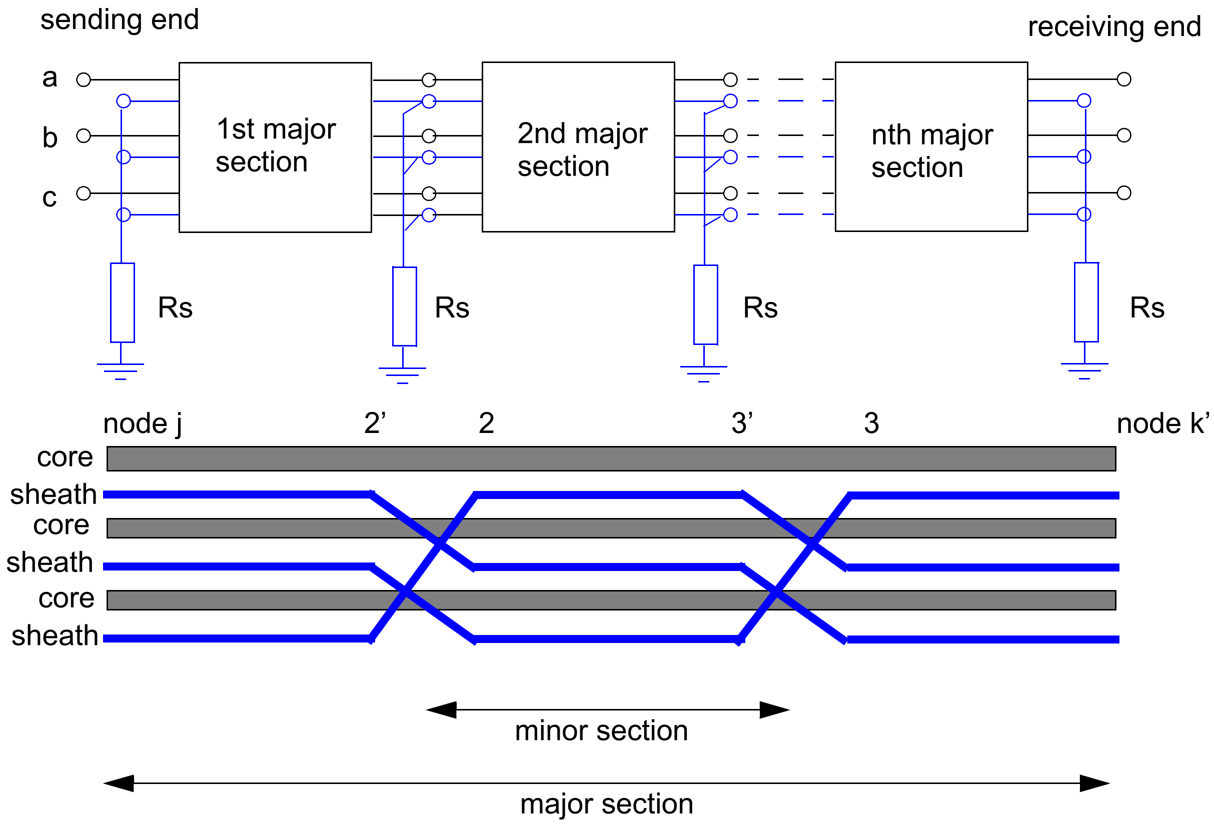


Figure 8: A Schematic Diagram of a Crossbonded Cable

At the sending and receiving ends of a cable, the resistances are lower than those at each major section, because of higher degree of grounding. (The details of grounding should be found in the standard of electrical apparatus or machinery, possibly in the ANSI.) Thus, the resistances at the sending and receiving ends are given by R's, which is different from Rs. In practice, Rs is 1 ohm to some tens ohm, and R's 0.1 ohm to 10 ohm depending on the method of grounding.

10.2 Modelling of a Crossbonded Cable

A crossbonded cable can be modelled as a uniform distributed parameter line. An equivalent circuit for one major section of the crossbonded cable is shown in Figure 9, below. Z" and Y" are the equivalent series impedance and shunt admittance respectively of one major section. Note that this equivalent circuit is a four-conductors system but not six-conductors system. This is due to the fact that the effect of the short-circuit of the three-phase sheath has been taken into account in this equivalent circuit, and thus three sheaths are reduced to one sheath. The sheath voltage in the equivalent circuit of Figure 9 is the same as the voltages of three sheaths in the original circuit of

Figure 9, and the sheath current in the equivalent circuits is the sum of the three-phase sheath currents in the original circuit.

