PSS®E 33.4

Transmission Line Characteristics (TMLC)

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SIEMENS

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Chapter 1

Introduction

The Transmission Line Characteristics (TMLC) program calculates transmission line constants used in many power system analysis problems. The constants include the series resistance and reactance and the shunt admittance parameters. Interactive input is allowed and is minimized by the availability of typical default parameters.

The TMLC program has been superseded by PSS®E LineProp, a fully interactive program with a Microsoft Windows based graphical user interface. Both TMLC and LineProp calculate line parameters of overhead lines given their tower configuration and conductor type, but they utilize different calculation engines. LineProp has been in use for many years, both in PSS®E and other Siemens PTI products, and has proven to be highly robust in comparison to both TMLC and other related products. It also has an extensive conductor database that is regularly updated. The large majority of PSS®E customers are now using LineProp and TMLC is slated to be dropped at the next major release of PSS®E. For information on the use of LineProp please see the PSS®E LineProp Manual.

1.1 Capabilities

Up to eight circuits are allowed with a maximum of 50 conductors total. Shield wires count as conductors. Input can be entered either interactively or via a data file. Several results are available such as outputting of phase, sequence, power flow, and short circuit parameters. Data is contained in the file "TMLCCD.DAT" representing most available ACSR, AAC, AAAC, and ACAR phase conductors as well as Alumoweld (AW) and EHS steel shield wires.

The following restrictions apply to the use of the 50 conductors:

1. Number of circuits = 8.
2. Number of shield wire types = 4.
3. Number of shield wire conductors/type = 4.
4. [3 x (Σ#conductors/bundle)] + (Σ#shield wires/type) $\leq$50.
5. 3 x (Σ#conductors/bundle) $\leq$40.

For each circuit, a different number of conductors per bundle may be used but the total is limited. The same applies to shield wires.

1.2 Program Operation

To run the program, click on the appropriate icon or type "TMLC". Upon initiation the program looks first for a file PMTMLC.DAT in the user's directory. If this file is not found, the program will then search for it in the same directory that the TMLC data file is stored. File PMTMLC.DAT sets some of the default parameters. It contains the following information:

```
ROHM, FREQ, UNITIN, UNITOU
```

where:

ROHM Is the earth resistivity in ohm-meters.

FREQ Is the system frequency in Hz.

UNITIN Is equal to F if input is in feet and M if input is in meters.

UNITOU Is equal to F if output is in feet and M if output is in meters.

If the file is not found, TMLC assumes:

- ROHM = 100.
- FREQ = 60.
- UNITIN = F.
- UNITOU = F.

The program will then ask whether data is to be entered interactively or via a data file.

1.2.1 Interactive Input

In the interactive mode, TMLC will ask for all pertinent data. Default values are allowed for some entries. Only a conductor name, such as Kiwi or Rail, is required input. Specific information related to the conductor, such as resistance, reactance, rating, etc., is contained in a data file associated with the program. Information about the conductor data file is given in Appendix E.
Specific interactive data required includes:

1. Conductor name.
2. Geometric location of circuit reference point.
3. Geometric location of phase bundle reference points with respect to circuit 1.
4. Conductor sag.
5. Shield wire name.
6. Shield wire geometric locations with respect to circuit 1 reference point.
7. Shield wire sag.

The first circuit sets a global reference point of (0,0) which is assumed to be at the base of its tower. For all subsequent circuits the user can specify reference points of the base of their towers or specify conductors with respect to the global reference point. All phase

bundles are located with respect to the reference points. Only the subconductor bundle spacing and not the individual locations of each subconductor is required input. All shield wires are located with respect to the circuit 1 reference point (0,0).
An example of interactive input follows.

1.2.2 Data File Input

The data file input format (free format) is shown in Appendix A. For conductors not contained in the TMLCCD.DAT data file, conductor characteristic data (resistance, etc.) is required. All geometric locations including subconductors must be entered via this data file. This input form is slightly more involved than the interactive form but has the capability of representing unusual subconductor bundle configurations as well as conductors not contained in the TMLCCD.DAT data file.

1.2.3 Output Options

Following the input mode, a data consistency check is made. If an error message is printed, no calculations are made. The user should either correct the data via the change data option or enter new data. The change data option (9) will prompt the user as to which data is to be changed. A carriage return or enter response to any question signifies no data is to be changed.
Following the consistency check and calculation, TMLC offers several output data presentations. The selections are:

1. Phase impedance matrix.
2. Full symmetrical component matrix.
3. Abbreviated symmetrical component matrix.
4. Data file.
5. Power flow.
6. Short circuit.
7. List out input data.

Except where a file is to be created for output presentation, the default output device is the CRT. The user can select an alternative device via the CHANGE OUTPUT DEVICE menu selection (10).
With the first four output options, characteristics are presented as series resistance and reactance in ohms/mi or ohms/km and shunt reactance in Mohm-mi or Mohm-km. Because the results are on a per mile or km basis, no long line corrections are included. With options five and six, hyperbolic long line corrections are included.

The phase impedance matrix presents the series and shunt impedance characteristics on a conductor basis (Figure 1-1*). Note that the output is inherently organized by circuits and within a circuit, by phases.

The full symmetrical component matrix format presents matrices for each circuit as well as for the coupling terms between circuits. The format is illustrated on Figure 1-2.

Abbreviated symmetrical components are also available. With this format only the zero and positive sequence self terms as well as the zero sequence mutual coupling terms between circuits are presented (Figure 1-3).

Output format No. 4 allows the phase impedance matrices to be written to a user-designated file. This allows the output to be easily accessed by other programs. The format is illustrated on Figure 1-4.

The power flow format presents line characteristics in a form similar to that used by power flow programs (Figure 1-5). In response to TMLC generated questions, the user interactively enters the base MVA, circuit kV and line length. The positive sequence R, X_L, and B are presented on a per unit basis. Long line corrections are included.

Output option No. 6 presents line characteristics that are typically used in short circuit programs. The user enters the base MVA, circuit kV, the circuit self length, and the circuit length that is common between the self circuit and every other circuit. The program then prints out the positive and zero sequence R, X_L, and B for each circuit as well as the zero sequence mutual R and X_L between circuits (Figure 1-6). Hyperbolic corrections are included.

Output option No. 7 simply presents the input data for documentation or verification purposes (Figure 1-7).

Option No. 8 creates an input data file. This file has the format shown in Appendix A and can be used in subsequent TMLC sessions.

1.3 Program Limitations

On rare occasions, the range of the earth correction terms (Carson's Equations) may be exceeded. If that should occur, a warning is printed on the CRT. The value of "R" used for entering Carson's Equations is also presented. Computation will continue at the user's option.

The system frequency is an input variable. However, any results obtained when the program is used outside the range of 45 to 75 Hz should be carefully considered. The program simply ratios the conductor X_L and X_C values by the new frequency divided by 60 Hz. R is unchanged. While this approach is valid for small frequency ranges, many of the assumptions used in the program are not valid outside this range. For example, Carson's Equations may be out of bounds. Phase conductor resistance as well as shield wire resistance and inductive reactance values could also be in error.

* For ease of readability, all figures are grouped together at the end of this chapter, beginning on page 5.

```
                    POWER TECHNOLOGIES, INC.
               TRANSMISSION LINE CHARACTERISTICS
               PROGRAM VER III          11-28-89
                            TEST CASE

                   ****PHASE PARAMETERS****
```

Z SERIES MATRIX(OHM/MI)

Phases	A	B	C	A	B	C
A	0.15772 0.90619					
B	0.12266 0.37157	0.16386 0.89920				
C	0.12410 0.28485	0.12897 0.36429	0.17095 0.89139			
A	0.12425 0.22752	0.13046 0.26783	0.13693 0.33680	0.19344 0.95346		
B	0.12210 0.20440	0.12848 0.23455	0.13539 0.28019	0.14308 0.39039	0.19341 0.95342	
C	0.11828 0.18761	0.12445 0.21137	0.13118 0.24477	0.13897 0.30961	0.14077 0.39288	0.18875 0.95843

CIRCUIT 1

Resistance
Inductive Reactance

CIRCUIT 1-2
CIRCUIT 2

Z SHUNT MATRIX(MOHM-MI)

0.15450					
0.02820	0.15358				
0.01199	0.02723	0.15202			
0.00428	0.00862	0.01978	0.16092		
0.00257	0.00473	0.00981	0.02854	0.16103	
0.00175	0.00292	0.00546	0.01286	0.02892	0.16176

Capacitive Reactance

Figure 1-1. Phase Impedance Matrix

```
        POWER TECHNOLOGIES, INC.
   TRANSMISSION LINE CHARACTERISTICS
   PROGRAM VER III          11-28-89

               TEST CASE


         *SEQUENCE PARAMETERS*
          Z SERIES-11-MATRIX
               (OHMS/MI)

    0.41466   0.02220  -0.03238
    1.57940  -0.00593  -0.01086

   -0.03238   0.03893  -0.04731
   -0.01086   0.55869   0.02890

    0.02220   0.04832   0.03893
   -0.00593   0.02647   0.55869

             X0/X1= 2.827

          Z SERIES-12-MATRIX
               (OHMS/MI)

    0.38384  -0.05233   0.03312
    0.73168  -0.05027  -0.06188

   -0.01786  -0.00485   0.01224
    0.05372  -0.01261  -0.00629

    0.02567  -0.01199   0.00493
    0.04676  -0.00632  -0.01223

          Z SERIES-22-MATRIX
               (OHMS/MI)

    0.47375   0.02274  -0.02100
    1.68370  -0.01764  -0.01258

   -0.02100   0.05093  -0.04747
   -0.01258   0.59081   0.02879

    0.02274   0.04871   0.05093
   -0.01765   0.02673   0.59081

             X0/X1= 2.850
```

