

# Model data options in Cable Data device

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## 1 Introduction

The Cable-Model module can produce transmission cable models for steady state and for time domain studies. The following cable models are available:

- FD: Frequency dependent cable model.
- CP: Constant-parameter cable model.
- Exact-PI: Exact frequency domain representation of a cable at a given frequency, for steady state and frequency scan simulations.
- Scan: Cable model parameters are calculated at given frequencies. No model is generated.
- Wideband: wideband cable model

## 2 FD model

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  $\mathbf{Y}_c$  and  $\mathbf{A}_p$  can be diagonalized by a modal transformation matrix  $\mathbf{Q}$  (also named  $\mathbf{T}_i$ ). In the following equations matrices are denoted by bold characters.

$$\mathbf{Y}_c^2 = \frac{\mathbf{G} + j\omega\mathbf{C}}{\mathbf{R} + j\omega\mathbf{L}} = \frac{\mathbf{Y}}{\mathbf{Z}}$$

$$\mathbf{A}_p = \mathbf{e}^{-\mathbf{Y}\ell}$$

$$\mathbf{Y}^2 = (\mathbf{G} + j\omega\mathbf{C})(\mathbf{R} + j\omega\mathbf{L})$$

The matrices  $\mathbf{Y}$  and  $\mathbf{Z}$  are in phase domain, also referred to as  $\mathbf{Y}_{\text{phase}}$  and  $\mathbf{Z}_{\text{phase}}$  respectively.

The variable  $\ell$  is the cable length. The modal transformation matrix  $\mathbf{Q}$  is the eigenvector matrix that diagonalizes the product  $\mathbf{YZ}$ , that is:

$$\mathbf{Q}^{-1}\mathbf{YZQ} = \hat{\mathbf{Y}}\hat{\mathbf{Z}}$$

The hatted matrices  $\hat{\mathbf{Y}}$  and  $\hat{\mathbf{Z}}$  are modal matrices, also referred to as  $\mathbf{Y}_{\text{modal}}$  and  $\mathbf{Z}_{\text{modal}}$  respectively. It is noticed that:

$$\mathbf{Q}^t\mathbf{ZQ} = \hat{\mathbf{Z}}$$

$$\mathbf{Q}^{-1}\mathbf{Y}(\mathbf{Q}^t)^{-1} = \hat{\mathbf{Y}}$$

The same transformation matrix is used to diagonalize  $\mathbf{Y}_c$  and  $\mathbf{A}_p$ :

$$\mathbf{Q}^{-1}\mathbf{Y}_c(\mathbf{Q}^t)^{-1} = \hat{\mathbf{Y}}_c$$

$$\mathbf{Q}^{-1}\mathbf{A}_p\mathbf{Q} = \hat{\mathbf{A}}_p$$

The elements of  $\hat{\mathbf{Y}}_c$  and  $\hat{\mathbf{A}}_p$  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  $\mathbf{Q}$  is normally frequency dependent, and its elements can be approximated with frequency dependent functions, which constitutes the FDQ type of matrix option. The FDQ option should be used when the highest accuracy is desired.

The Cable Data device model tab also offers the option of using a real  $\mathbf{Q}$  (Real  $T_i$  option) matrix. It is noticed, however, that the model generated for this matrix selection of FD is not supported in the current version of EMTP.

## 2.1 FD model data file format

After entering the remaining data in the data tabs following the Model data tab, the Model Data Calculation Function can be invoked from the “Save and run this case” data tab to generate the model data file. The model can be used with the FDQ cable model (FDQ m-phase device) by selecting the model data file after clicking on the “Select data file” button for “Time-domain model data”. It can be used for steady-state and/or time-domain simulations in EMTP.

The FDQ model data file format for a sample single core configuration with 3 propagation modes is shown in Figure 2–1. This is an automatically generated data file; the information below is provided only for documentation purposes.