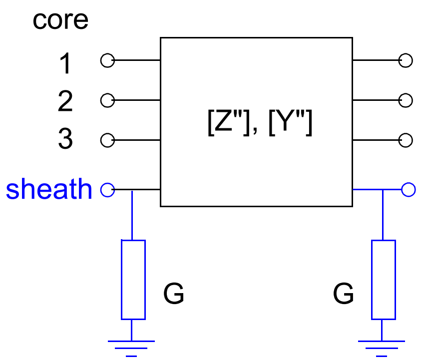


Figure 9: An Equivalent Uniform Distributed-Parameter Line for One Major Section

Also, it should be noted that the grounding conductance G is not taken into account in this equivalent circuit. Thus, the conductance G should be included as a boundary condition between two major sections.

The above equivalent circuit can be adopted to the EMTP, because it is a uniform distributed-parameter line.

A pi-circuit equivalent is quite often used to represent a distributed-parameter line, although it cannot take into account the frequency-dependent effect of the distributed-parameter line.

1. **Accurate Modelling:** Each minor section is represented by a six-phase pi-circuit, and is connected as shown in Figure 9.8. Then, each major section is connected as shown in Figure 9.8 including a grounding resistance.

2. Uniform Line Modelling: Each major section is represented by a four-phase pi-circuit of which R, L and C are given by Z" and Y" of Figure 9.9, i.e., Z" = R+ jwL and y"=jwC. Then, each major section is connected as shown in Figure 9.8 including a grounding resistance.

10.3 Data Format for Using the Crossbonded Cable Model

The data structure for the crossbonded cable model is the same as that for the usual (not crossbonded) cable (see Section 6.2), except the following two additional data cards are needed:

1. A card with "PUNCH" inputted in columns 1-5 should be put right after the "CABLE PARAMETERS" card (see "A2" and "B2" of Section 7.1).

2. Then, the following card should be inputted after the "miscellaneous data card" which was described as "A3" and "B3" data is Section 7.2.

	1		2	3		4 5 6 7 8
12345	67890	12345	6789012345	6789012345	6	7890123456789012345678901234567890123457890
NPAIS	NCROS	IRSEP	XMAJOR	RSG	CNAME	
I5	I5	I5	E10.1	E10.1	A1	

NPAIS (1-5)	Number of pi-sections a user should define except "NPAIS=0". The detailed explanation for 'NPAIS' will be given later.
NCROS (6-10)	= 0 the usual (not crossbonded) cable. ≠ 0 crossbonded cable. For the overhead like case, leave BLANK.
IRSEP (11-15)	= 0 (or blank) all the cable sheaths are short-circuited and grounded through resistance RSG between pi-sections. ≠ 0 each sheath is grounded separately from each other through resistance RSG between pi-sections. IRSEP does not apply to the overhead line case and to the cable case when "NPAIS > .0". In these cases, leave IRSEP blank.
XMAJOR (16-25)	Length of one major section for "NPAIS.LT.0" in the cable case. It is the length of one pi-section for "NPAIS.GT.0" in the cable case, and in the overhead line case. XMAJOR should equal to the total length of a cable or line divided by NPAIS, or total length = XMAJOR * NPAIS.
RSG (26-35)	Sheath grounding resistance at the end of a major section for a cable. RSG does not apply to the overhead line case, thus leave blank.
CNAME (36)	Node name of pi-circuits modelling a user should define in the case of NPAIS.NE.0. For NPAIS = 0 leave blank

More detailed explanation for NPAIS and the related variables is given here:

Case A: NPAIS ≠ 0: Data cards of a line or cable for pi-circuit modelling will be punched out.

(A-1) For the cable case (ITYPE 1):

(1-1) NPAIS.GT.0 and NCROS = 0 or BLANK: Uniform pi-circuit modelling of usual non-crossbonded cable.