Figure 1-2. Full Symmetrical Component Matrix (Sheet 1 of 2)

```
           Z SHUNT-11-MATRIX
               (MOHM-MI)

    0.00000   0.00513  -0.00513
    0.19831  -0.00181  -0.00181

   -0.00513   0.00000  -0.00891

   -0.00181   0.13089   0.00532

    0.00513   0.00891   0.00000
   -0.00181   0.00532   0.13089

             X0/X1= 1.515

           Z SHUNT-12-MATRIX
                MOHM-MI)

    0.00000  -0.00542   0.00542
    0.01997  -0.00569  -0.00569

   -0.00201  -0.00147   0.00277
    0.00635  -0.00275  -0.00148

    0.00201  -0.00277   0.00147
    0.00635  -0.00148  -0.00275

           Z SHUNT-22-MATRIX
               (MOHM-MI)

    0.00000   0.00432  -0.00432
    0.20812  -0.00290  -0.00290

   -0.00432   0.00000  -0.00926
   -0.00290   0.13780   0.00532

    0.00432   0.00926   0.00000
   -0.00290   0.00532   0.13780

             X0/X1= 1.510
```

Figure 0-0 (Cont). Full Symmetrical Component Matrix (Sheet 2 of 2)

```
          POWER TECHNOLOGIES, INC.
      TRANSMISSION LINE CHARACTERISTICS
      PROGRAM VER III          11-28-89

                 TEST CASE


        VALUES IN OHMS/MI AND MOHM-MI

          *SEQ.FOR CIRCUIT #1

           RO        XO          XCO
          0.41466   1.57940   0.19831
           R1        X1          XC1
          0.03893   0.55869   0.13089

          *SEQ. COUP. CIRCUITS #1-2

           R0        X0
          0.38384   0.73168

          *SEQ.FOR CIRCUIT #2

           RO        XO          XCO
          0.47375   1.68370   0.20812
           R1        X1          XC1
          0.05093   0.59081   0.13780
```

Figure 1-3. Abbreviated Symmetrical Components Matrix

```
0.6000E+01
0.1545E+06
0.2820E+05  0.1536E+06
0.1199E+05  0.2723E+05  0.1520E+06
0.4282E+04  0.8623E+04  0.1978E+05  0.1609E+06
0.2570E+04  0.4729E+04  0.9806E+04  0.2854E+05  0.1610E+06
0.1748E+04  0.2917E+04  0.5461E+04  0.1286E+05  0.2892E+05  0.1618E+06
0.1577E+00
0.1227E+00  0.1639E+00
0.1241E+00  0.1290E+00  0.1709E+00
0.1243E+00  0.1305E+00  0.1369E+00  0.1934E+00
0.1221E+00  0.1285E+00  0.1354E+00  0.1431E+00  0.1934E+00
0.1183E+00  0.1244E+00  0.1312E+00  0.1390E+00  0.1408E+00  0.1888E+00
0.9062E+00
0.3716E+00  0.8992E+00
0.2848E+00  0.3643E+00  0.8914E+00
0.2275E+00  0.2678E+00  0.3368E+00  0.9535E+00
0.2044E+00  0.2345E+00  0.2802E+00  0.3904E+00  0.9534E+00
0.1876E+00  0.2114E+00  0.2448E+00  0.3096E+00  0.3929E+00  0.9584E+00
```

Figure 1-4. Phase Impedance Matrices

```
                         POWER TECHNOLOGIES, INC.
                     TRANSMISSION LINE CHARACTERISTICS
                     PROGRAM VER III          11-28-89

                                TEST CASE

                     **HYPERBOLIC CORRECTION APPLIED**
                  LENGTH                          ****IN PU - TOTAL LENGTH****
CIRCUIT  KV(L-L)   (MI)    BASE MVA  SIL   RATING   R         X          B
   1       500.  200.000    100.    924.   2670.  0.0029    0.0434    3.87518
   2       345.  150.000    100.    417.   1960.  0.0062    0.0733    1.30614
```

Figure 1-5. Power Flow Data Output

```
                         POWER TECHNOLOGIES, INC.
                     TRANSMISSION LINE CHARACTERISTICS
                     PROGRAM VER III          11-28-89

                                TEST CASE
                          BASE MVA IS   100.00

                    ***********HYPERBOLIC CORRECTION APPLIED*************
                    ****************IN PU - TOTAL LENGTH*****************
 SELF TO            ****POSITIVE SEQUENCE****   ******ZERO SEQUENCE******
 CKT  CKT  KV   LNTH(MI)   R        X        B        R        X        B

  1        500. 200.000  0.0029   0.0434  3.87518  0.0297   0.1202  2.59024


       2   345.  75.000                            0.0166   0.0318


  2        345. 150.000  0.0062   0.0733  1.30614  0.0561   0.2063  0.87111
```

Figure 1-6. Short Circuit Data Output

```
                    POWER TECHNOLOGIES, INC.
               TRANSMISSION LINE CHARACTERISTICS
               PROGRAM VER III          11-28-89

                           TEST CASE

         RHO   15.0 OHM-M          FREQ  60.0 HZ

                  ********************
                  ***  CIRCUIT #1  ***
                  ********************


          POSITION OF COND. BUNDLE CENTER

                 PHASE 1   PHASE 2   PHASE 3
        HEIGHT     90.00     90.00     90.00
      LAT. POS    -35.00      0.00     35.00

  POS. OF REFERENCE: VERT    0.00 HORIZ    0.00


  REL. POS. OF SUB-COND. TO BUNDLE CENTER

                       1         2         3

       REL HT       0.00      0.00     -1.30
       REL LAT     -0.75      0.75      0.00


   CONDUCTOR NAME IS  DRAKE/AW

      SAG =  55.00                  R = 0.1129 OHM/MI
       XL = 0.3990 OHM/MI          XC = 0.0911 MOHM-MI


                  ********************
                  ***  CIRCUIT #2  ***
                  ********************


          POSITION OF COND. BUNDLE CENTER

                 PHASE 1   PHASE 2   PHASE 3
        HEIGHT     75.00     75.00     75.00
      LAT. POS    -25.00      0.00     25.00

   POS. OF REFERENCE: VERT    0.00 HORIZ  100.00
```

Figure 1-7. Input Data Listing (Sheet 1 of 2)

```
         REL. POS. OF SUB-COND. TO BUNDLE CENTER

                           1         2
            REL HT       0.00      0.00
            REL LAT     -0.75      0.75


                CONDUCTOR NAME IS  RAIL

    SAG =  45.00                    R = 0.0994 OHM/MI
     XL = 0.3950 OHM/MI            XC = 0.0896 MOHM-MI


             *****************************
             ***  SHIELD WIRE TYPE #1  ***
             *****************************


                   POSITION OF WIRES

                           1         2
             HEIGHT    120.00    120.00
           LAT. POS    -30.00     30.00


                CONDUCTOR NAME IS  3/8EHS

    SAG =  35.00                    R = 6.9300 OHM/MI
     XL = 1.4400 OHM/MI            XC = 0.1244 MOHM-MI


             *****************************
             ***  SHIELD WIRE TYPE #2  ***
             *****************************


                   POSITION OF WIRES

                           1         2
             HEIGHT     90.00     90.00
           LAT. POS     80.00    120.00


                CONDUCTOR NAME IS  7/16EHS

   SAG =  35.00                    R = 4.7400 OHM/MI
    XL = 1.2800 OHM/MI            XC = 0.1188 MOHM-MI
```

Figure 0-0 (Cont). Input Data Listing (Sheet 2 of 2)

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Appendix A

Input Data Requirements

Table 1 Input Data Requirements presents the input data requirements.There are instances where it is advantageous to have the data inputted via a file rather than interactively, such as highly complicated configurations containing many conductors, or conductors not contained in the TMLCCD.DAT data file. This appendix presents two different perspectives.

Table 1: Input Data Requirements

Line	Item	Description*
1		Heading, up to 60 characters
2	1	Earth resistivity (ohm-m)
	2	Frequency
	3	Number of circuits
	4	Number of shield wire types
3	1	Circuit number
	2	Number of conductors in bundle for this circuit
	3	Resistance per conductor (ohm/mi)
	4	Reactance to 1-ft spacing per conductor (ohm/mi)
	5	Capacitive reactance (Mohm-mi)
	6	Rating
3'		Conductor name
3A		
3B		Data for circuits 2, 3, 4, etc.
3C		
4I	1	Vertical position of bundle center for Phase A, conductor center 1 relative to HCOR
	2	Horizontal position of bundle center for Phase A, conductor center 1 relative to XCOR
	3	Vertical position of bundle center for Phase B, conductor center 1 relative to HCOR
	4	Horizontal position of bundle center for Phase B, conductor center 1 relative to XCOR
	5	Vertical position of bundle center for Phase C, conductor center 1 relative to HCOR
	6	Horizontal position of bundle center for Phase C, conductor center 1 relative to XCOR

Table 1: Input Data Requirements

Line	Item	Description*
	7	Vertical position of Circuit 1 reference, HCOR
	8	Horizontal position of Circuit 1 reference, XCOR
	9	Conductor sag
4IA	1	Vertical position of conductor 1 within bundle for conductor center 1 relative to bundle center
	2	Horizontal position of conductor 1 within bundle for conductor center 1 relative to bundle center
		Must be entered even if only one conductor
4IB		
4IC		Data for other conductors within bundle of Circuit 1
4ID		
4II		
4IIA		
4IIB		Data for Circuit 2
4IIC		
4IID		
4III		
4IIIA		
4IIIB		Data for Circuit 3
4IIIC		
4IIID		
	Etc.	
5	1	Shield wire type number
	2	Number of shield wires of this type (maximum of four per type)
	3	Resistance (ohm/mi)
	4	Reactance to 1-ft spacing (ohm/mi)
	5	Capacitive reactance to 1-ft spacing (Mohm-mi)
5’		Shield wire name
5A		
5B		Data for shield wire type 2, 3, etc.
6A	1	Vertical position of shield wire 1, type 1 relative to conductor center 1 reference position
	2	Horizontal position of shield wire 1, type 1 relative to conductor center 1 reference position
	3	Sag of shield wire type 1
6B	1	Relative vertical position of shield wire 2 to conductor center 1 reference position
	2	Relative horizontal position of shield wire 2 to conductor center 1 reference position
6C		
6D		Data for shield wire 3 and 4, type 1
7A	1	Vertical position of shield 1, type 2 relative to conductor center 1 reference position
	2	Horizontal position of shield wire 1, type 2 relative to conductor center 1 reference position

Table 1: Input Data Requirements

Line	Item	Description*
	3	Sag of shield wire type 2
7B	1	Relative vertical position of shield wire 2 to conductor center 1 reference position
	2	Relative horizontal position of shield wire 2 to conductor center 1 reference position
8A		
8B		Data for shield wire type 3, 4, etc.
9A		
9B		

**All dimensional data in feet (ft) or meters (m).*

If the resistance and reactance for a conductor or shield wire is not entered, the conductor must be in the conductor data file or the program will terminate with an appropriate message. Multiple studies can be performed from an input file by appending the second data set to the original starting with the title. For frequency other than 60 Hz, enter desired value for frequency and the 60-Hz values for all conductor parameters.
The following is an alternative presentation of the input data file.

