DC-TN-2065-2

Sensor and Simulation Notes

Note 62

A Parameter Study of Open-Circuited and Short-Circuited Transmission Line Simulation for Buried Structures of EMP Sensor and Simulation Note XXII

by

Terry L. Brown

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The Dikewood Corporation
1009 Bradbury Drive, S. E.
University Research Park
Albuquerque, New Mexico 87106

CONTENTS

ABSTRACT

The magnitude of open-circuited and short-circuited transmission line impedances versus frequency are graphed for various values of the geometric factor, depth of the transmission line and ground conductivity. A computer code that produces the plots for any value of the parameters is described and listed.

I. INTRODUCTION

In this note the influence of three parameters on the frequency versus the magnitude of the impedance for a buried transmission line simulator is studied; the study is based on an analysis by Carl E. Baum.* The simulator consists of two parallel plates of width 2a, separated by a distance of 2b, and a depth into the ground of ℓ. The geometry of the configuration is shown in Figure 1.

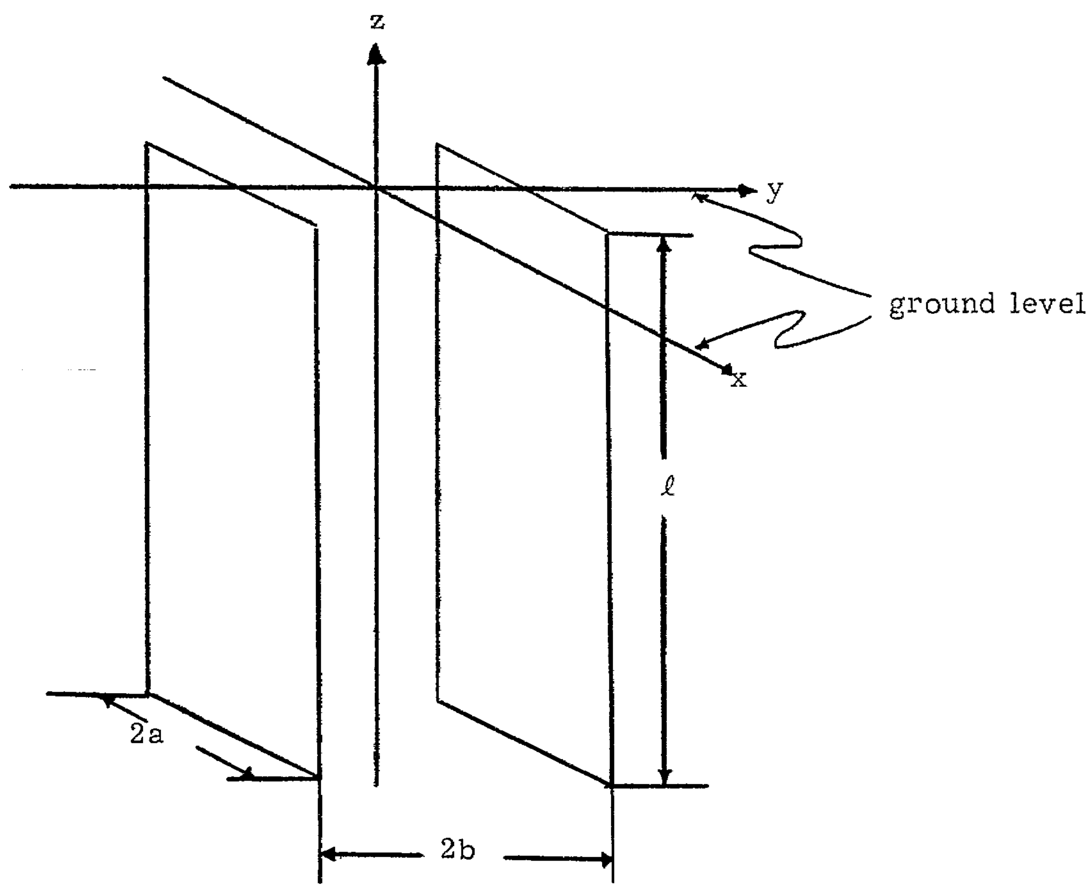

Figure 1

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* C. E. Baum, "A Transmission Line EMP Simulation Technique for Buried Structures," EMP Sensor and Simulation Note XXII, June 6, 1966.

The limit of our concern in this note is to compare frequency to the impedance of the open-circuited and short-circuited transmission line for various plate-depths, ground conductivity and geometric factors. A computer code that can easily be used to produce graphs for any value of the parameters is included since not all interesting combinations can be presented here.

II. OPERATION

General

The plots contained in this note were produced on the Calcomp Plotter. Each graph is logarithmic vertically and logarithmic horizontally with 150 points plotted along each curve. The heading of each graph contains the three parameters, that is, plate depth (L), conductivity, and the geometric factor.

Practically, it is more desirable to describe the geometry of the simulator in terms of the ratio of the plate separation to the plate width (b/a) than in terms of the geometric factor (f_g). For this reason, provisions have been made to list b/a to clarify the geometry. However, it should be noted that f_g and not b/a is necessary for the calculations in the program. The code does not calculate f_g from b/a. If the geometric factor is not known for a given b/a it can be determined with the computer code described in EMP Sensor and Simulation Note LII[1].

The impedances for the two curves of each graph are given by equations (1) and (2), below. These values are computed and plotted for various combinations of the parameters. Since these quantities are generally complex, the magnitude of each is plotted against frequency. The frequency is in cycles per second. The curves are distinguished by tagging

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* T. L. Brown and K. D. Granzow, "A Parameter Study of Two-Plate Transmission Line Simulators of EMP Sensor and Simulation Note XXI," EMP Sensor and Simulation Note LII, April 19, 1968.

them with $\left|Z_{L_o}\right|$ and $\left|Z_{L_s}\right|$ for the magnitude of the open-circuited and magnitude of the short-circuited transmission line impedance, respectively.

Accepting from Note XXII, along with their restrictions, we have the open-circuited transmission line impedance

$$Z_{L_o} = Z_{L_\infty} \frac{1 + e^{-j2k\ell}}{1 - e^{-j2k\ell}} \tag{1}$$

and the short-circuited transmission line impedance

$$Z_{L_s} = Z_{L_\infty} \frac{1 - e^{-j2k\ell}}{1 + e^{-j2k\ell}} \tag{2}$$

The impedance of an infinite or ideal transmission line is given by

$$Z_{L_\infty} = f_g \frac{1 + j}{\delta\sigma} \tag{3}$$

where the propagation constant, k, is

$$k \simeq \frac{1 - j}{\delta} \tag{4}$$

and skin depth is

$$\delta \simeq \sqrt{\frac{2}{\omega\mu\sigma}} = \sqrt{\frac{1}{\pi f \mu\sigma}} \tag{5}$$

A description of the variables is as follows:

Variable	Designation	Unit of Measure
μ	Ground permeability	$\mu = \mu_o = 4\pi \times 10^{-7}$ henrys/meter
f_g	Geometric factor	
σ	Ground conductivity	mhos/meter
k	Propagation constant	
f	Frequency	cycles/second
ℓ	Plate depth	meters
δ	Skin depth	