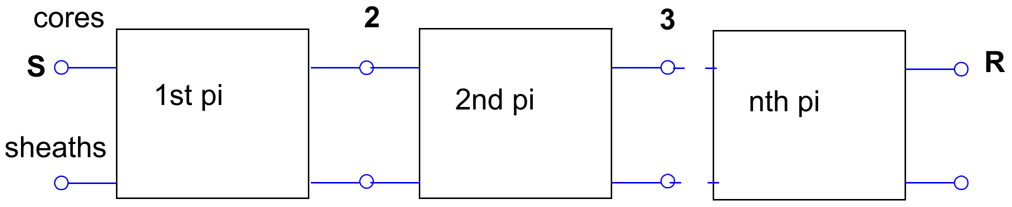


Figure 10: Uniform Pi-Circuit Modelling for a Non-Crossbonded Cable

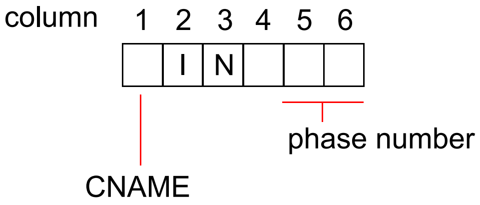
a) A user will get a cascade pi-circuit modelling shown in Figure 9.10 for a given distributed-parameter line. There is no grounding resistance and no connection other than the cascade connection between two pi–sections. Thus, IRSEP and RSG should be BLANK.

b) The number of pi-sections is given by NPAIS (n = NPAIS in Figure 10, above). NPAIS is arbitrary and thus a user should define it. But the following relation should always be satisfied:

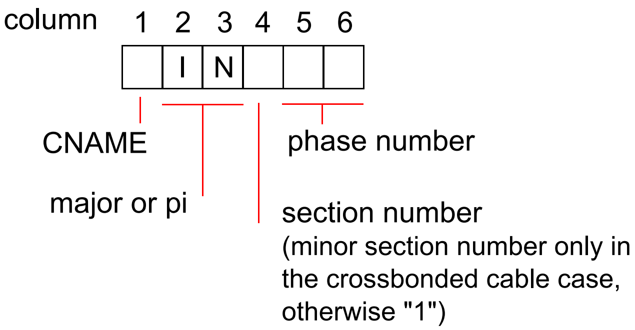
total length of a cable = NPAIS * XMAJOR

c) The user should define the node name of the pi-circuit modelling by CNAME. The data for CNAME is one alphabetic letter and is read by format "A1". Then, all the node names in this pi-circuit modelling are internally determined in the following form.

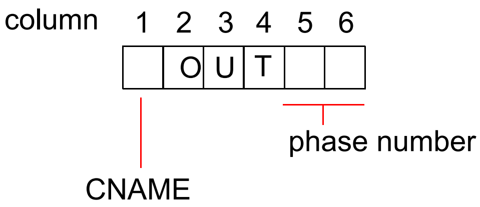
At the sending-end:



At an intermediate node:



At the receiving end:



(1-2) **NPAIS.GT.0 and NCROS = 0:** Uniform pi-circuit modelling of a crossbonded cable.

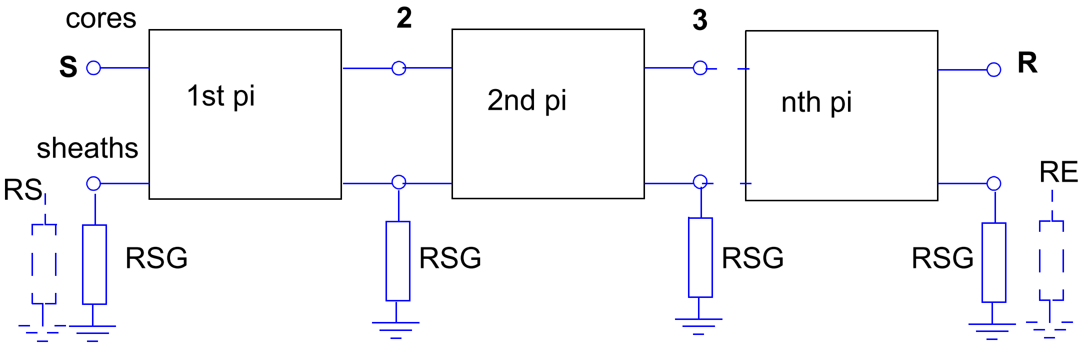


Figure 11: Uniform Pi-Circuit Modelling for a Crossbonded Cable

a) A user will get a pi-circuit modelling shown in Figure 9.11 for a given crossbonded cable. Each pi–section corresponds one major section of the crossbonded cable, and R, L and C are calculated in the method explained in Section 7. There is a grounding resistance RSG, and thus the user should define the value of RSG in his second Miscellaneous Data Card. But no need to define IRSEP because there exists only one sheath as explained in Section 7.