		Heading **Earth Resistivity, Frequency, Number of Circuits, Number of Types of Shield Wires**
Circuit 1 ↓ Number of Circuits		Circuit Number, Conductors In Bundle, Resistance Per Conductor, Reactance Per Conductor, Capacitive Reactance, Rating Conductor Name
Circuit 1 ↓ Number of Circuits		Y_A, X_A, Y_B, X_B, Y_C, X_C, Y_{REF}, X_{REF}, Sag Y_{COND-1}, X_{COND-1} ↓ Y_{COND-n}, X_{COND-n}
Shield Wire 1 ↓ Number of Shield Wire Types		Shield Wire Type, Number of This Type, Resistance, Reactance, Capacitive Reactance Shield Wire Name
Shield Wire 1 through Number of Shield Wire Types		Y_{S-1}, X_{S-1}, Sag ↓ Y_{S-nT}, X_{S-nT}, SagnT

where
Y_A, X_A, Y_B, X_B, Y_C, X_C, are positions of centers of bundles.

Y_{ref}, X_{ref} are positions of circuit reference.
Y_{COND-1}, X_{COND-1} through Y_{COND-N}, X_{COND-N} are positions of conductors within bundles.
Y_{S-1}, X_{S-1} is position of first shield wire of a type.
Y_{S-N}, X_{S-N} is position of subsequent shield wires.

Appendix B

Relationships Between Impedance Matrixes

An obvious difference exists between the symmetrical component Z_{11} series and Z_{22} series matrices shown in Figure B-1[*]. The difference is due to the phase relationship and physical configuration of the two circuits.

It is necessary to note that there is no symmetry about the midline of one circuit. This is due to the shield effects of the other circuit. But there is a physical symmetry about the midline between the two circuits, and it is reasonable to expect that one circuit should look like a mirror image of the other. As may be seen from the phase impedance matrix (Figure B-1), this is indeed the case.

TMLC assumes the phase relationship of the conductors to be A, B, C, A, B, C in the order of the conductors entered. This is necessary to establish a reference for the symmetrical transforms. The conductors were entered in the following order:

```
A-1                        o              o
B-2                   o    2    o    o    5    o
C-3                   1         3    4         6
A-4
B-5                         corresponding to
C-6                        o              o
                      o    B    o    o    B    o
                      A         C    A         C
```

Now, if the phase matrix is operated on by a symmetrical transform, T, it is obvious that the two different circuit phase matrices ($Z_{cir\ 1}$ and $Z_{cir\ 2}$) should result in different symmetrical component matrices. This is the case.

$$\frac{(T)^{-1}\;\Big|\;Z_{cir\ 1}\;\Big|\;(T)}{3} \qquad \text{and} \qquad \frac{(T)^{-1}\;\Big|\;Z_{cir\ 2}\;\Big|\;(T)}{3}$$

[*] For ease of readability, figures are grouped together at the end of this appendix, beginning on page 4.

If the conductors were entered in a different phase, as shown below, then complete electrical symmetry would be expected.

```
A-1                      o                                o
B-2                 o    2    o          o                5         o
C-3                 1         3          4                          6
A-6
B-5                      corresponding to
C-4                      o                                o
                    o    B     o         o                B         o
                    A          C         C                          A
```

That is, the phase impedance of Circuit 1 should be identical to that of Circuit 2—not a mirror image. The results shown in Figure B-2 indicate that this is the case. What is also significant is that the matrices representing the symmetrical components for the two circuits are also identical. Note that no change has been made with respect to the physical or electrical relationship between two distinct conductors. Essentially all that has been done was to interchange the rows and columns corresponding to the two conductor bundles.

Just to prove that the shield wires cause one circuit to be the mirror image of the other, two cases were run with no ground wires. The results are shown in Figures B-3 and B-4, and illustrate that the two phase matrices for the circuits are identical—not mirror images. If the phase order were changed to A, B, C, A, C, B, there would be a difference, and it is shown in Figure B-5.

Ground wires have a noticeable effect on the zero sequence characteristics of a transmission line. The effect is obvious if the symmetrical component matrices (Z_{11}series) of Figure B-1 and Figure B-3 are compared. The configuration shown in Figure B-1 contains shield wires while that shown in Figure B-3 does not. The zero sequence self terms are:

Table 1:

	R_0	X_0	Z_0	θ
Figure B-1	0.46087	1.91222	1.96697	76.44940
Figure B-3	0.31027	2.12845	2.15095	81.70625

The shield wires decrease the zero sequence magnitude by about 10%.

The above were for a double-circuit line. Four ground wires were present—two for each line. Figure B-6 illustrates the results for a single-circuit line with the same configuration as that of one circuit of the double-circuit case. Comparing the zero sequence self terms indicates the effect of the shield wires of the other circuit on the remaining circuit.

Table 2:

	R_0	X_0	Z_0	q
Figure B-1	0.46087	1.91222	1.96697	76.44940
Figure B-6	0.42943	1.98854	2.03438	77.81397

The shield wire effect of the other circuit has the effect of reducing the zero sequence self terms by about 3%. The closer the two towers are together, the greater the effect.
In the examples that follow, the figure describes the matrix and the text emulates the program.

```
     x   x                       x   x

       o                           o
       B                           B
  o         o                o          o
  A         C                A          C
```

Input

```
           POWER TECHNOLOGIES, INC.
       TRANSMISSION LINE CHARACTERISTICS
       PROGRAM VER III          11-28-89

    500KV DOUBLE CIRCUIT LINE - A,B,C,A,B,C

    RHO  150.0 OHM-M          FREQ  60.0 HZ


                ********************
                ***  CIRCUIT #1  ***
                ********************

        POSITION OF COND. BUNDLE CENTER

                  PHASE 1   PHASE 2   PHASE 3
         HEIGHT     53.30     73.30     53.30
       LAT. POS      0.00     34.80     69.60

  POS. OF REFERENCE: VERT    0.00 HORIZ    0.00

    REL. POS. OF SUB-COND. TO BUNDLE CENTER

                  1         2         3
  REL HT       0.00      1.30      1.30
  REL LAT      0.00     -0.75      0.75


  SAG =  22.20                R = 0.0978 OHM/MI
   XL = 0.3949 OHM/MI        XC = 0.0898 MOHM-MI
```

Figure B-1. Double Circuit With Ground Wires ABCABC (Sheet 1 of 5)

Input (Cont.)

```
*******************
***  CIRCUIT #2  ***
*******************

POSITION OF COND. BUNDLE CENTER

              PHASE 1   PHASE 2   PHASE 3
     HEIGHT     53.30     73.30     53.30
   LAT. POS    164.00    198.80    233.60

   POS. OF REFERENCE: VERT    0.00 HORIZ    0.00

      REL. POS. OF SUB-COND. TO BUNDLE CENTER

                 1          2          3
REL HT        0.00       1.30       1.30
REL LAT       0.00      -0.75       0.75


SAG =  22.20                   R = 0.0978 OHM/MI
 XL = 0.3949 OHM/MI           XC = 0.0898 MOHM-MI


*****************************
***  SHIELD WIRE TYPE #1  ***
*****************************

POSITION OF WIRES

                       1          2          3          4
     HEIGHT        86.90      86.90      86.90      86.90
   LAT. POS        10.20      59.40     174.20     223.40


SAG =  10.00                   R = 7.9000 OHM/MI
 XL = 3.1168 OHM/MI           XC = 0.1234 MOHM-MI
```

Figure 0-0 (Cont). Double Circuit With Ground Wires ABCABC (Sheet 2 of 5)

Output: Phase Parameters

```
                POWER TECHNOLOGIES, INC.
           TRANSMISSION LINE CHARACTERISTICS
           PROGRAM VER III          11-28-89

        500KV DOUBLE CIRCUIT LINE - A,B,C,A,B,C

                ****PHASE PARAMETERS****


 Z SERIES MATRIX(OHM/MI)
    0.17012
    1.02216

    0.14309   0.18236
    0.47005   1.01095

    0.13899   0.14548   0.17499
    0.40635   0.46717   1.01641

    0.13434   0.14039   0.13946   0.17499
    0.30550   0.32693   0.36762   1.01641

    0.13475   0.14070   0.14039   0.14548   0.18236
    0.28068   0.29858   0.32693   0.46717   1.01095

    0.12921   0.13475   0.13434   0.13899   0.14309   0.17012
    0.26756   0.28068   0.30550   0.40635   0.47005   1.02216


 Z SHUNT MATRIX(MOHM-MI)
    0.14701

    0.02135   0.15089

    0.00853   0.02121   0.14676

    0.00148   0.00330   0.00534   0.14676

    0.00122   0.00251   0.00330   0.02121   0.15089

    0.00062   0.00122   0.00148   0.00853   0.02135   0.14701
```

Figure 0-0 (Cont). Double Circuit With Ground Wires ABCABC (Sheet 3 of 5)

Output: Sequence Parameters

```
        POWER TECHNOLOGIES, INC.
   TRANSMISSION LINE CHARACTERISTICS
   PROGRAM VER III           11-28-89

      500KV DOUBLE CIRCUIT LINE -
              A,B,C,A,B,C

         *SEQUENCE PARAMETERS*
          Z SERIES-11-MATRIX
                OHMS/MI)

     0.46087   0.01248  -0.02115
     1.91222  -0.01014  -0.00352

    -0.02115   0.03330  -0.03825
    -0.00352   0.56865   0.02237

     0.01248   0.03847   0.03330
    -0.01014   0.02190   0.56865

             X0/X1= 3.363

          Z SERIES-12-MATRIX
                (OHMS/MI)

     0.40944  -0.03267   0.02153
     0.92000  -0.03361  -0.03265

    -0.01277  -0.00221   0.00598
     0.04509  -0.00551  -0.00341

     0.01751  -0.00594   0.00215
     0.03497  -0.00347  -0.00490

          Z SERIES-22-MATRIX
                (OHMS/MI)

     0.46087   0.01362  -0.01502
     1.91222  -0.01655  -0.00574

    -0.01502   0.03330  -0.03820
    -0.00574   0.56865   0.02236

     0.01362   0.03850   0.03330
    -0.01655   0.02194   0.56865

             X0/X1= 3.363
```