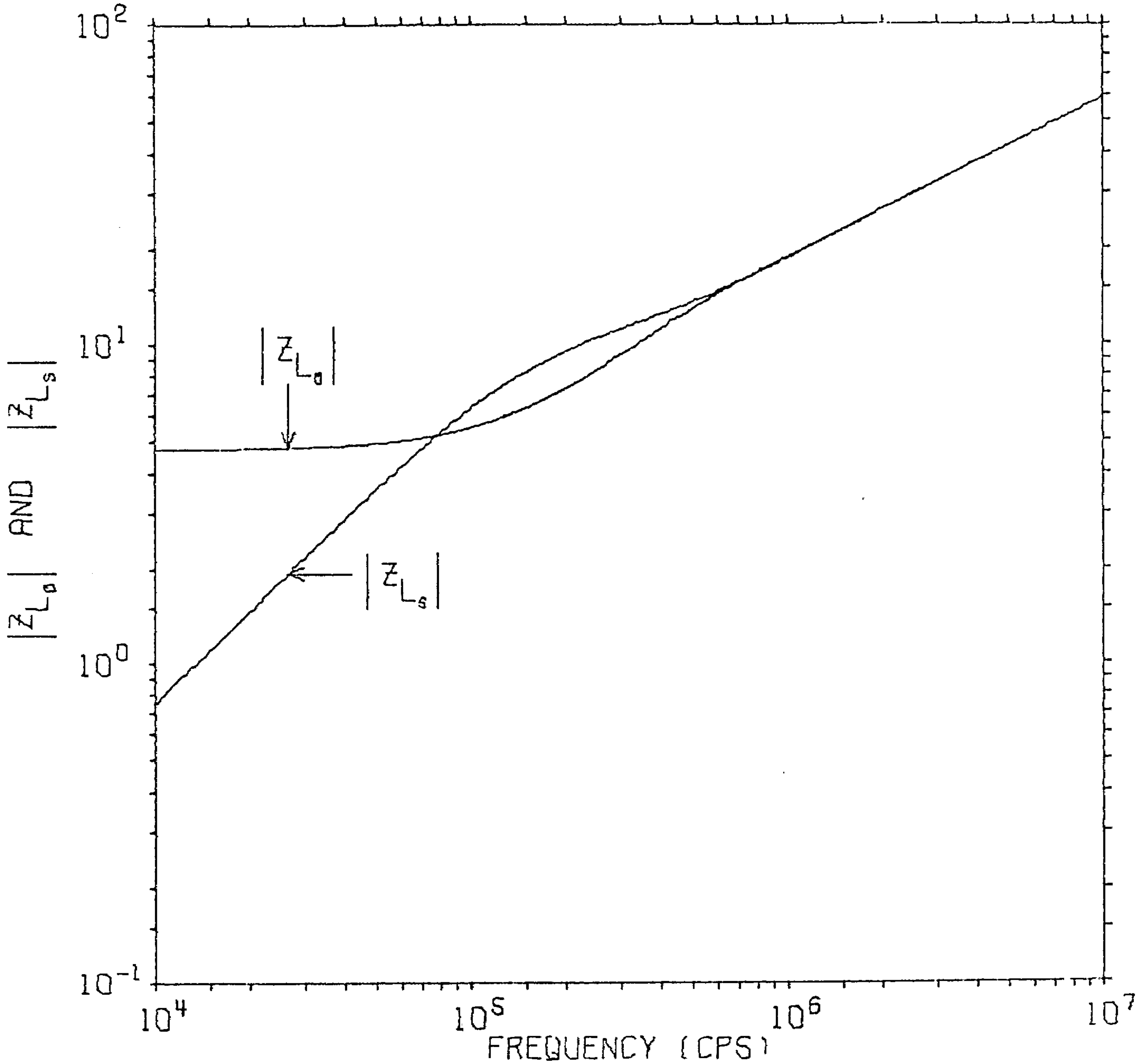
The table below summarizes the graphs found in this note.

f_g	b/a	ℓ	σ
.47263959	1.0	20.0	5.00×10^{-3}
		20.0	8.00×10^{-3}
		20.0	1.10×10^{-2}
		20.0	3.00×10^{-2}
		40.0	5.00×10^{-3}
		40.0	8.00×10^{-3}
		40.0	1.10×10^{-2}
		40.0	3.00×10^{-2}
		60.0	5.00×10^{-3}
		60.0	8.00×10^{-3}
		60.0	1.10×10^{-2}
		60.0	3.00×10^{-2}
		80.0	5.00×10^{-3}
		80.0	8.00×10^{-3}
		80.0	1.10×10^{-2}
		80.0	3.00×10^{-2}

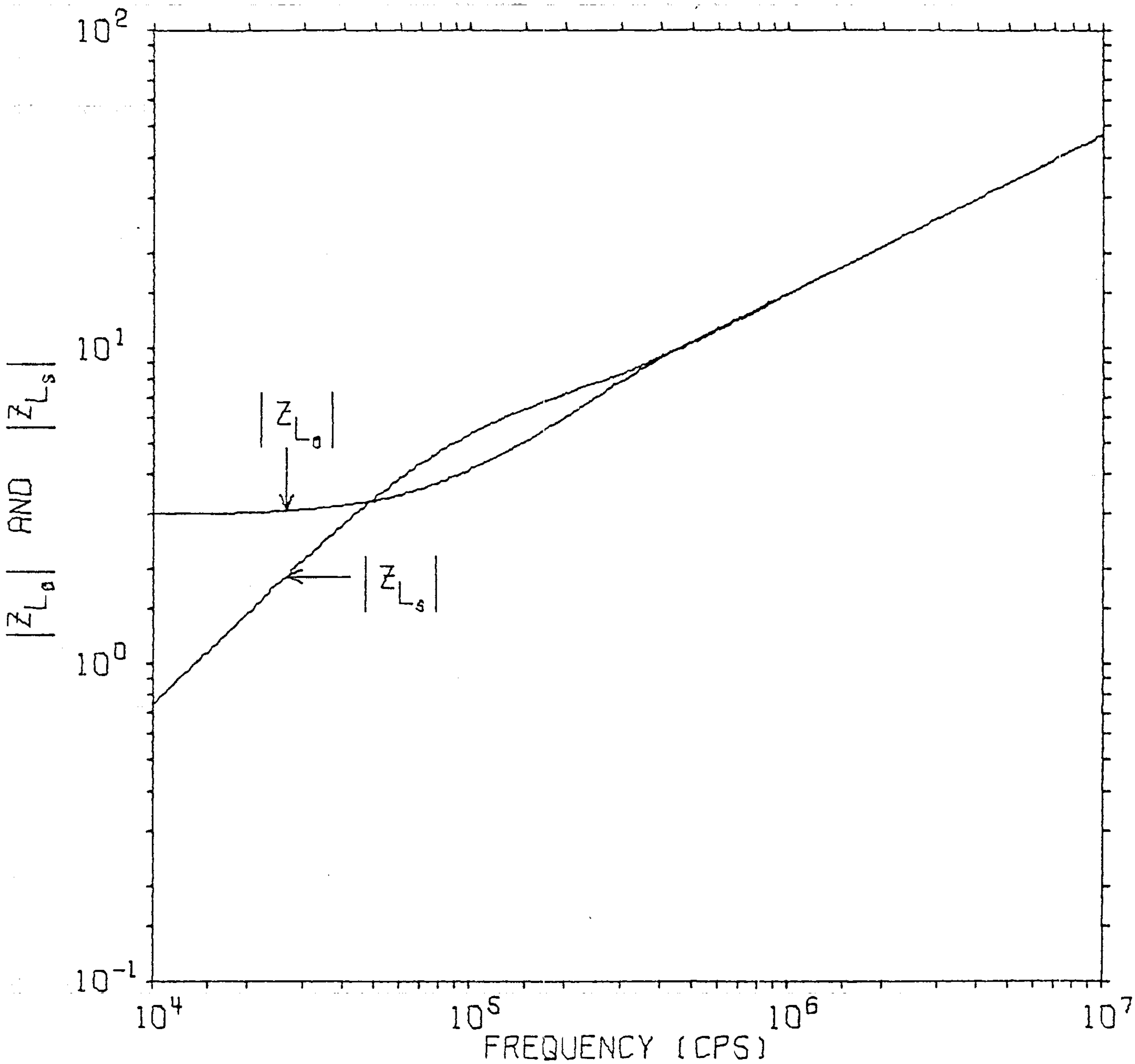
f_g	b/a	ℓ	σ
.47263959	1.0	100.0	5.00×10^{-3}
		100.0	8.00×10^{-3}
		100.0	1.10×10^{-2}
		100.0	3.00×10^{-2}

The following graphs were reproduced directly from the Calcomp plots.