The following data lines are needed in the model data file:

- The first line is mandatory. It provides the model data calculation function identification, followed by the model identification (FD) and the number of phases (modes). Each mode is associated to a wire on the “FDQ m-phase” device drawing, from top to bottom.
- The following comment lines (starting with C on the first column) are not mandatory.
- The following section is for the modal characteristic admittance matrix fitting. For each mode:
  - The first line gives the number of poles.
  - The next line gives the value  $\mathbf{Y}_c$  at infinite frequency.
  - The next lines contain the residues for the above number of poles.
  - The next lines contain the poles.
  - The line following the last pole data line must be a comment line.
- The following section presents the fitting of the propagation function  $\mathbf{A}_p$ . For each mode:
  - The first line gives the number of poles.
  - The next line gives the travel time of the mode.
  - The next lines contain the residues for the above number of poles.
  - The next lines contain the poles.
  - The line following the last pole data line must be a comment line.
- Next is the fitting section of the transformation matrix elements. For each element of  $\mathbf{Q}$ :
  - The first line gives the number of poles.
  - The next line gives the value  $\mathbf{Q}$  element at infinite frequency.
  - The next lines contain the residues for the above number of poles.
  - The next lines contain the poles.
  - The line following the last pole data line must be a comment line.

```

C CABLE DATA, FD, 3
C
C FD-MODEL OF CABLE: FDQ 1.00-KM 54 66 77
C 1 2 3 4 5 6 7 8
C 3456789 1234567890 234567890 234567890 234567890 234567890 234567890 234567890
C -1 -4 3
C -2 -4 3
C -3 -4 3
C APPROXIMATION OF YC, MODE 1
18
1.8607357951373416D-02
-1.3937971157960966D-04 3.6267203118985000D-03 -3.7517641619171918D-03
7.4467277456838961D-05 -4.1333910923295469D-03 -3.1768544957906527D-03
-8.0654041151193845D-03 7.0965838802848835D-01 -7.9259834007793639D-01
-4.1863541208851268D-01 -1.1851357101648228D+00 -1.7052982116750217D+00
-4.7961114649509202D+00 -1.1377796982693127D+01 -1.3132410945140725D+01
-5.2170073529533830D+01 -1.1457625434911105D+02 -5.9357580583396509D+02
1.9852711191026812D-01 1.8323964182801558D+00 1.8573959335252079D+00
2.5521115377086261D+00 3.0884648634568044D+00 1.3814738007531481D+01
4.7552201685640476D+01 1.2404527534168361D+02 1.2546606691566328D+02
2.7666360478759123D+02 7.1511663314659131D+02 1.1098655771536889D+03
1.6264965463458188D+03 2.8338362500660792D+03 6.2065718904213327D+03
6.0174241255791785D+04 2.5745870775314243D+05 1.3101725481395524D+06
C APPROXIMATION OF YC, MODE 2
16
3.3729604218093234D-02
-1.0444087907646171D-04 -1.1971845679406990D-04 2.2604208982424504D-03
-1.2133777175785447D-02 -3.5887772863917944D-03 -3.2648825402897569D-02
-1.2122227455407096D-01 -1.8119068021255280D-01 -4.0295151002814045D-01
-7.0524809289340164D-04 -6.2962238717636474D+00 -2.1877682968228555D+01
-2.0891431113064051D+01 -3.0519392787787361D+01 -1.0073166414374413D+02
-1.0995877484610564D+03
7.2161754177056711D-02 1.8223483917813377D+00 2.8371592133921992D+00
3.6756568756863430D+00 1.4548487557318062D+01 1.8078596030677502D+01
3.3656598890586388D+01 4.1094644800646186D+01 2.9215507271350475D+02
1.7496227057111914D+03 2.1159797249289913D+03 2.9018842539650991D+03
4.6112805622411361D+03 1.8625412033119374D+04 1.2835528519417591D+05
1.3936880310587757D+06
C APPROXIMATION OF YC, MODE 3
20
2.6167494789815667D-02
-7.4646798963841568D-05 2.1242743546194863D-03 -3.8624779330200159D-03
-5.9096315094221766D-03 -7.6405774956398850D-03 1.5528240517229781D+00
-1.6361699652177533D+00 -5.0422027709210691D-02 -8.5270288610474837D-02
-2.6444020719469302D-01 -6.8509129643190636D-01 9.3439944174384693D-01
-4.5660589018960058D+00 -8.7413490892990193D+00 -1.1163823196192334D+01
-1.6720884251135573D+01 -3.4538388727628920D+01 -1.4257051924318677D+02
-1.1514397996190068D+02 -1.3448088070874364D+03
6.7924814124681945D-02 1.9162023816535123D+00 2.1382057073297287D+00
4.8985929236844248D+00 1.4177049526077155D+01 2.0099233242358302D+01
2.0210008082764258D+01 3.6711234126939637D+01 6.6452662105930941D+01
7.5623516469955132D+02 9.2696874549740244D+02 1.4975117114141267D+03
1.6104801785338504D+03 2.3532277699219135D+03 3.0761315305411586D+03
5.2815583937596903D+03 2.8073735859041568D+04 2.4083624488121259D+05
3.5992003612977365D+05 4.3713110221721875D+06
C APPROXIMATION OF AP, MODE 1
21
6.2356248561459442D-06
1.1394462440256881D-06 5.7476578418368808D-05 5.6585881631888636D-05
1.2323663756495836D-03 4.1446240724274976D-03 1.5081920482143744D-02
3.6622966328274428D-02 8.3275943517540349D-02 5.5183260303662418D-01
9.1502974088512468D-01 1.3427849548741724D+00 5.3050698466389690D+01
1.5367912188439147D+03 7.3221980188345060D+03 6.0798748558742955D+04
1.5176272916344024D+05 1.0007841875829264D+06 3.0443160271395161D+05
1.71659175872423340D+06 2.4114738354811244D+07 -6.4359975491803866D+06
1.9868606784477195D-02 1.8746492748822967D+00 1.8807030774197053D+00
2.0267376578592977D+01 3.4059630966619864D+01 6.1742315046451239D+01
7.4915222193513472D+01 8.6007420014813420D+01 2.8371239286684920D+02