b) For each pi-section corresponds to one major section, the number of pi-sections not arbitrary, and should be identical to the number of the major sections in the given crossbonded cable, i.e.,

NPAIS = total length of the cable / XMAJOR

c) The user should define the node name of the pi-circuit modelling by CNAME. The data for CNAME is one alphabetic letter and is read by format "A1". Then, all the node names in this pi-circuit modelling are internally determined in the following form.

d) A user should add the parallel resistances RS and RE to the RSG at the sending- and receiving-ends as shown in Figure 11, above after he gets the punched out data cards for his pi-circuit modelling, because the grounding resistances at both ends are, in general, different from RSG. In other words, the user can get the correct grounding resistances by adding RS and RE, i.e.,

correct resistance at the sending-end = $(1/\mathrm{RSG} + 1/\mathrm{RS})^{-1}$

correct resistance at the receiving-end = $(1/\mathrm{RSG} + 1/\mathrm{RE})^{-1}$

(2-1) NPAIS.LT.0 and NCROS = 0 or BLANK: Discrete pi-circuit modelling of a usual cable

a) A user will get a pi-circuit modelling shown in Figure 12 below (which is the same as Figure 11 in fact) for a given cable. Each pi-circuit corresponds to one major section of the cable. There is a grounding resistance RSG, and thus, the user should define the value of RSG. Also, IRSEP should be defined, although, in most practical cases, the sheaths are short-circuited and grounded, i.e., "IRSEP = 0".

b) For each pi-section corresponds to one major section, the number of pi-sections not arbitrary, and should be identical to the number of the major sections in the given crossbonded cable, i.e.,

NPAIS = total length of the cable / XMAJOR

c) The user should define the node name of the pi-circuit modelling by CNAME. The data for CNAME is one alphabetic letter and is read by format "A1". Then, all the node names in this pi-circuit modelling are internally determined in the following form.

d) A user should add the parallel resistances RS and RE to the RSG at the sending- and receiving-ends as shown in Figure 11 after he gets the punched out data cards for his pi-circuit modelling, because the grounding resistances at both ends are, in general, different from RSG. In other words, the user can get the correct grounding resistances by adding RS and RE, i.e.,

correct resistance at the sending-end = $(1/\text{RSG} + 1/\text{RS})^{-1}$

correct resistance at the receiving-end = $(1/\text{RSG} + 1/\text{RE})^{-1}$

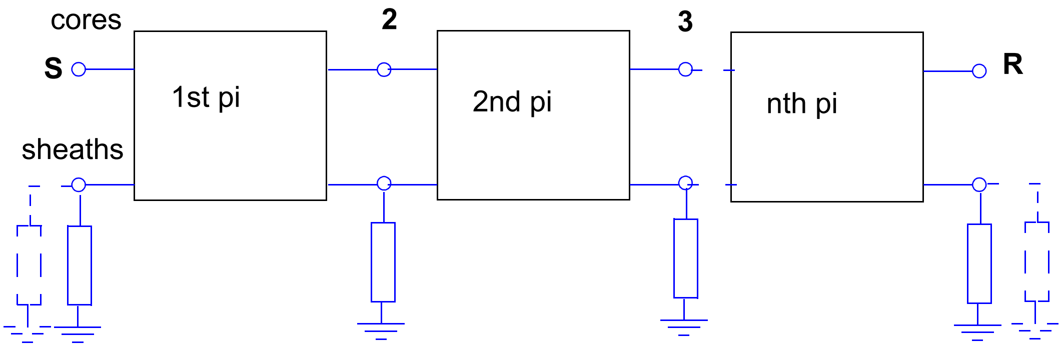


Figure 12: Discrete Pi-Circuit Modelling for a Usual Cable

(2-2) **NPAIS.LT.0 and NCROS ≠ 0:** Discrete pi-circuit modelling of a crossbonded cable

a) In this case, a user will get a pi-circuit modelling shown in Figure 10.13, below. One major section consists of three pi-circuits, of which each pi-circuit corresponds to one minor section. Within one major section, crossbonding of three-phase sheaths are carried out. Since there is a grounding resistance, the user should define its value. Also, IRSEP should be defined.