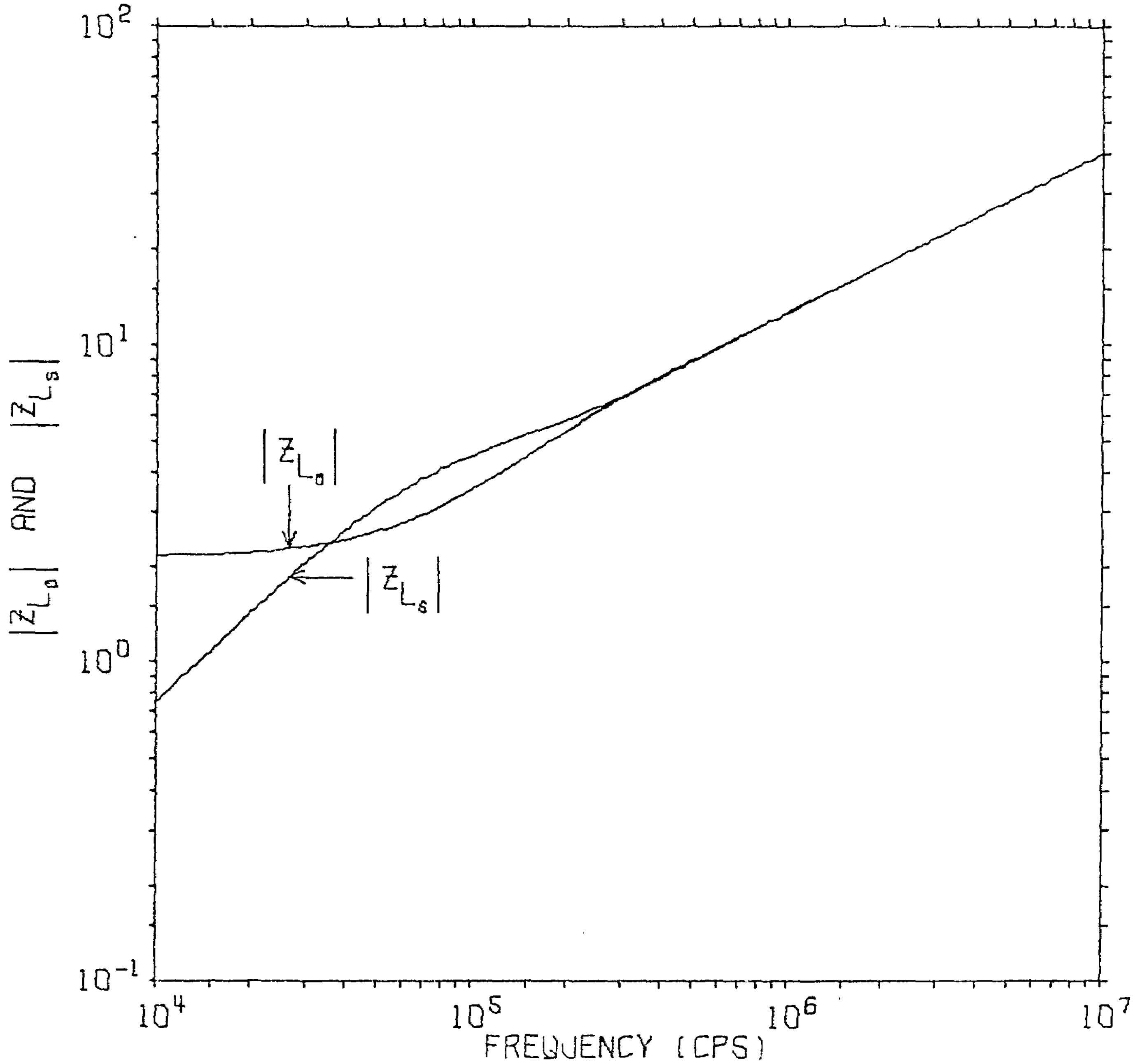
MAGNITUDE OF OPEN-CIRCUITED AND SHORT-CIRCUITED TRANSMISSION LINE IMPEDANCE VERSUS FREQUENCY FOR
L = 20.0 METERS, CONDUCTIVITY = 5.00E-03 MHOS/METER
FG = .473 (B/A = 1 00)



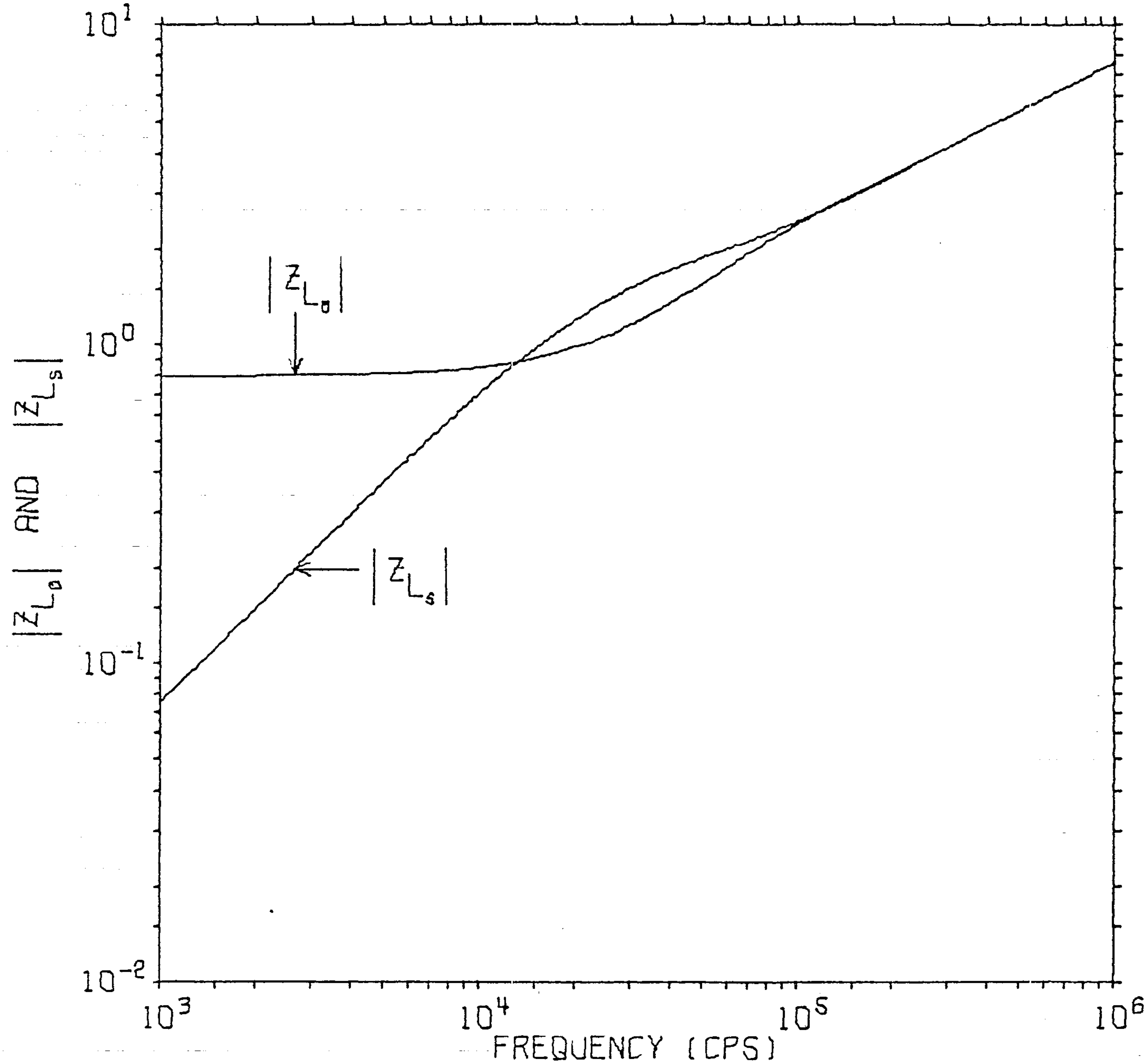
MAGNITUDE OF OPEN-CIRCUITED AND SHORT-CIRCUITED TRANSMISSION LINE IMPEDANCE VERSUS FREQUENCY FOR
L = 20.0 METERS, CONDUCTIVITY = 8.00E-03 MHOS/METER
FG = .473 (B/A = 1.00)