```

|                               |                         |                        |
|-------------------------------|-------------------------|------------------------|
| 4.7209130101031798D+02        | 6.9861656782649447D+02  | 6.8853764759803444D+03 |
| 9.7730436856633969D+04        | 2.3999982005434716D+05  | 9.8809786955693609D+05 |
| 2.5419788429525406D+06        | 7.1746681602217909D+06  | 7.8657963320753900D+06 |
| 1.6259779145587130D+07        | 4.4098965842173472D+07  | 4.7402321900976038D+08 |
| C APPROXIMATION OF AP, MODE 2 |                         |                        |
| 22                            |                         |                        |
| 6.2353883842447305D-06        |                         |                        |
| 1.2037463641634577D-06        | 4.9642580222203390D-05  | 5.8481688543194389D-05 |
| 3.2667879495937557D-04        | 6.3780842060240145D-04  | 9.2569202620317503D-04 |
| 1.0866509001775412D-03        | 9.2584788581703513D-03  | 4.1472564496683670D-02 |
| 2.8679181148615407D-01        | 1.0369152079987527D+00  | 4.6542334493440798D+00 |
| 2.2694912971989498D+00        | 5.3429979847071323D+01  | 1.9652430647086605D+03 |
| 6.1638009137433846D+03        | 6.1964064342887017D+04  | 4.0682598212094116D+05 |
| 1.4004857433152120D+06        | 1.4285534996670661D+06  | 2.3507925087580774D+07 |
| -6.2895360357603002D+06       |                         |                        |
| 1.9868574631505292D-02        | 1.6341277324713575D+00  | 1.9257767846393663D+00 |
| 5.3776999365315135D+00        | 1.0496106653155264D+01  | 1.5252695838788366D+01 |
| 1.7904415489379904D+01        | 1.5319570465224157D+02  | 3.3895798676844669D+02 |
| 5.8611637961099564D+02        | 1.0294072418669857D+03  | 1.1740993851032854D+03 |
| 1.2521505976082462D+03        | 6.9419536086243997D+03  | 1.2175633327693015D+05 |
| 2.0590565393614376D+05        | 1.0073074626945982D+06  | 3.4154542977567879D+06 |
| 1.0289987298562117D+07        | 1.5647729850953279D+07  | 4.3260922499899216D+07 |
| 4.8320870671970749D+08        |                         |                        |
| C APPROXIMATION OF AP, MODE 3 |                         |                        |
| 23                            |                         |                        |
| 6.2354226854374210D-06        |                         |                        |
| 1.2018262202270126D-06        | 4.7491781050509414D-05  | 5.8355047237505824D-05 |
| 3.7415936528235216D-04        | 6.0860576347635312D-04  | 6.3100233725767348D-04 |
| 4.3443768747700286D-03        | 8.0457407751766581D-03  | 3.3038653008086789D-02 |
| 2.2700745060490085D-01        | 8.6570237787750937D-01  | 4.8308053922118201D+00 |
| 5.5148625449967381D-01        | 5.3618708783340153D+01  | 4.0258126963772124D+03 |
| 5.9012839022082999D+03        | 5.5350447501290597D+04  | 1.7853730535770644D+05 |
| 5.4031115513806499D+05        | 6.8319464055095019D+05  | 1.9468613933323710D+06 |