Figure 0-0 (Cont). Double Circuit With Ground Wires ABCABC (Sheet 4 of 5)

Output: Sequence Parameters (Cont.)

```
          Z  SHUNT-11-MATRIX
               (MOHM-MI)

 0.00000   0.00489  -0.00489
 0.18228  -0.00270  -0.00270

-0.00489   0.00000  -0.00621
-0.00270   0.13119   0.00357

 0.00489   0.00621   0.00000
-0.00270   0.00357   0.13119

            X0/X1= 1.389

          Z  SHUNT-12-MATRIX
               (MOHM-MI)

 0.00000  -0.00089   0.00089
 0.00682  -0.00175  -0.00175

-0.00107  -0.00016   0.00071
 0.00165  -0.00068  -0.00041

 0.00107  -0.00071   0.00016
 0.00165  -0.00041  -0.00068

          Z  SHUNT-22-MATRIX
               (MOHM-MI)

 0.00000   0.00478  -0.00478
 0.18228  -0.00289  -0.00289

-0.00478   0.00000  -0.00620
-0.00289   0.13119   0.00359

 0.00478   0.00620   0.00000
-0.00289   0.00359   0.13119

            X0/X1= 1.389
```

Figure 0-0 (Cont). Double Circuit With Ground Wires ABCABC (Sheet 5 of 5)

```
    x   x                    x   x

      o                        o
      B                        B
 o         o              o         o
 A         C              C         A
```

Input

```
          POWER TECHNOLOGIES, INC.
      TRANSMISSION LINE CHARACTERISTICS
      PROGRAM VER III          11-28-89

   500KV DOUBLE CIRCUIT LINE - A,B,C,A,B,C

   RHO  150.0 OHM-M          FREQ  60.0 HZ


             *******************
             ***  CIRCUIT #1  ***
             *******************

       POSITION OF COND. BUNDLE CENTER

                 PHASE 1   PHASE 2   PHASE 3
        HEIGHT     53.30     73.30     53.30
      LAT. POS      0.00     34.80     69.60

 POS. OF REFERENCE: VERT   0.00 HORIZ   0.00

   REL. POS. OF SUB-COND. TO BUNDLE CENTER

                 1         2         3
 REL HT       0.00      1.30      1.30
 REL LAT      0.00     -0.75      0.75
```

Figure B-2. Double Circuit With Ground Wires ABCCBA (Sheet 1 of 5)

Input (Cont.)

```
*******************
***  CIRCUIT #2  ***
*******************

POSITION OF COND. BUNDLE CENTER

              PHASE 1   PHASE 2   PHASE 3
     HEIGHT     53.30     73.30     53.30
   LAT. POS    233.60    198.80    164.00

POS. OF REFERENCE: VERT    0.00 HORIZ    0.00

REL. POS. OF SUB-COND. TO BUNDLE CENTER

               1         2         3
REL HT       0.00      1.30      1.30
REL LAT      0.00     -0.75      0.75

SAG =  22.20                R = 0.0978 OHM/MI
 XL = 0.3949 OHM/MI        XC = 0.0898 MOHM-MI


*****************************
***  SHIELD WIRE TYPE #1  ***
*****************************

POSITION OF WIRES

                   1         2         3         4
     HEIGHT    86.90     86.90     86.90     86.90
   LAT. POS    10.20     59.40    174.20    223.40

SAG =  10.00                R = 7.9000 OHM/MI
 XL = 3.1168 OHM/MI        XC = 0.1234 MOHM-MI
```

Figure 0-0 (Cont). Double Circuit With Ground Wires ABCCBA (Sheet 2 of 5)

Output: Phase Parameters

```
                 POWER TECHNOLOGIES, INC.
             TRANSMISSION LINE CHARACTERISTICS
             PROGRAM VER III           11-28-89

          500KV DOUBLE CIRCUIT LINE - A,B,C,A,B,C

                  ****PHASE PARAMETERS****


 Z SERIES MATRIX(OHM/MI)
    0.17012
    1.02216

    0.14309   0.18236
    0.47005   1.01095


    0.13899   0.14548   0.17499
    0.40635   0.46717   1.01641

    0.12921   0.13475   0.13434   0.17012
    0.26756   0.28068   0.30550   1.02216

    0.13475   0.14070   0.14039   0.14309   0.18236
    0.28068   0.29858   0.32693   0.47005   1.01095

    0.13434   0.14039   0.13946   0.13899   0.14548   0.17499
    0.30550   0.32693   0.36762   0.40635   0.46717   1.01641


 Z SHUNT MATRIX(MOHM-MI)
    0.14701

    0.02135   0.15089

    0.00853   0.02121   0.14676

    0.00062   0.00122   0.00148   0.14701

    0.00122   0.00251   0.00330   0.02135   0.15089

    0.00148   0.00330   0.00534   0.00853   0.02121   0.14676
```

Figure 0-0 (Cont). Double Circuit With Ground Wires ABCCBA (Sheet 3 of 5)

Output: Sequence Parameters

```
             POWER TECHNOLOGIES, INC.
        TRANSMISSION LINE CHARACTERISTICS
        PROGRAM VER III          11-28-89

     500KV DOUBLE CIRCUIT LINE - A,B,C,A,B,C


              *SEQUENCE PARAMETERS*
               Z SERIES-11-MATRIX
                    (OHMS/MI)

           0.46087   0.01248  -0.02115
           1.91222  -0.01014  -0.00352

          -0.02115   0.03330  -0.03825
          -0.00352   0.56865   0.02237

           0.01248   0.03847   0.03330
          -0.01014   0.02190   0.56865

                  X0/X1= 3.363

               Z SERIES-12-MATRIX
                    (OHMS/MI)

           0.40944  -0.03267   0.02153
           0.92000  -0.03361  -0.03265

           0.02153  -0.00004  -0.00532
          -0.03265   0.00688   0.00059

          -0.03267   0.00587  -0.00003
          -0.03361   0.00084   0.00688

               Z SERIES-22-MATRIX
                    (OHMS/MI)

           0.46087   0.01248  -0.02115
           1.91222  -0.01014  -0.00352

          -0.02115   0.03330  -0.03825
          -0.00352   0.56865   0.02237

           0.01248   0.03847   0.03330
          -0.01014   0.02190   0.56865

                  X0/X1= 3.363
```

Figure 0-0 (Cont). Double Circuit With Ground Wires ABCCBA (Sheet 4 of 5)

Output: Sequence Parameters (Cont.)

```
          Z SHUNT-11-MATRIX
              (MOHM-MI)

  0.00000   0.00489  -0.00489
  0.18228  -0.00270  -0.00270

 -0.00489   0.00000  -0.00621
 -0.00270   0.13119   0.00357

  0.00489   0.00621   0.00000
 -0.00270   0.00357   0.13119

            X0/X1= 1.389

          Z SHUNT-12-MATRIX
              (MOHM-MI)

  0.00000  -0.00089   0.00089
  0.00682  -0.00175  -0.00175

  0.00089   0.00000  -0.00067
 -0.00175   0.00082   0.00020

 -0.00089   0.00067   0.00000
 -0.00175   0.00020   0.00082

          Z SHUNT-22-MATRIX
              (MOHM-MI)

  0.00000   0.00489  -0.00489
  0.18228  -0.00270  -0.00270

 -0.00489   0.00000  -0.00621
 -0.00270   0.13119   0.00357

  0.00489   0.00621   0.00000
 -0.00270   0.00357   0.13119

            X0/X1= 1.389
```

Figure 0-0 (Cont). Double Circuit With Ground Wires ABCCBA (Sheet 5 of 5)

```
      o                         o
      B                         B
 o          o              o          o
 A          C              A          C
```

Input

```
                POWER TECHNOLOGIES, INC.
            TRANSMISSION LINE CHARACTERISTICS
            PROGRAM VER III          11-28-89


500KV DOUBLE CIRCUIT LINE - A,B,C,A,B,C


RHO  150.0 OHM-M          FREQ  60.0 HZ



              ********************
              ***  CIRCUIT #1  ***
              ********************


         POSITION OF COND. BUNDLE CENTER


                 PHASE 1   PHASE 2   PHASE 3
       HEIGHT      53.30     73.30     53.30
     LAT. POS       0.00     34.80     69.60

  POS. OF REFERENCE: VERT    0.00 HORIZ    0.00


     REL. POS. OF SUB-COND. TO BUNDLE CENTER


                 1         2         3
REL HT        0.00      1.30      1.30
REL LAT       0.00     -0.75      0.75

SAG =  22.20                 R = 0.0978 OHM/MI
 XL = 0.3949 OHM/MI         XC = 0.0898 MOHM-MI
```

Figure B-3. Double Circuit With No Ground Wires ABCABC (Sheet 1 of 4)

Output: Phase Parameters

```
            POWER TECHNOLOGIES, INC.
        TRANSMISSION LINE CHARACTERISTICS
        PROGRAM VER III          11-28-89

     500KV DOUBLE CIRCUIT LINE - A,B,C,A,B,C


            ****PHASE PARAMETERS****

Z SERIES MATRIX(OHM/MI)
   0.12559
   1.08840

   0.09244   0.12449
   0.54218   1.08960

   0.09269   0.09244   0.12559
   0.47511   0.54218   1.08839

   0.09127   0.09155   0.09239   0.12559
   0.37260   0.39982   0.43842   1.08839

   0.09042   0.09068   0.09155   0.09244   0.12449
   0.34956   0.37327   0.39982   0.54218   1.08960

   0.09000   0.09042   0.09127   0.09269   0.09244   0.12559
   0.33104   0.34956   0.37260   0.47511   0.54218   1.08840

Z SHUNT MATRIX(MOHM-MI)
   0.15131

   0.02841   0.16347

   0.01221   0.02841   0.15131

   0.00307   0.00646   0.00782   0.15131

   0.00312   0.00624   0.00646   0.02841   0.16347

   0.00159   0.00312   0.00307   0.01221   0.02841   0.15131
```