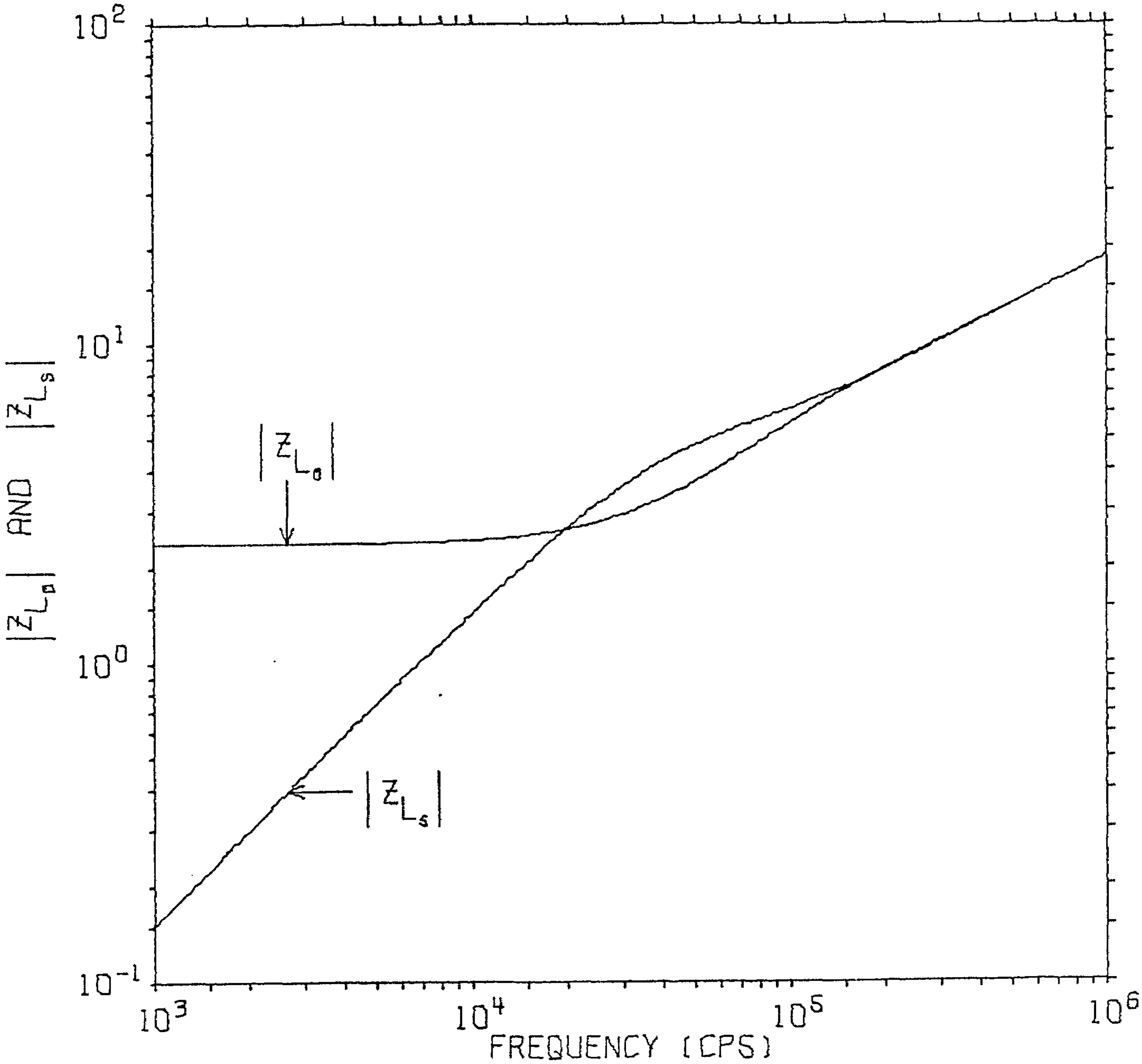
MAGNITUDE OF OPEN-CIRCUITED AND SHORT-CIRCUITED TRANSMISSION LINE IMPEDANCE VERSUS FREQUENCY FOR L = 20.0 METERS, CONDUCTIVITY = 1.10E-02 MHOS/METER FG = .473 (B/A = 1.00)



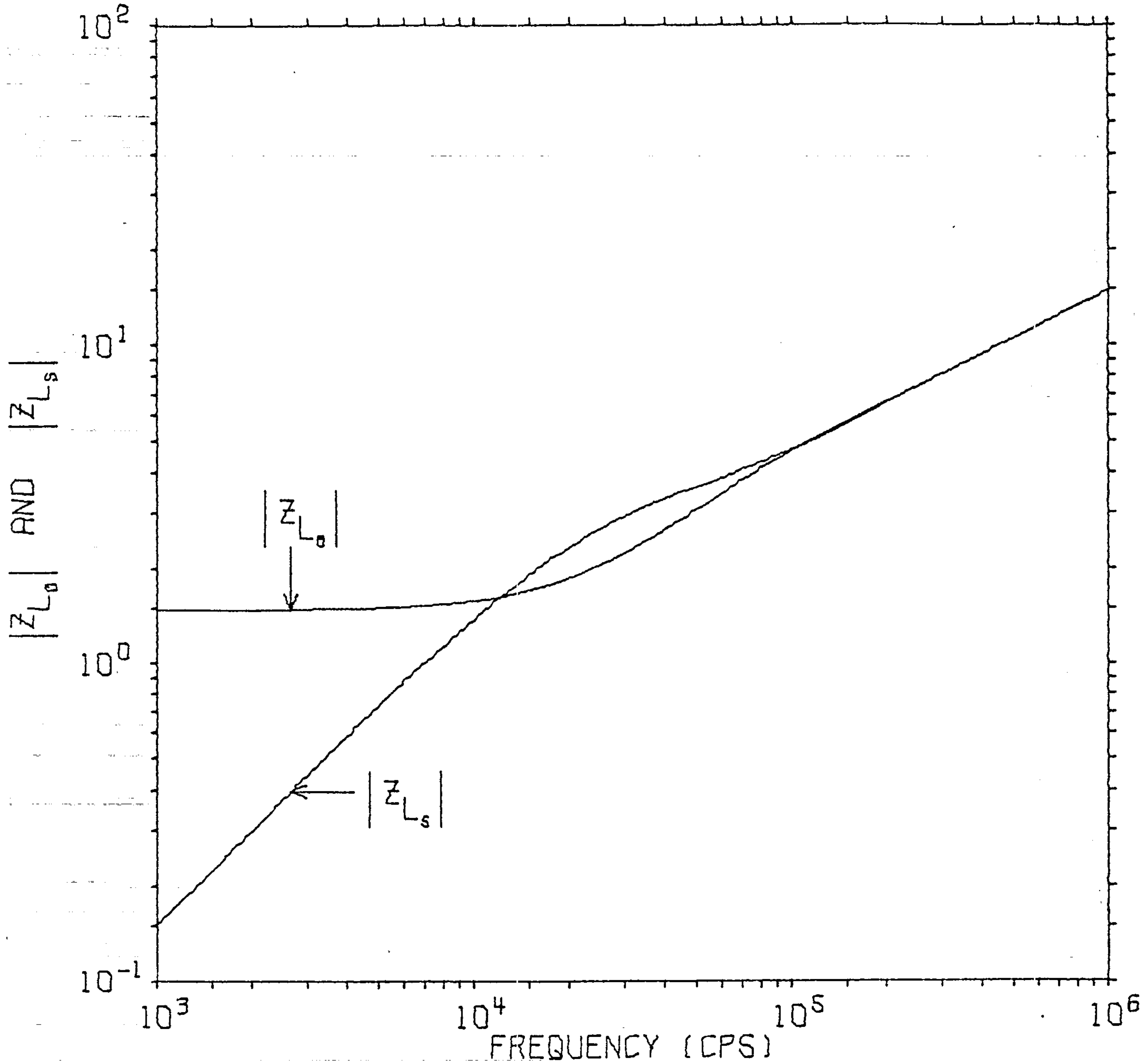
MAGNITUDE OF OPEN-CIRCUITED AND SHORT CIRCUITED TRANSMISSI[illegible]
LINE IMPEDANCE VERSUS FREQUENCY FOR
L = 20.0 METERS, CONDUCTIVITY = 3.00E-02 MHOS/METER
FG = .473 (B/A = 1.00)