| 2.4219840614489809D+07        | -6.7120447334254086D+06 |                        |
| 1.9868575591675659D-02        | 1.5633938398253524D+00  | 1.9215387128355725D+00 |
| 6.1587358325592438D+00        | 1.0005437720022444D+01  | 1.0405657768522591D+01 |
| 7.1605492022786052D+01        | 1.3247312424157613D+02  | 2.7059369921125449D+02 |
| 4.6401945154715213D+02        | 8.4514608844012434D+02  | 9.3452031356301995D+02 |
| 9.3976801776179093D+02        | 6.9635488412092809D+03  | 1.2991005233059816D+05 |
| 3.7910740217688517D+05        | 9.1515447111233580D+05  | 2.8522399308483461D+06 |
| 6.2730437171216803D+06        | 7.8658925315614892D+06  | 1.7223361056269512D+07 |
| 4.4099035237522997D+07        | 3.2920621878467035D+08  |                        |
| C APPROXIMATION OF Q( 1, 1)   |                         |                        |
| 18                            |                         |                        |
| 9.5202483417446571D-01        |                         |                        |
| 1.0666733856273426D-04        | 1.4739756643549090D-03  | 2.3390230099445209D-03 |
| 7.8143250946665754D-03        | 1.5217003400003431D-02  | 1.0953916291861789D-01 |
| 4.3727850831123438D-01        | 1.4244359123288441D+00  | 4.0248376701935040D+00 |
| 9.6386585757635519D+00        | 2.3561814968802270D+01  | 5.4662674817680440D+01 |
| 7.3721165681203587D+01        | 1.5008336784474537D+02  | 4.8934886240647683D+02 |
| 5.2195182541868905D+02        | 1.2595527967338267D+03  | 7.9966879580746979D+02 |
| 1.9814864246633677D-02        | 1.6232798020156622D+00  | 2.5855672048727358D+00 |
| 8.6319776463589886D+00        | 1.6840974372045387D+01  | 6.0702261478366097D+01 |
| 2.4243143635833044D+02        | 7.9230318875768046D+02  | 2.2385611895988977D+03 |
| 5.3847714756457572D+03        | 1.3138123313249935D+04  | 3.0531567608688194D+04 |
| 4.1594842006957595D+04        | 8.4442788568729768D+04  | 2.6721084564048017D+05 |
| 2.9416122587787814D+05        | 3.5906262975269771D+05  | 4.6276813932427915D+05 |
| C APPROXIMATION OF Q( 2, 1)   |                         |                        |
| 1                             |                         |                        |
| 1.0000000000000000D+00        |                         |                        |
| 0.0000000000000000D+00        |                         |                        |
| 1.0000000000000000D+00        |                         |                        |
| C APPROXIMATION OF Q( 3, 1)   |                         |                        |
| 18                            |                         |                        |
| 9.5202483417446571D-01        |                         |                        |
| 1.0666733856273426D-04        | 1.4739756643549090D-03  | 2.3390230099445209D-03 |
| 7.8143250946665754D-03        | 1.5217003400003431D-02  | 1.0953916291861789D-01 |
| 4.3727850831123438D-01        | 1.4244359123288441D+00  | 4.0248376701935040D+00 |