Figure 0-0 (Cont). Double Circuit With No Ground Wires ABCABC (Sheet 2 of 4)

Output: Sequence Parameters

```
          POWER TECHNOLOGIES, INC.
      TRANSMISSION LINE CHARACTERISTICS
      PROGRAM VER III          11-28-89

   500KV DOUBLE CIRCUIT LINE - A,B,C,A,B,C


            *SEQUENCE PARAMETERS*

              Z SERIES-11-MATRIX
                   (OHMS/MI)

         0.31027   0.01993  -0.01949
         2.12845  -0.01099  -0.01177

        -0.01948   0.03270  -0.03827
        -0.01177   0.56897   0.02233

         0.01993   0.03847   0.03270
        -0.01099   0.02198   0.56897

                 X0/X1= 3.741

              Z SERIES-12-MATRIX
                   (OHMS/MI)

         0.27318  -0.02620   0.02471
      1.12890  -0.03711  -0.03859

        -0.01903  -0.00196   0.00602
         0.04124  -0.00518  -0.00341

         0.02106  -0.00596   0.00200
         0.04069  -0.00351  -0.00526

              Z SERIES-22-MATRIX
                   (OHMS/MI)

         0.31027   0.01993  -0.01948
         2.12845  -0.01099  -0.01177

        -0.01948   0.03270  -0.03827
        -0.01177   0.56897   0.02233

         0.01993   0.03847   0.03270
        -0.01099   0.02198   0.56897

                 X0/X1= 3.741
```

Figure 0-0 (Cont). Double Circuit With No Ground Wires ABCABC (Sheet 3 of 4)

Output: Sequence Parameters (Cont.)

```
        Z SHUNT-11-MATRIX
            (MOHM-MI)

  0.00000   0.00819  -0.00819
  0.20138  -0.00473  -0.00473

 -0.00819   0.00000  -0.00584
 -0.00473   0.13235   0.00337

  0.00819   0.00584   0.00000
 -0.00473   0.00337   0.13235

          X0/X1= 1.522

        Z SHUNT-12-MATRIX
            (MOHM-MI)

  0.00000  -0.00044   0.00044
  0.01365  -0.00294  -0.00294

 -0.00232   0.00013   0.00087
  0.00185  -0.00063  -0.00050

  0.00232  -0.00087  -0.00013
  0.00185  -0.00050  -0.00063

        Z SHUNT-22-MATRIX
            (MOHM-MI)

  0.00000   0.00819  -0.00819
  0.20138  -0.00473  -0.00473

 -0.00819   0.00000  -0.00584
 -0.00473   0.13235   0.00337

  0.00819   0.00584   0.00000
 -0.00473   0.00337   0.13235

          X0/X1= 1.522
```

Figure 0-0 (Cont). Double Circuit With No Ground Wires ABCABC (Sheet 4 of 4)

```
          o                         o
          B                         B
    o           o             o           o
    A           C             C           A
```

Input

```
                 POWER TECHNOLOGIES, INC.
            TRANSMISSION LINE CHARACTERISTICS
            PROGRAM VER III          11-28-89


         500KV DOUBLE CIRCUIT LINE - A,B,C,A,B,C


         RHO   150.0 OHM-M          FREQ   60.0 HZ



                   ********************
                   ***   CIRCUIT #1   ***
                   ********************


             POSITION OF COND. BUNDLE CENTER


                   PHASE 1   PHASE 2   PHASE 3
          HEIGHT     53.30     73.30     53.30
        LAT. POS      0.00     34.80     69.60

      POS. OF REFERENCE: VERT     0.00 HORIZ     0.00


         REL. POS. OF SUB-COND. TO BUNDLE CENTER


                    1          2          3
   REL HT         0.00       1.30       1.30
   REL LAT        0.00      -0.75       0.75


   SAG =   22.20                 R  = 0.0978 OHM/MI
    XL = 0.3949 OHM/MI           XC = 0.0898 MOHM-MI
```

Figure B-4. Double Circuit With No Ground Wires ABCCBA (Sheet 1 of 4)

Output: Phase Parameters

```
                    POWER TECHNOLOGIES, INC.
               TRANSMISSION LINE CHARACTERISTICS
               PROGRAM VER III          11-28-89

            500KV DOUBLE CIRCUIT LINE - A,B,C,A,B,C

                    ****PHASE PARAMETERS****


Z SERIES MATRIX(OHM/MI)
   0.12559
   1.08840

   0.09244   0.12449
   0.54218   1.08960

   0.09269   0.09244   0.12559
   0.47511   0.54218   1.08839

   0.09000   0.09042   0.09127   0.12559
   0.33104   0.34956   0.37260   1.08840

   0.09042   0.09068   0.09155   0.09244   0.12449
   0.34956   0.37327   0.39982   0.54218   1.08960

   0.09127   0.09155   0.09239   0.09269   0.09244   0.12559
   0.37260   0.39982   0.43842   0.47511   0.54218   1.08839

Z SHUNT MATRIX(MOHM-MI)
   0.15131

   0.02841   0.16347

   0.01221   0.02841   0.15131

   0.00159   0.00312   0.00307   0.15131

   0.00312   0.00624   0.00646   0.02841   0.16347

   0.00307   0.00646   0.00782   0.01221   0.02841   0.15131
```

Figure 0-0 (Cont). Double Circuit With No Ground Wires ABCCBA (Sheet 2 of 4)

Output: Sequence Parameters

```
               POWER TECHNOLOGIES, INC.
          TRANSMISSION LINE CHARACTERISTICS
          PROGRAM VER III          11-28-89

       500KV DOUBLE CIRCUIT LINE - A,B,C,A,B,C

                *SEQUENCE PARAMETERS*


                 Z SERIES-11-MATRIX
                      (OHMS/MI)

             0.31027   0.01993  -0.01949
             2.12845  -0.01099  -0.01177

            -0.01948   0.03270  -0.03827
            -0.01177   0.56897   0.02233

             0.01993   0.03847   0.03270
            -0.01099   0.02198   0.56897

                    X0/X1= 3.741

                 Z SERIES-12-MATRIX
                      (OHMS/MI)

             0.27318  -0.02620   0.02471
             1.12890  -0.03711  -0.03859

             0.02471  -0.00006  -0.00556
            -0.03859   0.00692   0.00090

            -0.02620   0.00546  -0.00006
            -0.03711   0.00089   0.00692

                 Z SERIES-22-MATRIX
                      (OHMS/MI)

             0.31027   0.01993  -0.01949
             2.12845  -0.01099  -0.01177

            -0.01948   0.03270  -0.03827
            -0.01177   0.56897   0.02233

             0.01993   0.03847   0.03270
            -0.01099   0.02198   0.56897

                    X0/X1= 3.741
```

Figure 0-0 (Cont). Double Circuit With No Ground Wires ABCCBA (Sheet 3 of 4)

Output: Sequence Parameters (Cont.)

```
      Z SHUNT-11-MATRIX
          (MOHM-MI)

 0.00000   0.00819  -0.00819
 0.20138  -0.00473  -0.00473

-0.00819   0.00000  -0.00584
-0.00473   0.13235   0.00337

 0.00819   0.00584   0.00000
-0.00473   0.00337   0.13235

        X0/X1= 1.522

      Z SHUNT-12-MATRIX
          (MOHM-MI)

 0.00000  -0.00044   0.00044
 0.01365  -0.00294  -0.00294

 0.00044   0.00000  -0.00048
-0.00294   0.00100   0.00043

-0.00044   0.00048   0.00000
-0.00294   0.00043   0.00100

      Z SHUNT-22-MATRIX
          (MOHM-MI)

 0.00000   0.00819  -0.00819
 0.20138  -0.00473  -0.00473

-0.00819   0.00000  -0.00584
-0.00473   0.13235   0.00337

 0.00819   0.00584   0.00000
-0.00473   0.00337   0.13235

        X0/X1= 1.522
```

Figure 0-0 (Cont). Double Circuit With No Ground Wires ABCCBA (Sheet 4 of 4)

```
      o                      o
      B                      C
o            o          o           o
A            C          A           B
```

Input

```
            POWER TECHNOLOGIES, INC.
       TRANSMISSION LINE CHARACTERISTICS
       PROGRAM VER III          11-28-89


    500KV DOUBLE CIRCUIT LINE - A,B,C,A,B,C


    RHO  150.0 OHM-M          FREQ  60.0 HZ




                 *******************
                 ***  CIRCUIT #1  ***
                 *******************


        POSITION OF COND. BUNDLE CENTER


              PHASE 1   PHASE 2   PHASE 3
     HEIGHT     53.30     73.30     53.30
   LAT. POS      0.00     34.80     69.60


 POS. OF REFERENCE: VERT    0.00 HORIZ    0.00


    REL. POS. OF SUB-COND. TO BUNDLE CENTER


              1         2         3
REL HT      0.00      1.30      1.30
REL LAT     0.00     -0.75      0.75

SAG =  22.20                R = 0.0978 OHM/MI
 XL = 0.3949 OHM/MI        XC = 0.0898 MOHM-MI
```

Figure B-5. Double Circuit With No Ground Wires ABCACB (Sheet 1 of 4)

Output: Phase Parameters

```
            POWER TECHNOLOGIES, INC.
       TRANSMISSION LINE CHARACTERISTICS
       PROGRAM VER III          11-28-89

    500KV DOUBLE CIRCUIT LINE - A,B,C,A,B,C

            ****PHASE PARAMETERS****


Z SERIES MATRIX(OHM/MI)

   0.12559
   1.08840

   0.09244   0.12449
   0.54218   1.08960

   0.09269   0.09244   0.12559
   0.47511   0.54218   1.08839

   0.09127   0.09155   0.09239   0.12559
   0.37260   0.39982   0.43842   1.08838

   0.08981   0.09014   0.09101   0.09224   0.12449
   0.33082   0.35050   0.37200   0.47080   1.08962

   0.09065   0.09101   0.09187   0.09294   0.09244   0.12560
   0.34992   0.37200   0.40091   0.55894   0.54218   1.08837

Z SHUNT MATRIX(MOHM-MI)
   0.15131

   0.02841   0.16347

   0.01221   0.02841   0.15131

   0.00307   0.00646   0.00782   0.15130

   0.00233   0.00452   0.00436   0.01517   0.16348

   0.00216   0.00436   0.00468   0.02684   0.02841   0.15130
```