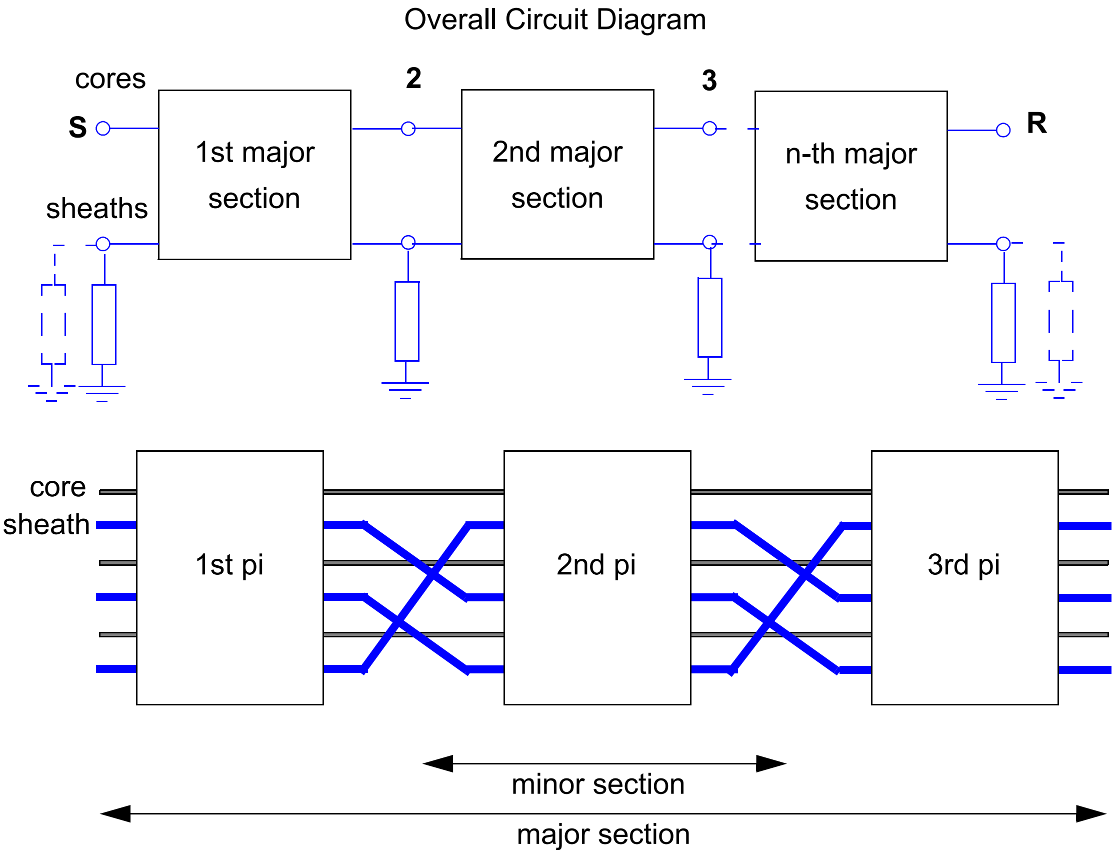


Figure 13: Discrete Pi-Circuit Modelling for a Crossbonded Cable

b) The number of major sections is given by NPAIS and is not arbitrary. The user should give the actual number of the major sections of his crossbonded cable as NPAIS in his data card, but the following condition should be kept.

total length of the cable = NPAIS * XMAJOR

c) The user should define the node name of the pi-circuit modelling by CNAME. The data for CNAME is one alphabetic letter and is read by format "A1". Then, all the node names in this pi-circuit modelling are internally determined in the following form.

d) A user should add the parallel resistances RS and RE to the RSG at the sending- and receiving-ends as shown in Figure 11 after he gets the punched out data cards for his pi-circuit modelling, because the grounding resistances at both ends are, in general, different from RSG. In other words, the user can get the correct grounding resistances by adding RS and RE, i.e.,

correct resistance at the sending-end = $(1/\mathrm{RSG} + 1/\mathrm{RS})^{-1}$

correct resistance at the receiving-end = $(1/\mathrm{RSG} + 1/\mathrm{RE})^{-1}$

(A-2) For the overhead line case (ITYPEC = 1):

In this case, NPAIS should be greater than '0' ("NPAIS.GT.0."). The model circuit configuration and the data input are the same as those explained in the case of (1-1): NCROS = 0 of (A-1) for the cable case.