| 9.6386585757635519D+00        | 2.3561814968802270D+01  | 5.4662674817680440D+01 |
| 7.3721165681203587D+01        | 1.5008336784474537D+02  | 4.8934886240647683D+02 |
| 5.2195182541868905D+02        | 1.2595527967338267D+03  | 7.9966879580746979D+02 |

```

1.9814864246633677D-02  1.6232798020156622D+00  2.5855672048727358D+00
8.6319776463589886D+00  1.6840974372045387D+01  6.0702261478366097D+01
2.4243143635833044D+02  7.9230318875768046D+02  2.2385611895988977D+03
5.3847714756457572D+03  1.3138123313249935D+04  3.0531567608688194D+04
4.1594842006957595D+04  8.4442788568729768D+04  2.6721084564048017D+05
2.9416122587787814D+05  3.5906262975269771D+05  4.6276813932427915D+05
C  APPROXIMATION OF Q( 1, 2)
18
-5.2519638359385967D-01
5.5460554976767186D-05  7.6495871282133315D-04  1.2229777045819768D-03
4.0795773867955392D-03  7.9763338947433406D-03  5.7558772486907661D-02
2.3054416616256976D-01  7.5361005111208168D-01  2.1364079600945165D+00
5.0412651710255885D+00  1.2831198076497202D+01  2.8027726115241670D+01
4.0772659849433566D+01  8.2870699115322765D+01  2.4247671665277616D+02
2.7919847612669753D+02  7.1542904953807727D+02  4.5902167260632797D+02
1.9923637685816783D-02  1.6247814913580987D+00  2.5879591022595414D+00
8.6399625374146591D+00  1.6856554892194669D+01  6.0814555405816378D+01
2.4288046336381072D+02  7.9376844144468203D+02  2.2427082634782869D+03
5.2921956710718150D+03  1.3417484621367179D+04  2.9436343916034442D+04
4.2479001391141734D+04  8.6237997610599065D+04  2.5766557462088292D+05
2.8906237698064721D+05  3.6737667068721092D+05  4.6362466027887247D+05
C  APPROXIMATION OF Q( 2, 2)
1
1.0000000000000000D+00
0.0000000000000000D+00
1.0000000000000000D+00
C  APPROXIMATION OF Q( 3, 2)
18
-5.2519638359385967D-01
5.5460554976767186D-05  7.6495871282133315D-04  1.2229777045819768D-03
4.0795773867955392D-03  7.9763338947433406D-03  5.7558772486907661D-02
2.3054416616256976D-01  7.5361005111208168D-01  2.1364079600945165D+00
5.0412651710255885D+00  1.2831198076497202D+01  2.8027726115241670D+01
4.0772659849433566D+01  8.2870699115322765D+01  2.4247671665277616D+02
2.7919847612669753D+02  7.1542904953807727D+02  4.5902167260632797D+02
1.9923637685816783D-02  1.6247814913580987D+00  2.5879591022595414D+00
8.6399625374146591D+00  1.6856554892194669D+01  6.0814555405816378D+01
2.4288046336381072D+02  7.9376844144468203D+02  2.2427082634782869D+03
5.2921956710718150D+03  1.3417484621367179D+04  2.9436343916034442D+04
4.2479001391141734D+04  8.6237997610599065D+04  2.5766557462088292D+05
2.8906237698064721D+05  3.6737667068721092D+05  4.6362466027887247D+05
C  APPROXIMATION OF Q( 1, 3)
1
1.0000000000000000D+00
0.0000000000000000D+00
1.0000000000000000D+00
C  APPROXIMATION OF Q( 2, 3)
1
0.0000000000000000D+00
0.0000000000000000D+00
1.0000000000000000D+00
C  APPROXIMATION OF Q( 3, 3)
1
-1.0000000000000000D+00
0.0000000000000000D+00
1.0000000000000000D+00
C  ----- END OF FD-MODEL OF CABLE