Figure 0-0 (Cont). Double Circuit With No Ground Wires ABCACB (Sheet 2 of 4)

Output: Sequence Parameters

```
        POWER TECHNOLOGIES, INC.
   TRANSMISSION LINE CHARACTERISTICS
   PROGRAM VER III          11-28-89

500KV DOUBLE CIRCUIT LINE - A,B,C,A,B,C

         *SEQUENCE PARAMETERS*


          Z SERIES-11-MATRIX
               (OHMS/MI)

      0.31027   0.01993  -0.01949
      2.12845  -0.01099  -0.01177

     -0.01948   0.03270  -0.03827
     -0.01177   0.56897   0.02233

      0.01993   0.03847   0.03270
     -0.01099   0.02198   0.56897

            X0/X1= 3.741

          Z SERIES-12-MATRIX
               (OHMS/MI)

      0.27323  -0.02644   0.02494
      1.12899  -0.03708  -0.03857

      0.02106  -0.00560   0.00213
      0.04018  -0.00249  -0.00619

     -0.01907  -0.00207   0.00565
      0.04166  -0.00621  -0.00250

          Z SERIES-22-MATRIX
               (OHMS/MI)

      0.31031  -0.02485   0.02532
      2.13674  -0.00878  -0.00983

      0.02532   0.03268   0.05133
     -0.00983   0.56482   0.01792

     -0.02485  -0.05117   0.03268
     -0.00878   0.01809   0.56482

          X0/X1= 3.783
```

Figure 0-0 (Cont). Double Circuit With No Ground Wires ABCACB (Sheet 3 of 4)

Output: Sequence Parameters (Cont.)

```
             Z SHUNT-11-MATRIX
                 (MOHM-MI)

        0.00000    0.00819   -0.00819
        0.20138   -0.00473   -0.00473

       -0.00819    0.00000   -0.00584
       -0.00473    0.13235    0.00337

        0.00819    0.00584    0.00000
       -0.00473    0.00337    0.13235

               X0/X1= 1.522

             Z SHUNT-12-MATRIX
                 (MOHM-MI)

        0.00000   -0.00044    0.00044
        0.01326   -0.00285   -0.00285

        0.00000   -0.00044    0.00030
        0.00205   -0.00049   -0.00073

        0.00000   -0.00030    0.00044
        0.00205   -0.00073   -0.00049

             Z SHUNT-22-MATRIX
                 (MOHM-MI)

        0.00000    0.00015   -0.00015
        0.20230   -0.00450   -0.00450

       -0.00015    0.00000    0.01025
       -0.00450    0.13189    0.00291

        0.00015   -0.01025    0.00000
       -0.00450    0.00291    0.13189

               X0/X1= 1.534
```

Figure 0-0 (Cont). Double Circuit With No Ground Wires ABCACB (Sheet 4 of 4)

```
              x               x

                      o
                      B

        o                          o
        A                          C
```

Input

```
                 POWER TECHNOLOGIES, INC.
            TRANSMISSION LINE CHARACTERISTICS
            PROGRAM VER III          11-28-89


            500KV SINGLE CIRCUIT LINE - A,B,C


         RHO   150.0 OHM-M          FREQ   60.0 HZ




                    ********************
                    ***  CIRCUIT #1  ***
                    ********************


             POSITION OF COND. BUNDLE CENTER


                     PHASE 1    PHASE 2    PHASE 3
            HEIGHT     53.30      73.30      53.30
          LAT. POS      0.00      34.80      69.60


      POS. OF REFERENCE: VERT     0.00 HORIZ     0.00


         REL. POS. OF SUB-COND. TO BUNDLE CENTER
```

Figure B-6. Single Circuit With Ground Wires ABC (Sheet 1 of 3)

Output: Phase Parameters

```
    POWER TECHNOLOGIES, INC.
TRANSMISSION LINE CHARACTERISTICS
PROGRAM VER III          11-28-89

500KV SINGLE CIRCUIT LINE - A,B,C

    ****PHASE PARAMETERS****


Z SERIES MATRIX(OHM/MI)
   0.16173
   1.04478

   0.13392   0.17235
   0.49406   1.03643

   0.12839   0.13392   0.16173
   0.43170   0.49406   1.04478

Z SHUNT MATRIX(MOHM-MI)
   0.14705

   0.02144   0.15107

   0.00864   0.02144   0.14705
```

Figure 0-0 (Cont). Single Circuit With Ground Wires ABC (Sheet 2 of 3)

Output: Sequence Parameters

```
     POWER TECHNOLOGIES, INC.
TRANSMISSION LINE CHARACTERISTICS
PROGRAM VER III          11-28-89

500KV SINGLE CIRCUIT LINE - A,B,C

      *SEQUENCE PARAMETERS*

        Z SERIES-11-MATRIX
            (OHMS/MI)

   0.42943   0.01290  -0.01828
   1.98854  -0.01366  -0.00434

  -0.01828   0.03319  -0.03834
  -0.00434   0.56872   0.02231

   0.01290   0.03849   0.03319
  -0.01366   0.02205   0.56872

          X0/X1= 3.497

        Z SHUNT-11-MATRIX
            (MOHM-MI)

   0.00000   0.00486  -0.00486
   0.18273  -0.00280  -0.00280

  -0.00486   0.00000  -0.00623
  -0.00280   0.13122   0.00360

   0.00486   0.00623   0.00000
  -0.00280   0.00360   0.13122

          X0/X1= 1.393
```

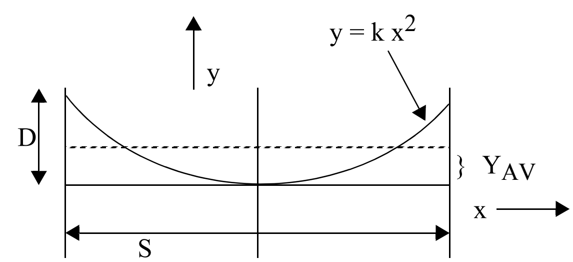
Figure 0-0 (Cont). Single Circuit With Ground Wires ABC (Sheet 3 of 3)

Appendix C

Effective Height of a Transmission Line

Transmission line inductances and capacitances are functions of conductor height. The derivation of the line equations assume parallel conductors horizontal with the surface of the earth. While lower voltage lines have a negligible sag, the spacing between towers on EHV transmission lines results in an appreciable sag. It would be extremely difficult to account for the nonhorizontal effect of the conductor in an exact sense. However, an adequate correction is obtained by using the average conductor height. This is satisfactory because the height of the conductor comes into the calculation as an argument of a logarithm term. Minor errors in the argument of a logarithm term have only a small effect on the logarithm.

A conductor under tension hangs in a catinary curve, and for short spans this equation can be approximated by a parabola. The average height above the midspan height can be calculated using the following diagram of the span sag.



Note:k = w/2H
where:
H = Conductor tension.
w = Weight per unit length.

The average height over a span S with a sag D can be found by finding the average area under the parabola.

$$S \times Y_{AV} = k \int_{-\frac{S}{2}}^{\frac{S}{2}} x^2 dx = k \left. \frac{x^3}{3} \right|_{-\frac{S}{2}}^{\frac{S}{2}} = 2\frac{\left(\frac{S}{2}\right)^3}{3}k$$

$$Y_{AV} = \frac{1}{3}\left(\frac{S}{2}\right)^2 k$$

But, for the system defined above, the sag is defined by the formula for the parabola evaluated for x = S/2, y = D.

$$Sag = D = \left(\frac{S}{2}\right)^2 k$$

Therefore, the average height is:

$$Y_{AV} = \frac{SAG}{3}$$

SIEMENS

Appendix D

Effect of Earth Resistivity on Zero Sequence Parameters

The effect of the earth resistivity on the zero sequence transmission line parameters for a typical 500 kV configuration is shown on Figure D-1. Illustrated are the results for two cases: 1) with steel ground wires, and 2) with no ground wires. It should be noted that the change in the steel ground wire characteristics with load was not considered.

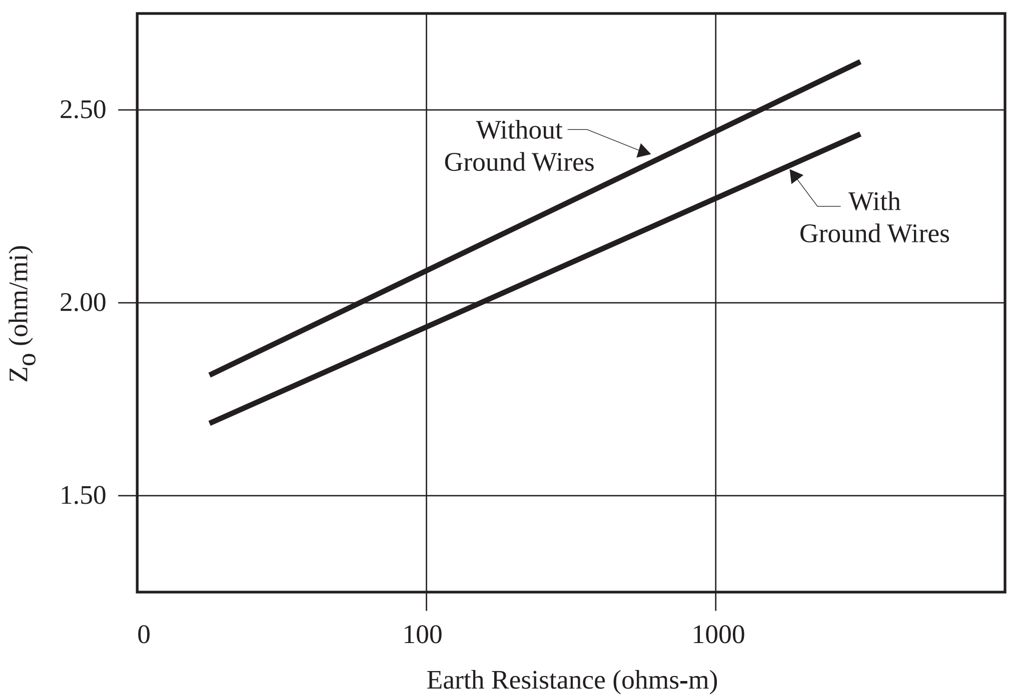


Figure D-1. A Typical 500 kV Configuration

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Appendix E

Conductor Data File

The only data in the conductor data file used by TMLC for calculations are RDC, RAC, XL, and XC; AMPS is merely used as a rating. The following summarizes the significance, units, and origin of all terms in the conductor data file.