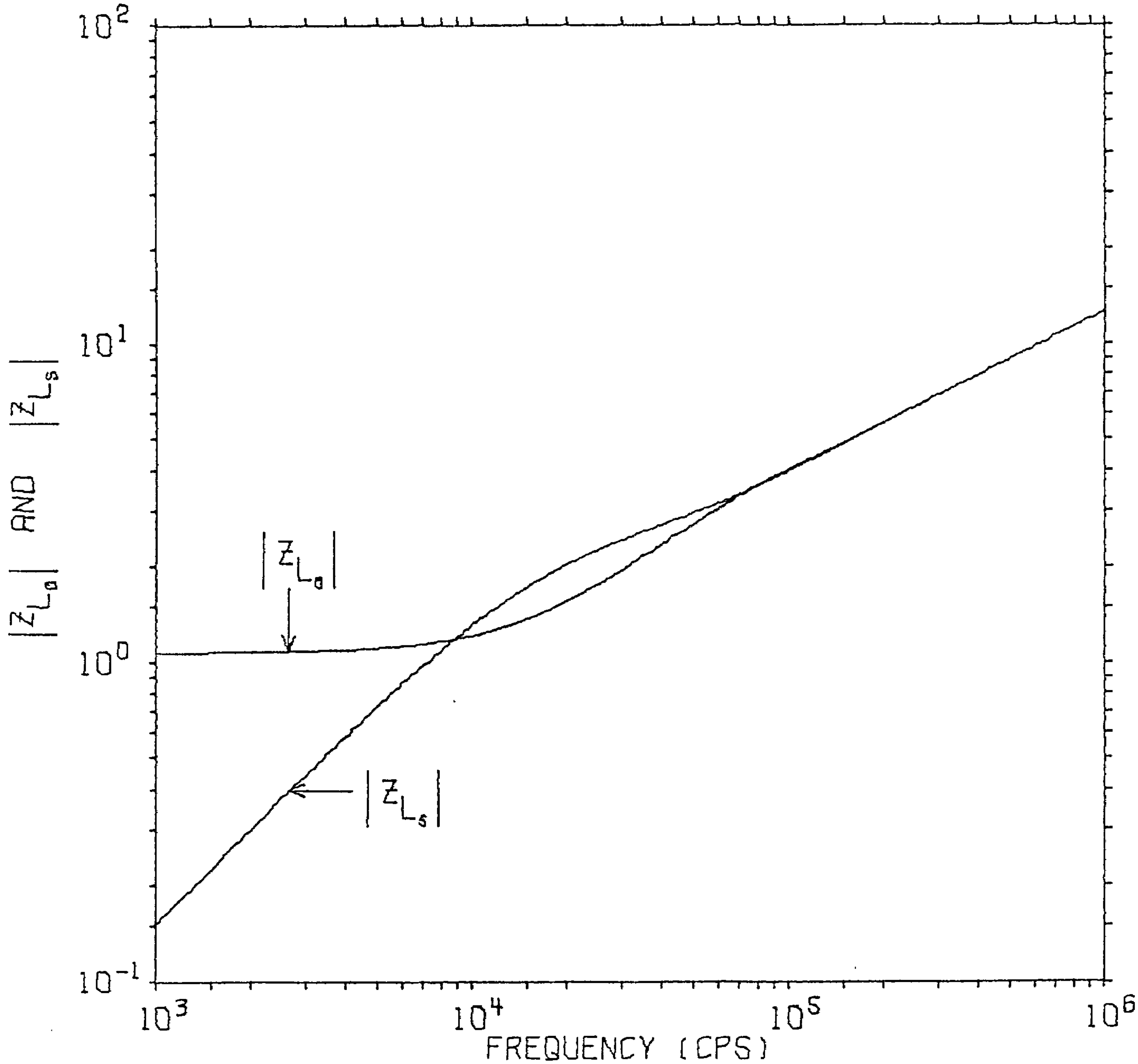
MAGNITUDE OF OPEN-CIRCUITED AND SHORT-CIRCUITED TRANSMISSION LINE IMPEDANCE VERSUS FREQUENCY FOR
L = 40.0 METERS. CONDUCTIVITY = 5.00E-03 MHOS/METER
FG = .473 (B/A = 1.00)



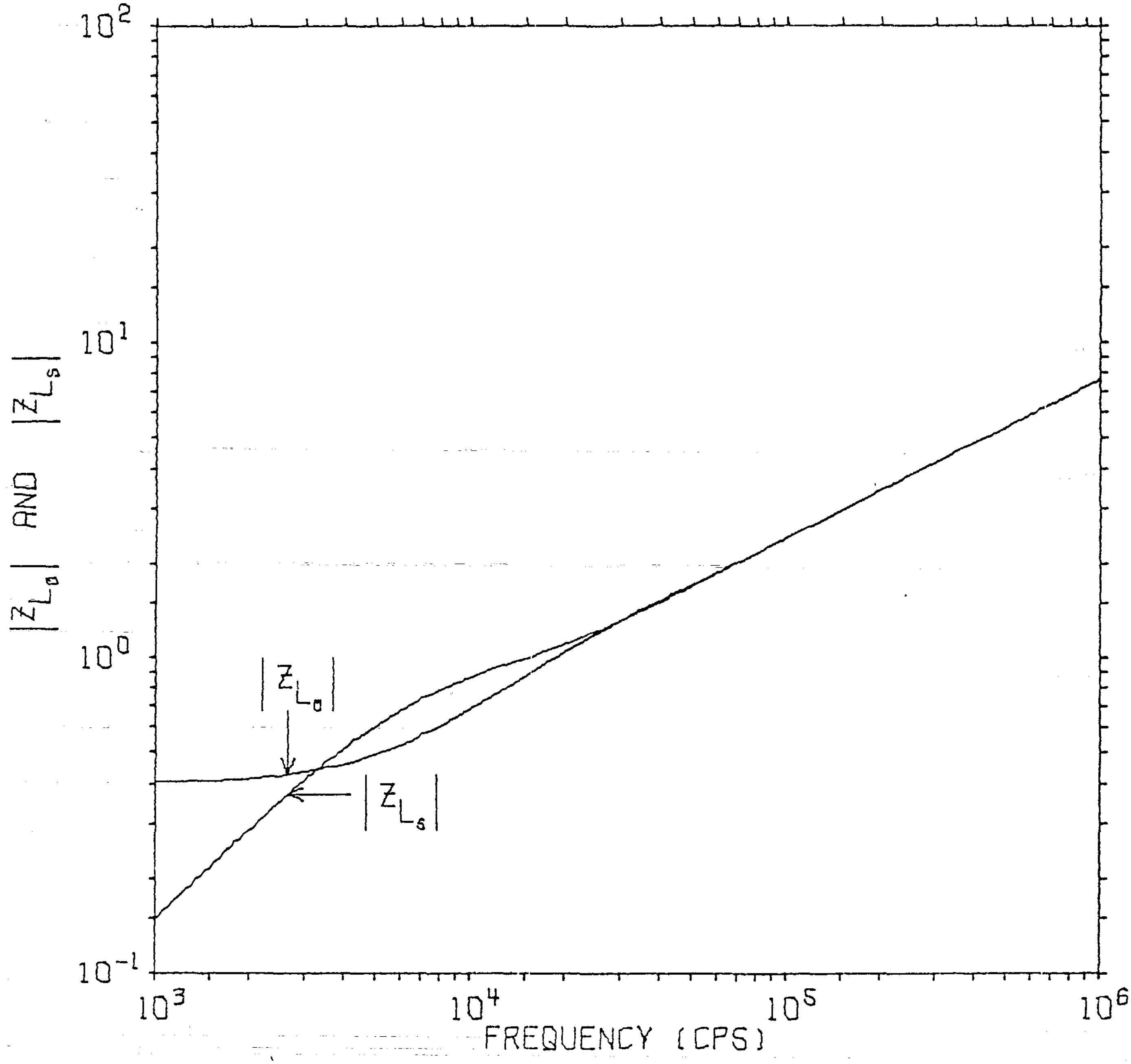
MAGNITUDE OF OPEN-CIRCUITED AND SHORT-CIRCUITED TRANSMISSIO
LINE IMPEDANCE VERSUS FREQUENCY FOR
L = 40.0 METERS, CONDUCTIVITY = 8.00E-03 MHOS/METER
FG = .473 (B/A = 1.00)