```

**Figure 2–1 FD mode data file format for the FDQ matrix selection**

### 3 CP model

The CP model (constant parameter cable model) assumes that the cable parameters R, L, and C are constant, and they are calculated at a user-supplied model 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 modeled by the FD model) is an important factor for the accurate simulation of transients. However, the CP model is

computationally faster and it is generally used as an alternative to model secondary lines or cables.

This only type of matrix that can be calculated for this model is the Real  $T_i$ . It is evaluated at the entered “Model frequency”.

### 3.1 CP model data file format

After entering all required data, the Model Data Calculation Function can be invoked from the “Save and run this case” data tab to generate the model data file. The model can be used with the CP line model (CP m-phase device) by selecting the model data file (also called “model file”) through the “Load data file” option in the device data. It can be used for all simulation options of this device. The format of this file can be found in the documentation of the CP m-phase device.

## 4 Exact PI model

The Exact PI cable model (also called pi-exact) is used for steady-state or frequency scan solutions; it is not valid for time-domain simulations. This model is an exact lumped-impedance multiphase representation of the cable as seen from its end points.

The model data produced for this model is given in terms of a Y-matrix representation that includes the series and shunt branches of the multiphase pi model. This Y-matrix is produced for each frequency point in a specified logarithmic or linear frequency interval.

This model can be generated for the following transformation matrices:

- ❑ **Complex  $T_i$** : The transformation matrix is evaluated at the “Model Frequency” field value, its columns are rotated (to minimize the imaginary parts), and its imaginary part is retained to make  $T_i$  (  $Q$  ) complex and constant. This option is only for testing, and it is not recommended for actual studies.
- ❑ **FDQ**: The transformation matrix is assumed as frequency dependent and evaluated at the specified frequency points.

This model is capable to generate the frequency parameters based on a logarithmic or linear scale. On output, the model data file (“model file”) contains the matrices  $Y_{series}(\omega)$  and  $Y_{shunt}(\omega)$  (see Figure 4–1 below) at every frequency requested in “Frequency range”. Note that the specified “Frequency range” must be identical to the one chosen through the “Frequency scan” option in EMTPWorks Simulation Options.

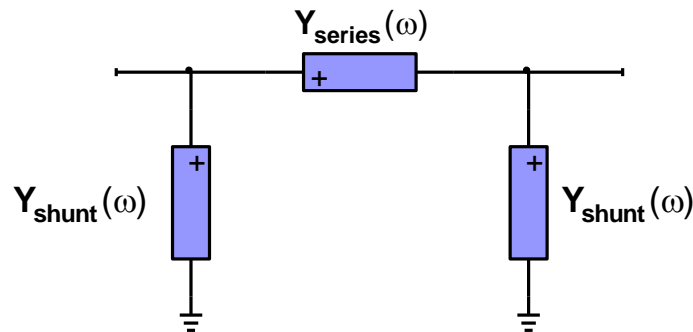


Figure 4–1 Circuit representation of PI-EXACT model

After entering the remaining data for the cable system, the Model Data Calculation Function can be invoked from “Save and run this case” data tab to generate the model data file. The model can be used with the FDQ cable model (FDQ m-phase device) by selecting the model data file after clicking on the “Select data file” button for “Frequency-domain model data”. It can be used for steady-state or for frequency scan simulations in EMTP.

The FDQ model data file format is identical to the one used in the Line Data device.

## **5 Scan (No model) option**

This selection is for the Scan option where cable parameters in either phase, modal or sequence quantities are computed at the specified frequencies. Results are shown in the output file. No model is generated.