Data units are as follows:

RDC	ohms/mi at 25°C.
RAC	ohms/mi at 25°C.
XL	ohms/mi.
XC	Mohm-mi.
AMPS	Ampacity based on 40°C conductor temperature rise over 40°C ambient with 2 ft/sec crosswind, 0.5 emissivity, and no sun.
KCMIL	Aluminum cross-sectional area in thousands of circular mils.
OD	Conductor diameter in inches.
STRANDING	Number of aluminum strands/number of core strands.
OD-OUTER	Aluminum strand diameter, or if not round, effective diameter, in inches.
UTS	Rated breaking strength of the conductor in pounds (lb).
S-S	Stress-strain curve number for the conductor and refers to a polynomial curve in file wires.stress.dat (not used in TMLC).
AREA	Total cross-sectional area of the conductor in square inches includes the core area.
#STD-OL	Number of strands in outer layer.
WEIGHT	Total conductor weight in lb/1000 ft.

There are many references for the data contained in the TMLC conductor data file. RDC, UTS, and WEIGHT were calculated based on the methods described in the following ASTM standards:

- B231 for AAC.
- B232 for ACSR.
- B397-5005 and B399-6201 for AAAC.

- B524 for ACAR.
- B549 for ACSR/AW.
- B7-1 for ACSR/SD.

The tensile strength of the strands is a function of strand diameter as described in the standards and adjustment of resistance, strength and weight to account for helical stranding is also described.

The following material conductivities and temperature coefficients of resistivity were assumed:

1350-H19 aluminum:	61.2% at 20°C with 0.00404 C-1
1350-H0 aluminum:	63.0% at 20°C
5005 aluminum:	53.5% at 20°C with 0.00353 C-1
6201 aluminum:	52.5% at 20°C with 0.00347 C-1
Galvanized steel core:	8.0% at 20°C with 0.00320 C-1
AW steel core:	20.0% at 20°C with 0.00360 C-1

RAC equals RDC multiplied by a skin effect factor first calculated by H.B. White. The factor for the various conductors is derived from Figure 3-8 in the *Aluminum Association Electrical Conductor Handbook*. For SDC and T2 conductors, the skin effect factor was supplied by the manufacturer. One may expect RAC values given in the table to be within 0.5% of the value calculated in the suggested manner. Small differences result from errors in reading the skin effect ratio graph. A further correction could be made to the AC resistance of single layer (6/1, 7/1, 12/7, 16/19, 8/1) ACSR and three layer (42/7, 45/7, 48/7, 54/7, 54/19) ACSR due to magnetic flux effects in the steel core. The RAC correction is a function of the current on the conductor. The correction for single layer ACSR can reach about 20% whereas the correction for three layer ACSR is typically less than 5%.

The correction for single layer ACSR is in Table 4-15 of the *Aluminum Association Electrical Conductor Handbook*. The correction for three layer ACSR may be taken from the IEEE paper 84 SM 700-1, "AC Resistance of ACSR - Magnetic and Temperature Effects."

XL and XC are primarily taken from the EPRI "Red Book."

The calculation of the overhead line conductor constants, X_L and X_C are from Lackey (page 147):

$$L = 0.08 + 0.74\log(D/r)\ \text{mH/mi}$$

and from Clarke Vol. 1 (page 445):

for a 2-wire system, $C = 0.03883/(\log(D/r))\ \text{uFarad/mi}$

where:

D = Distance between centers of two wires.

r = Radius of the wire.

provided both are in the same unit.

As an example, for 175 mm^2 ACSR conductor:

$$r = 9.765\ \text{mm}$$

$D = 304.8 \text{ mm}$ (i.e., 1 ft. spacing)

$L = 0.08 + 0.74 \log(304.8/9.765) = 1.1858 \text{ mH/mile}$

$X_L = wL$

If f = 50 Hz, $X_L = 0.37253 \text{ ohms/mi}$

If f = 60 Hz, $X_L = 0.44704 \text{ ohms/mi}$

$C = 0.03883/(\log(304.8/9.765)) \text{ uFarad/mi} = 0.02598 \text{ uF/mi}$

$X_C = 1/wC$

If f = 50 Hz, $X_C = 0.12250 \text{ Mohm-mi}$

If f = 60 Hz, $X_C = 0.10208 \text{ Mohm-mi}$

Further information can be found in the following sources:

- "Fault Calculations," Lackey, pp. 147-149.
- "Circuit Analysis of AC Power Systems," Clarke, Vol. 1, pp. 444-445.
- "Electrical Power Systems." Guile & Paterson, pp.114-115.
- "Electric Power Systems." Weedy, pp. 114-116.
- "The Transmission & Distribution of Electrical Energy." Cotton & Barber, pp. 81-93.

AMPS is taken from the *Alcoa Bare Overhead Conductor Product Data Book*. The tabulated value in amperes should be taken as accurate within 1%. The relatively larger ampacity of T2 conductors is due to their larger circumference per kcmil. This advantage is balanced by greater solar heat input, and thus reduced ampacity when ampacity is calculated with the sun.

KCMIL is equal to the outer strand diameter (or effective strand diameter) in mils squared times the number of such strands, and in the case of ACAR, plus the inner strand diameter in mils squares times the number of inner strands.

OD is used in wind and ice load calculations. It is 10% reduced for /TW and /SD conductors. For T2 conductors, the OD is an effective OD that represents the increased ice and wind load of its "figure eight" cross-section.

STRANDING for standard homogeneous conductors, such as AAC, AAAC6201, AAAC5005, Alumoweld, and HS and EHS Shield Wire, is simply the total number of strands. For standard composite conductors, such as ACSR, ACSR/AW, ACSR/EHS, and ACAR, it is the ratio of the number of outer to the number of inner strands. This is also true for SSAC which has round but full annealed aluminum strands over a standard steel core. For ACSR/SD, ACSR/TW and ACSR/OD conductors, which consist of trapezoidal aluminum strands over a stranded steel core, the STRANDING is the ratio of the effective number of round aluminum strands (OD-OUTER is the effective diameter of these strands) to the actual number of steel core strands. This is done in order to allow the proper calculation of conductor cost by programs such as PTI's TLOP. Note that the calculation of radio noise will be incorrect for ACSR/SD, ACSR/OD and ACSR/TW conductors. The other odd case is that with T2-ACSR conductors. Here the OD-OUTER is the actual diameter of the aluminum strands and the STRANDING is the ratio of the total number of aluminum strands in the two subconductors to the total number of steel core strands in the subconductors. Thus T2/IBIS which is made up of two 26/7 conductors is given a stranding of 52/14.

#STD-OL is the number of strands in the outer layer for standard conductors. For non-standard conductors, it is equal to the number of strands in the outer layer of the equivalent standard conductor.

The conductor types listed are:

1. Multilayer ACSR.
2. Single-layer ASCR.
3. Single-layer high-strength aluminum.
4. All aluminum.
5. All aluminum alloy conductor 5005.
6. All aluminum alloy conductor 6201.
7. Aluminum conductor-alloy-reinforced.
8. Aluminum clad-steel (Alumoweld)
9. Extra-high-strength steel.

The following conductors are contained in the conductor data file:

AAAC5005
(All Aluminum Alloy Conductor)

SOLAR	RAGOUT	KITTLE	KAZOO
SPAR	REDE	KOPECK	AN587
RUNE	RADIAN	KAYAK	IN604
RUBLE	RADAR	KIBE	IN649
REMEX	RAMIE	KENCH	AN659
REX	RATCH	KAKI	AN759

AAAC6201
(All Aluminum Alloy Conductor)

GREELEY	AMES	T621AG	T182NG
FLINT	ALTON	T851NG	T182AG
ELGIN	AKRON	T851AG	T228NG
DARIEN	FPL3	T1144NG	T228AG
CAIRO	ALCAN1	T1144AG	T288NG
CANTON	REYN2	T1600NG	T288AG
BUTTE	T289NG	T1600AG	T366NG
ALLIANCE	T289AG	T117NG	T366AG
AMHERST	T445NG	T117AG	T570NG
ANAHEIM	T445AG	T148AG	T570AG
AZUSA	T621NG	T148NG	

AAC
(All Aluminum Alloy Conductor)

BLUEBONNET	T2DAHLIA	VIOLET	DAISY
TRILLIUM	MARIGOLD	FLAG	VALERIAN
LUPINE	LARKSPUR	VERBENA	SNEEZEWORT
T2MARIGOLD	BLUEBELL	T2TULIP	OXLIP
T2BLUEBELL	HAWKWEED	ORCHID	PHLOX
COWSLIP	CAMELLIA	MEADOWSWEET	ASTER
T2COCKSCOMB	GOLDENROD	MISTLETOE	POPPY
JESSAMINE	MAGNOLIA	DAHLIA	PANSY
COREOPSIS	T2COSMOS	T2DAISY	IRIS
T2ARBUTUS	SNAPDRAGON	HYACINTH	ROSE
GLADIOLUS	COCKSCOMB	ZINNIA	PEACHBELL
CARNATION	CROCUS	SYRINGA	
T2VIOLET	ANEMONE	COSMOS	
COLUMBINE	LILAC	GOLDENTUFT	
T2GLOXINIA	ARBUTUS	CANNA	
T2ORCHID	T2CANNA	DAFFODIL	
NARCISSUS	CATTAIL	TULIP	
HAWTHORN	PETUNIA	PEONY	
T2DAYLILLY	NASTURTIUM	LAUREL	

ACAR
(Aluminum Conductor Alloy Reinforced)