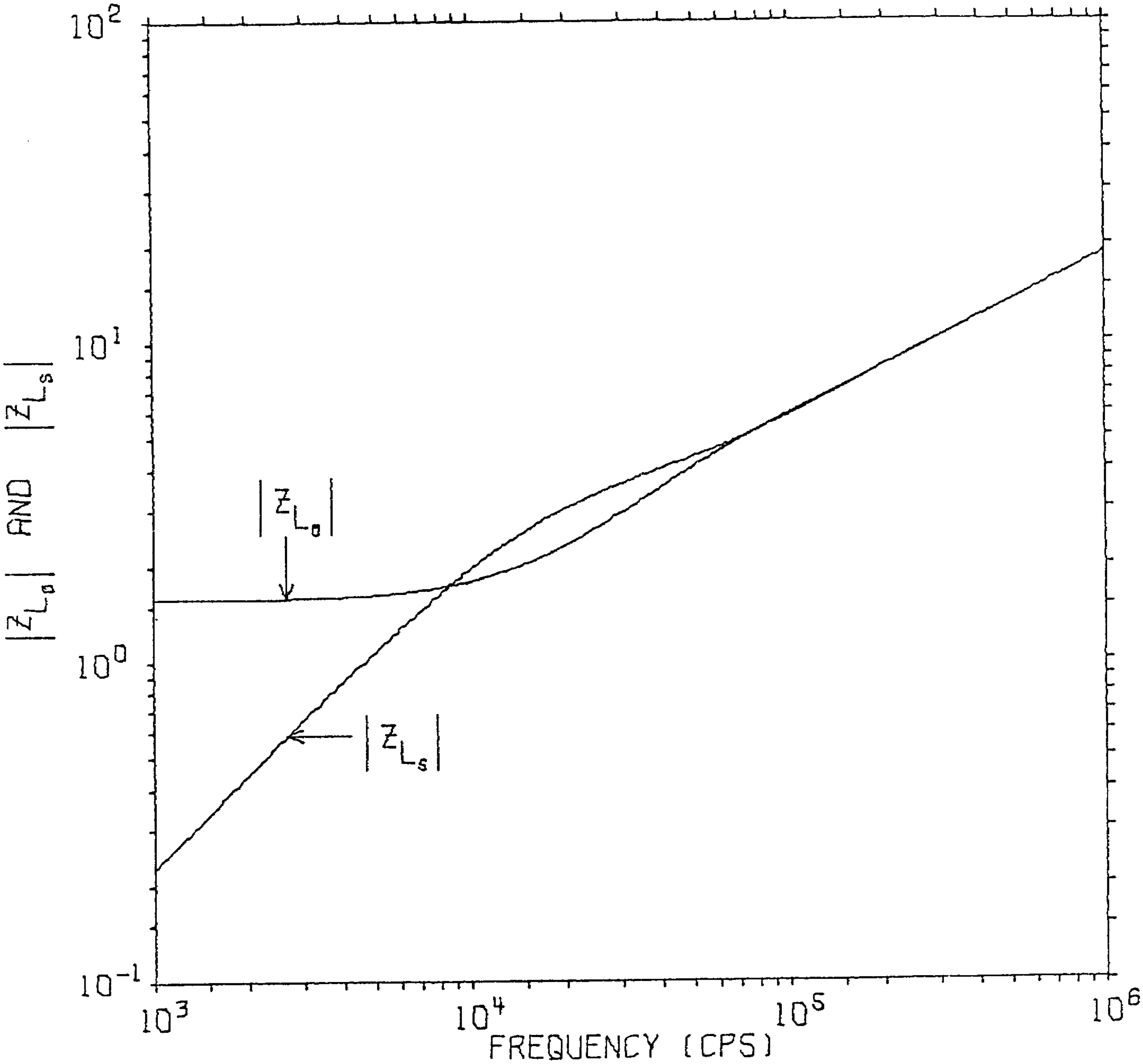
MAGNITUDE OF OPEN-CIRCUITED AND SHORT-CIRCUITED TRANSMISSION LINE IMPEDANCE VERSUS FREQUENCY FOR
L = 40.0 METERS, CONDUCTIVITY = 1.10E-02 MHOS/METER
FG = .473 (B/A = 1.00)



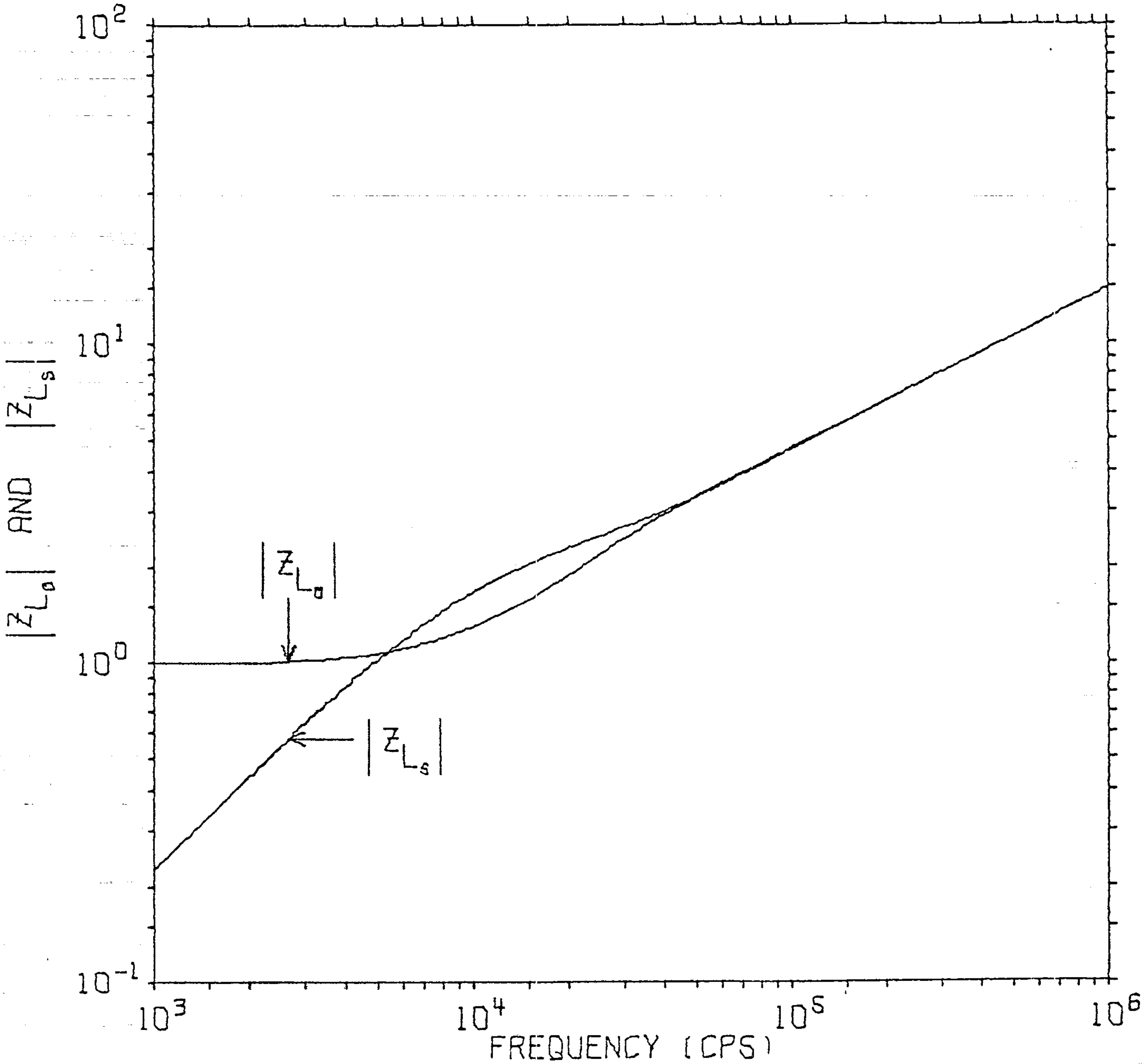
MAGNITUDE OF OPEN-CIRCUITED AND SHORT-CIRCUITED TRANSMISSION LINE IMPEDANCE VERSUS FREQUENCY FOR L = 40.0 METERS, CONDUCTIVITY = 3.00E-02 MHOS/METER FG = .473 (B/A = 1.00)