Case B: NPAIS = 0 or Blank:

No data card will be punched out.

(B-1) NCROS = 0 or BLANK

In this case, a user will get exactly the same version of the CABLE PARAMETERS as that in the 1980 version. Thus, leave BLANK all the data in the second Miscellaneous Data Card.

(B-2) NCROS 0: Crossbonded Cable

This is only for the cable case (ITYPEC = 1). In this case, XMAJOR should be defined. A user will get printouts of various cable parameters for his crossbonded cable the same as those in the case of NCROS = 0.

Summarizing all the above explanation for the second Miscellaneous Data Card, the following table is obtained

NPAIS < 0	need all the data
NPAIS > 0 & NCROS ≠ 0	need all the data
NPAIS > 0 & NCROS = 0	need XMAJOR and CNAME
NPAIS = 0 & NCROS = 0	need only XMAJOR
NPAIS = 0 & NCROS ≠ 0	no data, just one BLANK card

ITYPEC = 1: NPAIS < 0 cannot be used.

11 CABLE-PARAMETERS Example

Following is an example of pi-circuit modelling of a crossbonded cable with one major section. The cable configuration is illustrated in Figure 9.14. The cable consists of core, sheath and armour. The armours are solidly grounded and the sheaths are crossbonded. To eliminate the grounded armours, NGRND (No. of solidly grounded conductors) is taken as 2. Since the cable is crossbonded, NCROS = 1 (or not equal to zero). The sheaths being short-circuited and grounded to both ends of the major section, IRSEP = 0 and RSG = 0.1 ohm.

In the same manner, one can handle cable of which the both armours (or pipe) and sheaths are grounded, using the Discrete Pi-Circuit Modelling, i.e., use NGRND for grounding the armours or pipe and ground the sheaths by RSG and IRSEP.