2300_1	BUNTING1	RAIL2	DOVE1
2300_2	BUNTING2	RAIL3	DOVE2
2300_3	BUNTING3	RAIL4	PELICAN1
BLUEBIRD1	BLUEJAY1	RAIL5	PELICAN2
BLUEBIRD2	BLUEJAY2	DRAKE1	MERLIN1
BLUEBIRD3	BLUEJAY3	DRAKE2	MERLIN2
KIWI1	CURLEW1	DRAKE3	ACAR900.1
KIWI2	CURLEW2	DRAKE4	ACAR2000.1
KIWI3	CURLEW3	DRAKE5	ACAR1600.1
CHUKAR1	CURLEW4	DRAKE6	ACAR1000.1
CHUKAR2	ORTOLAN1	TERN1	ACAR1000.2
CHUKAR3	ORTOLAN2	TERN2	ACAR1200.1
LAPWING1	ORTOLAN3	TERN3	ACAR1200.2
LAPWING2	CARDINAL1	GROSBEAK1	CHAMERA
LAPWING3	CARDINAL2	GROSBEAK2	1500_1
BITTERN1	CARDINAL3	GROSBEAK3	1081_1
BITTERN2	RAIL1	GROSBEAK4	

ACSR
(Aluminum Conductor Steel Reinforced)

JOREE	FALCON/SD	DIPPER	BUNTING/SD
KINGFISHER	FALCON/SSAC	FRIGATE/SD	BUNTING/SSAC
THRASHER	FALCON	MARTIN/SD	BUNTING
T2BLUEJAY	BITTERN/OD	MARTIN/SSAC	GRACKLE/SD
KIWI/SD	NUTHATCH/SSAC	MARTIN	GRACKLE/SSAC
KIWI	HUTHATCH/SSA	T2JAEGER	GRACKLE
BLUEBIRD/SD	NUTHATCH	T2FLAMINGO	RAIL/OD
BLUEBIRD/SSAC	PARROT/SSAC	SCISSORTL/SD	T2KINGLET
BLUEBIRD/SSA	PARROT	BITTERN/TW	BLUEJAY/SD
BLUEBIRD	BUNTING/OD	BITTERN/SD	BLUEJAY/SSAC
T2ORTOLAN	POPINJAY/SD	BITTERN/SSAC	BLUEJAY
T2TWINSTONE	BOBOLINK/SD	BITTERN	FINCH/SD
SMEW/SD	BOBOLINK/SSAC	T2TURACOS	FINCH/SSAC
CHUKAR/SD	BOBOLINK/SSA	PHEASANT/SD	FINCH
CHUKAR/SSAC	BOBOLINK	PHEASANT/SSAC	T2PARAKEET
CHUKAR	T2DUNLIN	PHEASANT/SSA	SNOWBIRD/SD
DIPPER/OD	PLOVER/SD	PHEASANT	T2FLYCATCHER
LAPWING/TW	PLOVER/SSAC	T2ROOK	ORTOLAN/TW
LAPWING/SD	PLOVER	ORTOLAN/OD	ORTOLAN/SD
LAPWING/SSAC	RINGDOVE/SD	T2SKUA	ORTOLAN/SSAC
LAPWING	DIPPER/SD	OXBIRD/SD	ORTOLAN
T2TURBIT	DIPPER/SSAC	T2KITTIWAKE	T2CREEPER

CURLEW/SD	TURBIT	GROSBEAK/SSA	LINNET/SD
CURLEW/SSAC	PUFFIN/SD	GROSBEAK	LINNET/SSAC
CURLEW	PUFFIN	EGRET/SSAC	LINNET
NONAME	CONDOR/SD	EGRET	ORIOLE/SSAC
TERN/OD	CONDOR/SSAC	SCOTER	ORIOLE
PHOENIX/SD	CONDOR	DUCK	PHOEBE
T2PELICAN	CUCKOO	PEACOCK/SSAC	GADWALL
T2TATLER	DRAKE/SD	PEACOCK	OSTRICH/SSAC
CORNCRAKE	DRAKE/SSAC	SQUAB/SSAC	OSTRICH
RAIL/TW	DRAKE	SQUAB	PIPER/SSAC
RAIL/SD	T2IBIS	TEAL/SSAC	PIPER
RAIL/SSAC	MALLARD/SSAC	TEAL	WAXWING
RAIL	MALLARD	WOODDUCK	PARTRIDGE/SD
NOCODE	SKIMMER	OSPREY	PARTRIDGE
CARDINAL/SD	GROSBEAK/OD	PARAKEET/SD	JUNCO
CARDINAL/SSAC	GREBE	PARAKEET/SSAC	PENGUIN
CARDINAL/SSA	CROW	PARAKEET/SSA	PIGEON
CARDINAL	STILT/SSAC	PARAKEET	QUAIL
REDBIRD	STILT	DOVE/SD	RAVEN
T2HAWK	STARLING/SSAC	DOVE/SSAC	ROBIN
MER-GANSER/SSAC	STARLING/SSA	DOVE	SPARROW
MERGANSER/SS	STARLING	EAGLE/SSAC	SPARATE
MERGANSER	REDWING/SSAC	EAGLE	SWAN
TURNSTONE	REDWING	T2WAXWING	SWANATE
RUDDY/SSAC	BUTEO	T2PARTRIDGE	TURKEY
RUDDY	T2MERLIN	PELICAN	ALCAN2
NOWORD	T2LINNET	FLICKER/SD	ALCAN3
REDSTART	GULL	FLICKER/SSAC	ALCAN4
CANARY/SSAC	FLAMINGO/SSAC	FLICKER	JOREE/TW
CANARY	FLAMINGO/SSA	HAWK/SD	THRASHER/TW
BALDPATE/SSAC	FLAMINGO	HAWK/SSAC	BLUEBIRD/TW
BALDPATE/SSA	GANNET/SSAC	HAWK	FALCON/TW
BALDPATE	GANNET	HEN/SSAC	MARTIN/TW
WILLET	DOVE/OD	HEN	PHEASANT/TW
CRANE	SWIFT	CHICKADEE	CURLEW/TW
COOT	PIPIT/SD	BRANT/SSAC	CARDINAL/TW
MACAW/SD	KINGBIRD	BRANT	DRAKE/TW
T2CHICKADEE	KILLDEER/SD	IBIS/SD	CUCKOO/TW
T2PTARMIGAN	ROOK/SD	IBIS/SSAC	FLAMINGO/TW
TERN/TW	ROOK/SSAC	IBIS	FLICKER/TW
TERN/SD	ROOK	LARK/SSAC	SQUIRREL
TERN/SSAC	GOOSE	LARK	GOPHER
TERN	GROSBEAK/SD	MERLIN	WEASEL
	GROSBEAK/SSAC	WIDGEON	FOX

FERRET	BEAR	LAPWING/OD	TA147NG
RABBIT	GOAT	CHUKAR/TW	TA153AG
MINK	SHEEP	T2GROSBEAK	TA198AG
BEAVER	ANTELOPE	DOG	TA210AG
RACCOON	BISON	TA116AG	TA248AG
OTTER	DEER	TA21ONG	TA281AG
CAT	ZEBRA	TA248NG	TA298AG
COUGAR	ELK	TA281NG	TA329AG
HARE	CAMEL	TA298NG	TA445AG
TIGER	MOOSE	TA515NG	TA515AG
DINGO	SPEC6	TA116NG	TA617AG42
WOLF	SPEC5	TA153NG	MORCULLA
CARACAL	SPEC4	TA198NG	GATINEAU
LYNX	SPEC3	TA329NG	BERSIMIS
JAGUAR	SPEC2	TA445NG	SNOWBIRD
PANTHER	SPEC1	TA617NG42	
LION	KATE1	TA147AG	

ACSR/AW
(Aluminum Conductor Steel Reinforced with ALUMOWELD Core)

JOREE/AW	BLUEJAY/AW	ROOK/AW	MERLIN/AW
KINGFISHER/AW	CURLEW/AW	KINGBIRD/AW	OSTRICH/AW
THRASHER/AW	ORTOLAN/AW	TEAL/AW	PARTRIDGE/AW
KIWI/AW	CARDINAL/AW	SQUAB/AW	WAXWING/AW
BLUEBIRD/AW	RAIL/AW	PEACOCK/AW	PENGUIN/AW
CHUKAR/AW	CANARY/AW	EAGLE/AW	PIGEON/AW
FALCON/AW	RUDDY/AW	DOVE/AW	QUAIL/AW
LAPWING/AW	CRANE/AW	PARAKEET/AW	RAVEN/AW
PARROT/AW	MALLARD/AW	OSPREY/AW	ROBIN/AW
NUTHATCH/AW	DRAKE/AW	HEN/AW	SPARATE/AW
PLOVER/AW	CONDOR/AW	HAWK/AW	SPARROW/AW
BOBOLINK/AW	TERN/AW	FLICKER/AW	SWANATE/AW
MARTIN/AW	REDWING/AW	PELICAN/AW	SWAN/AW
DIPPER/AW	STARLING/AW	LARK/AW	TURKEY/AW
PHEASANT/AW	CROW/AW	IBIS/AW	ALCOA1
BITTERN/AW	GANNET/AW	BRANT/AW	ALCOA2
GRACKLE/AW	FLAMINGO/AW	CHICKADEE/AW	REYN1
BUNTING/AW	EGRET/AW	ORIOLE/AW	REYN3
FINCH/AW	GROSBEAK/AW	LINNET/AW	

ACSR/EHS

BRAHMA	DOTTEREL	MINORCA
COCHIN	GUINEA	PETREL
DORKING	LEGHORN	GROUSE

ALUMOWELD

37#5AW	19#5AW	7#5AW	3#5AW
37#6AW	19#6AW	7#6AW	3#6AW
37#7AW	19#7AW	7#7AW	3#7AW
37#8AW	19#8AW	7#8AW	3#8AW
37#9AW	19#9AW	7#9AW	3#9AW
37#10AW	19#10AW	7#10AW	3#10AW

CU

CU2	3#8CW	4/OEK-CWC	19#8CW
CU1/0	3#9CW	3/OEK-CWC	19#9CW
CU4/0	3#10DW	2/OK-CWC	7#4CW
CU250	350E-CWC	1/OK-CWC	7#6CW
CU500	300E-CWC	1K-CWC	7#7CW
CU1000	250E-CWC	2K-CWC	7#8CW
3#5CW	350EK-CWC	19#5CW	7#9CW
3#6CW	300EK-CWC	19#6CW	7#10CW
3#7CW	250EK-CWC	19#7CW	

EHS
(Extra-High-Strength Steel)

5/8EHS	7/16EHS	5/16EHS
1/2EHS	3/8EHS	

HS
(High-Strength Steel)

5/8HS
1/2HS
7/16HS
3/8HS