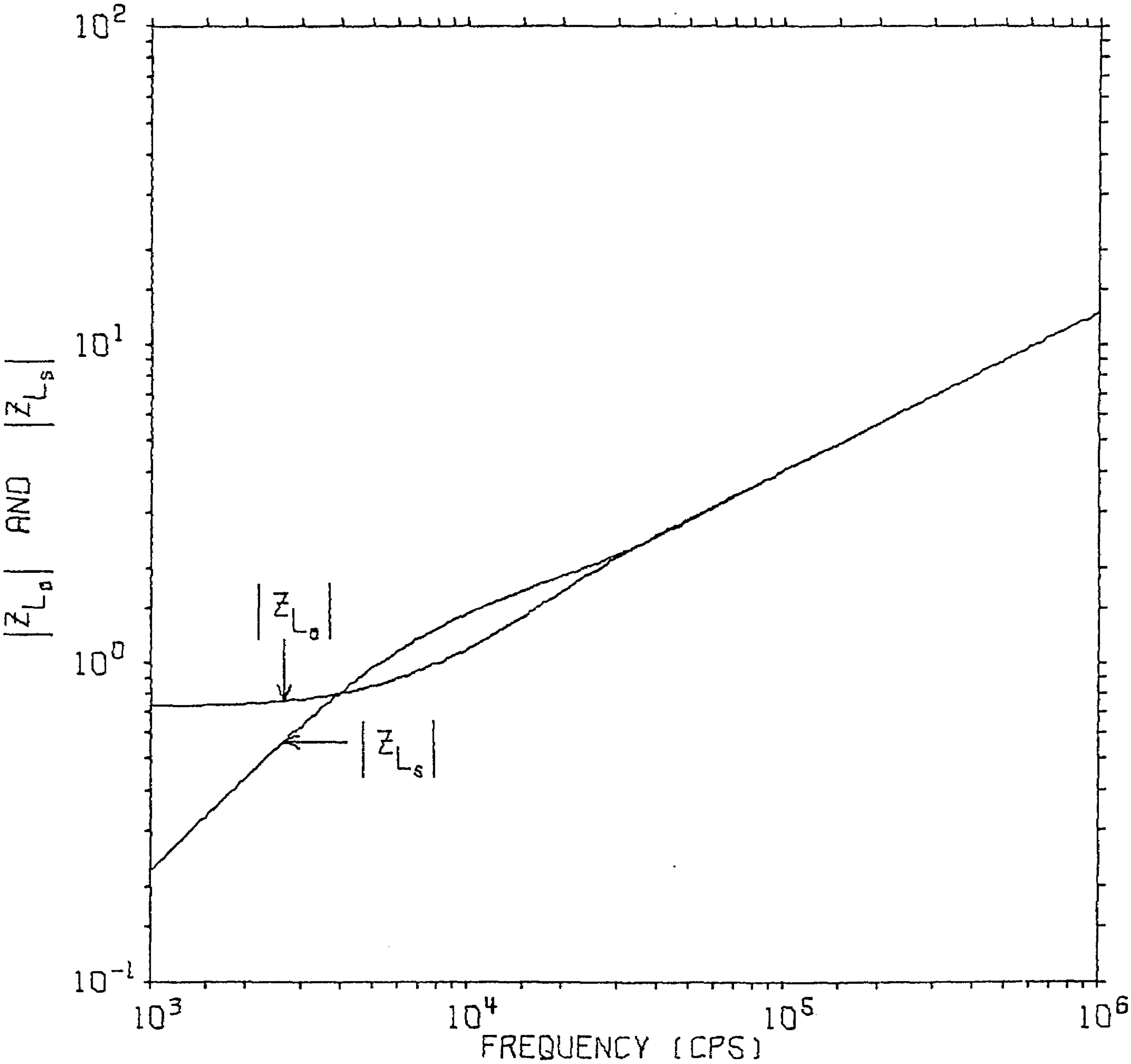
MAGNITUDE OF OPEN-CIRCUITED AND SHORT-CIRCUITED TRANSMISSION LINE IMPEDANCE VERSUS FREQUENCY FOR
L = 60.0 METERS, CONDUCTIVITY = 5.00E-03 MHOS/METER
FG = .473 (B/A = 1.00)



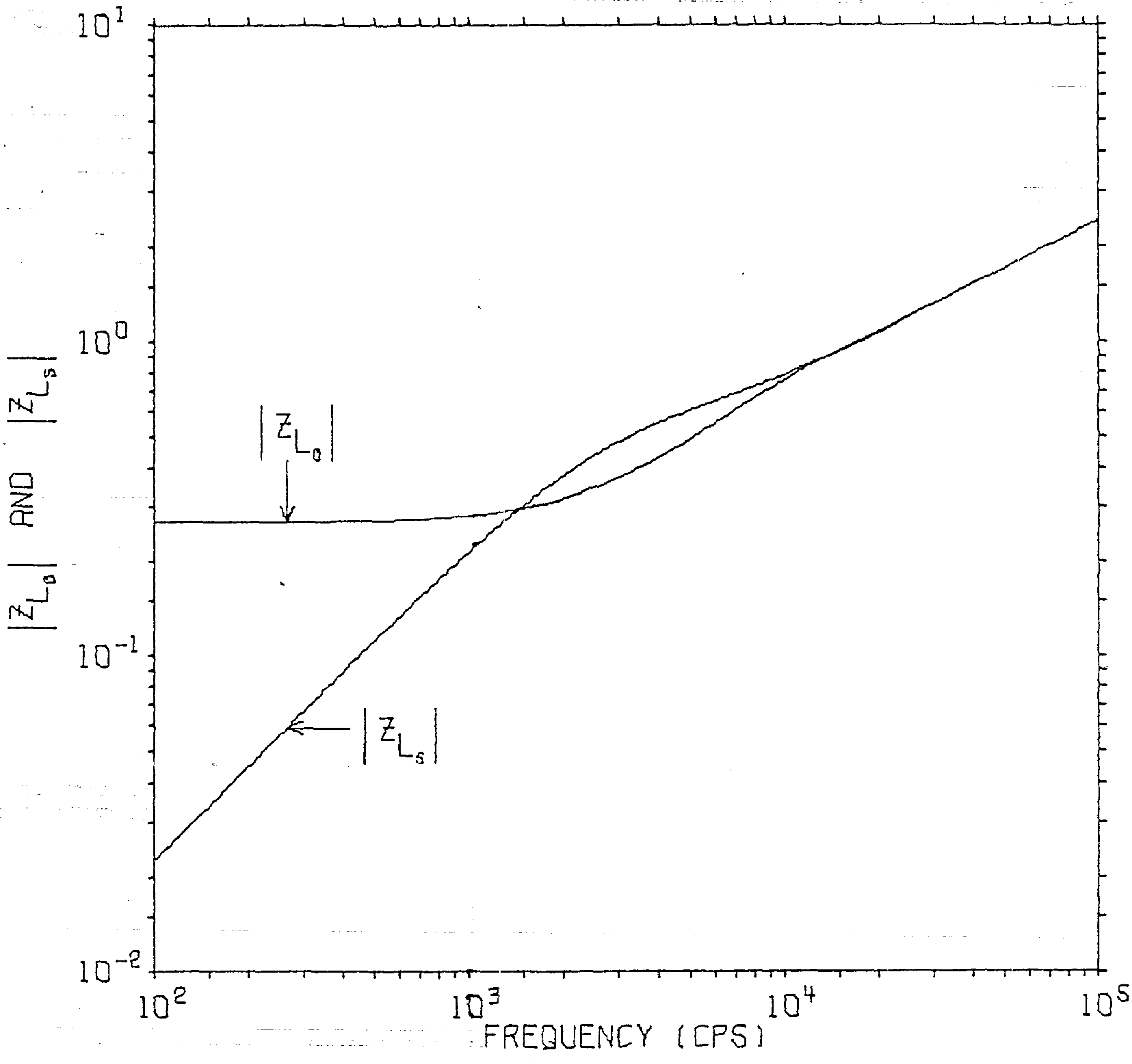
MAGNITUDE OF OPEN-CIRCUITED AND SHORT-CIRCUITED TRANSMISSION LINE IMPEDANCE VERSUS FREQUENCY FOR
L = 60.0 METERS, CONDUCTIVITY = 8.00E-03 MHOS/METER
FG = .473 (B/A = 1.00)