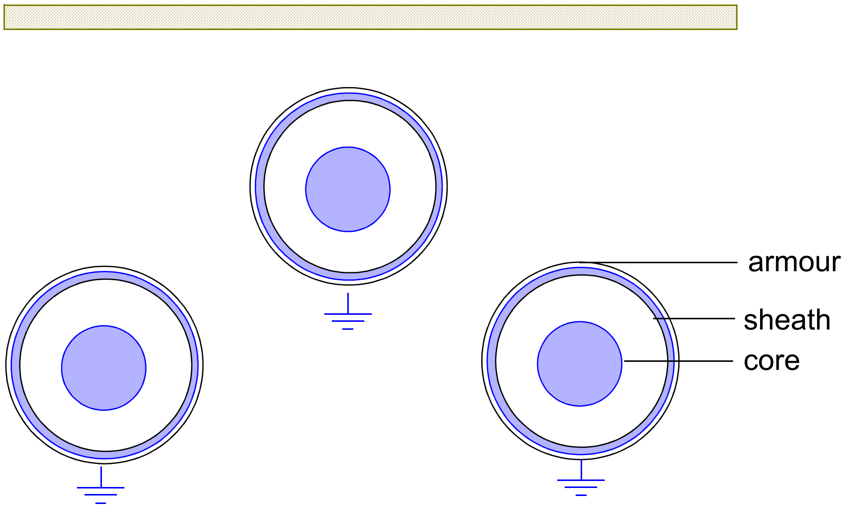


Figure 14: A Three-Phase Crossbonded Cable

First comes the listing of the data case:

```
C tcase9.dat
C
C -----------------------------------------------------------------------------
C      Cable-Parameters data case
C      TEPCO OF 275 KV CABLE ****
C
CABLE CONSTANTS
C
C
C --key--------|                                                         |<ipch<irun
CABLE-PARAMETERS
PUNCH
```

```
C
C 345678901234567890123456789012345678901234567890123456789012345678901234567890
C ITY ISYS  NPC IEAR KMOD IZFL IYFL  NPP NGRN
    2   -1    3    0    1    1    1    0    2
C
C Data for cross-bonded model
C   N    N    I         X         RC
C   P    C    R         M         SN
C   A    R    S         A         GA
C   I    O    E         J          M
C   S    S    P         R          E
   -1    1    0      1.E3     1.E-1A
C
C NPC NPCC NPCC NPCC NPCC NPCC ...
    3    3    3
C
C CONDUCTOR
C       R1        R2        R3        R4        R5        R6        R7
C       RC        UC       UI1       EI1        RS        US       UI2       EI2
  0.013200  0.024900  0.054200  0.057000  0.063000     .0660     0.720
.18900E-07     1.000     1.000     2.300     .3E-7     1.000     1.000     3.500
     .3E-7     1.000     1.000     3.500
C
C CONDUCTOR
C       R1        R2        R3        R4        R5        R6        R7
C       RC        UC       UI1       EI1        RS        US       UI2       EI2
  0.013200  0.024900  0.054200  0.057000  0.063000     .0660     0.720
.18900E-07     1.000     1.000     2.300     .3E-7     1.000     1.000     3.500
     .3E-7     1.000     1.000     3.500
C
C CONDUCTOR
C       R1        R2        R3        R4        R5        R6        R7
C       RC        UC       UI1       EI1        RS        US       UI2       EI2
  0.013200  0.024900  0.054200  0.057000  0.063000     .0660     0.720
.18900E-07     1.000     1.000     2.300     .3E-7     1.000     1.000     3.500
     .3E-7     1.000     1.000     3.500
C
C
C    VERT1    HORIZ1     VERT2    HORIZ2     VERT3    HORIZ3     . . .
     2.000     0.000    1.8095     0.110     2.000     0.220
C
C        REARTH           FREQ
C        REARTH           FREQ IDEC IPNT   DIST2
           100.          1000.
BLANK CARD ENDING FREQUENCY CARDS
BLANK CARD ENDING CABLE CONSTANT DATA CASE
BEGIN NEW DATA CASE
BLANK
```

The pi-circuit branch cards resulted on the punched file LUNIT are:

```
$VINTAGE, 1
  AIN   4                       0.10000E+00
 1AIN   1A 11 1                 0.31876E-01     0.65708E-01     0.54835E-01
 2AIN   2A 11 2                 0.32590E-04     0.51255E-05     0.00000E+00
                                0.31876E-01     0.65708E-01     0.54835E-01
 3AIN   3A 11 3                 0.32595E-04     0.51274E-05     0.00000E+00
```

```
                                       0.32590E-04     0.51255E-05     0.00000E+00
                                       0.31876E-01     0.65708E-01     0.54835E-01
 4AIN  4A 11 4                         0.10876E-01     0.92798E-02    -0.54835E-01
                                       0.32590E-04     0.51255E-05     0.00000E+00
                                       0.32595E-04     0.51274E-05     0.00000E+00
                                       0.20291E-01     0.87483E-02     0.70334E+00
 5AIN  4A 11 5                         0.32590E-04     0.51255E-05     0.00000E+00
                                       0.10876E-01     0.92798E-02    -0.54835E-01
                                       0.32590E-04     0.51255E-05     0.00000E+00
                                       0.32590E-04     0.51255E-05     0.00000E+00
                                       0.20291E-01     0.87483E-02     0.70334E+00
 6AIN  4A 11 6                         0.32595E-04     0.51274E-05     0.00000E+00
                                       0.32590E-04     0.51255E-05     0.00000E+00
                                       0.10876E-01     0.92798E-02    -0.54835E-01
                                       0.32595E-04     0.51274E-05     0.00000E+00
                                       0.32590E-04     0.51255E-05     0.00000E+00
                                       0.20291E-01     0.87483E-02     0.70334E+00
 1A 11 1A 12 1AIN  1A 11 1
 2A 11 2A 12 2
 3A 11 3A 12 3
 4A 11 6A 12 4
 5A 11 4A 12 5
 6A 11 5A 12 6
 1A 12 1AOUT 1AIN  1A 11 1
 2A 12 2AOUT 2
 3A 12 3AOUT 3
 4A 12 6AOUT 4
 5A 12 4AOUT 4
 6A 12 5AOUT 4
  AOUT 4      AIN  4
$VINTAGE, 0
```