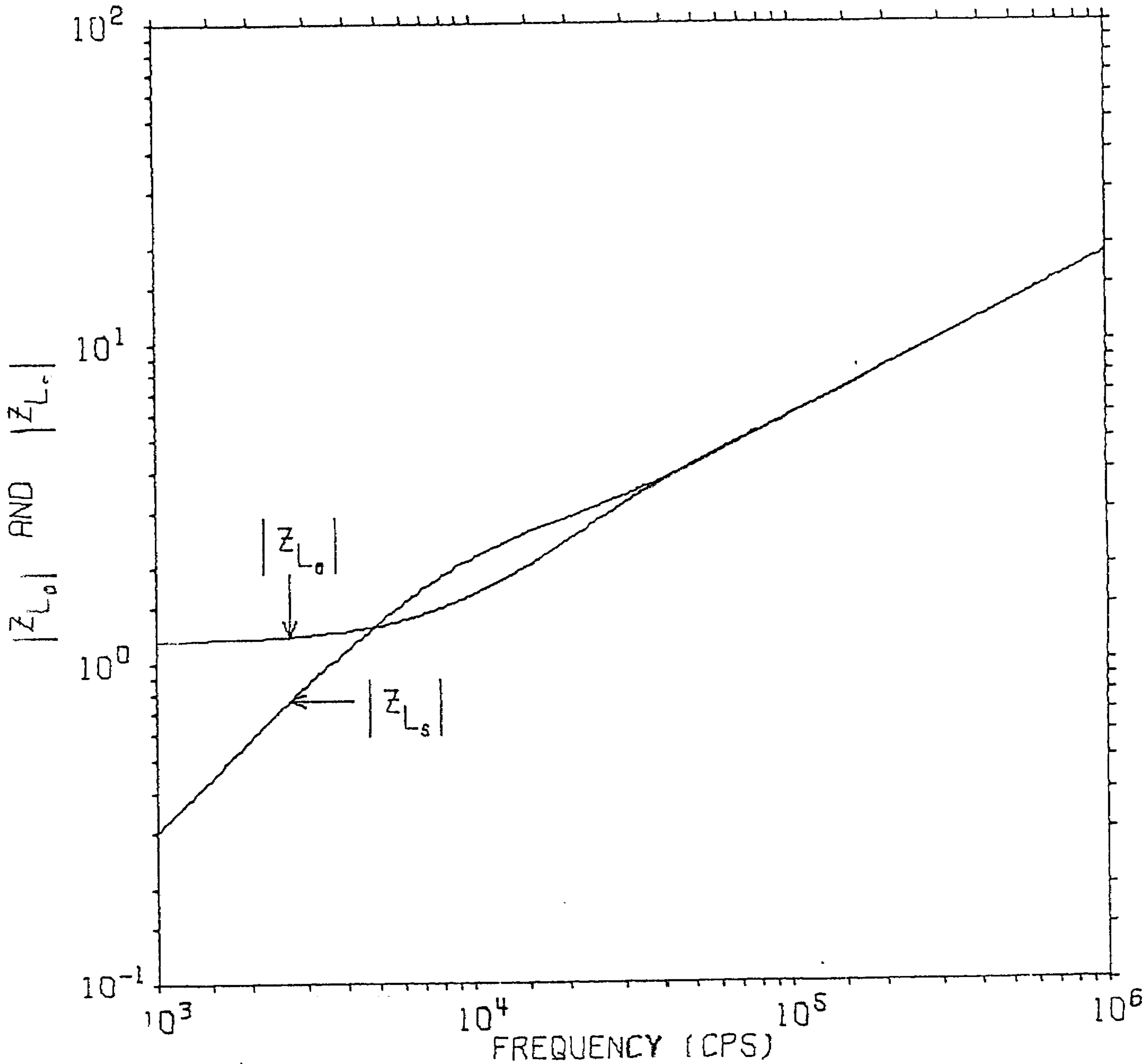
MAGNITUDE OF OPEN-CIRCUITED AND SHORT-CIRCUITED TRANSMISSION LINE IMPEDANCE VERSUS FREQUENCY FOR
L = 60.0 METERS, CONDUCTIVITY = 1.10E-02 MHOS/METER
FG = .473 (B/A = 1.00)



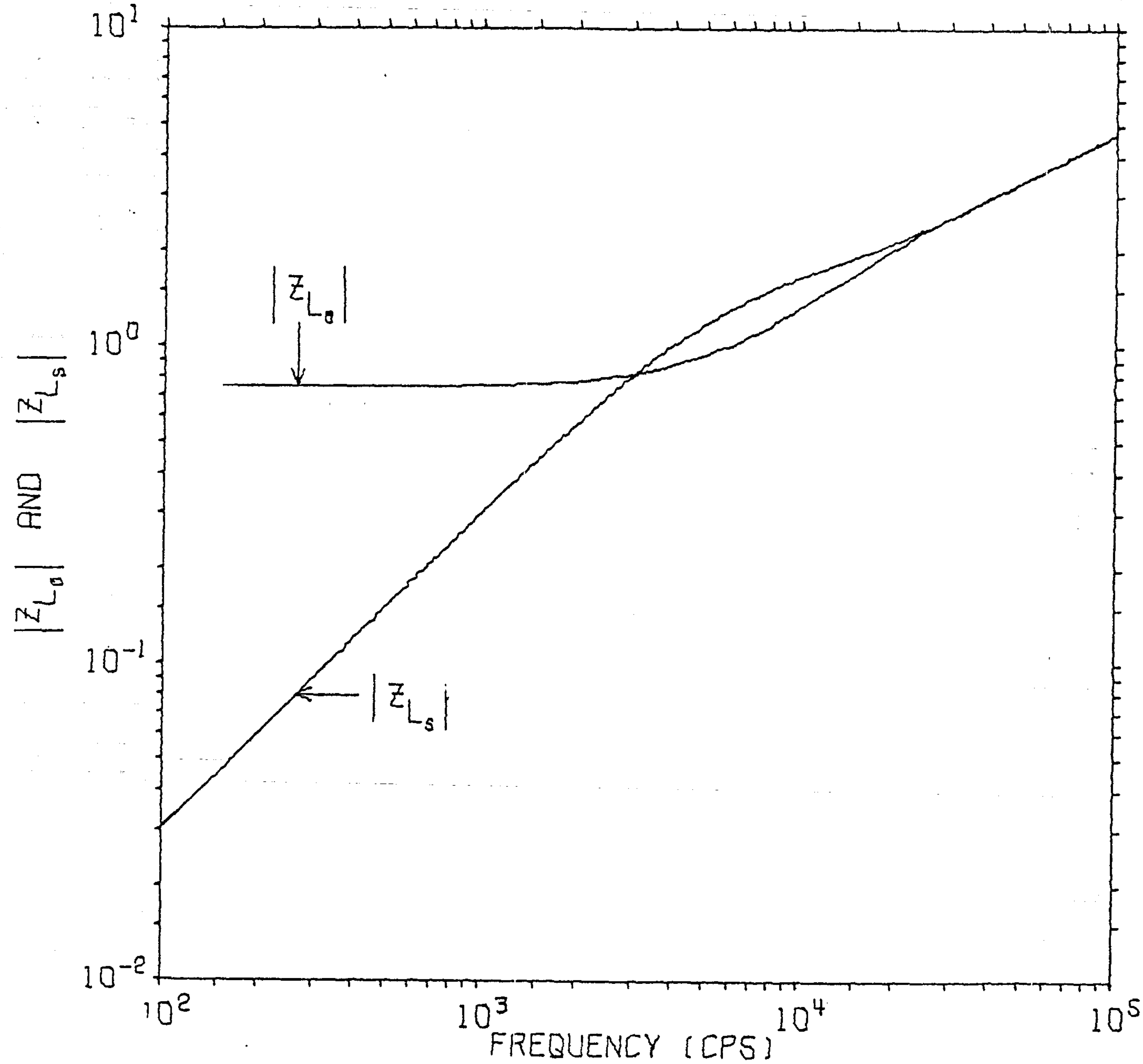
MAGNITUDE OF OPEN-CIRCUITED AND SHORT-CIRCUITED TRANSMISSI[
LINE IMPEDANCE VERSUS FREQUENCY FOR
L = 60.0 METERS, CONDUCTIVITY = 3.00E-02 MHOS/METER
FG = .473 (B/A = 1.00)



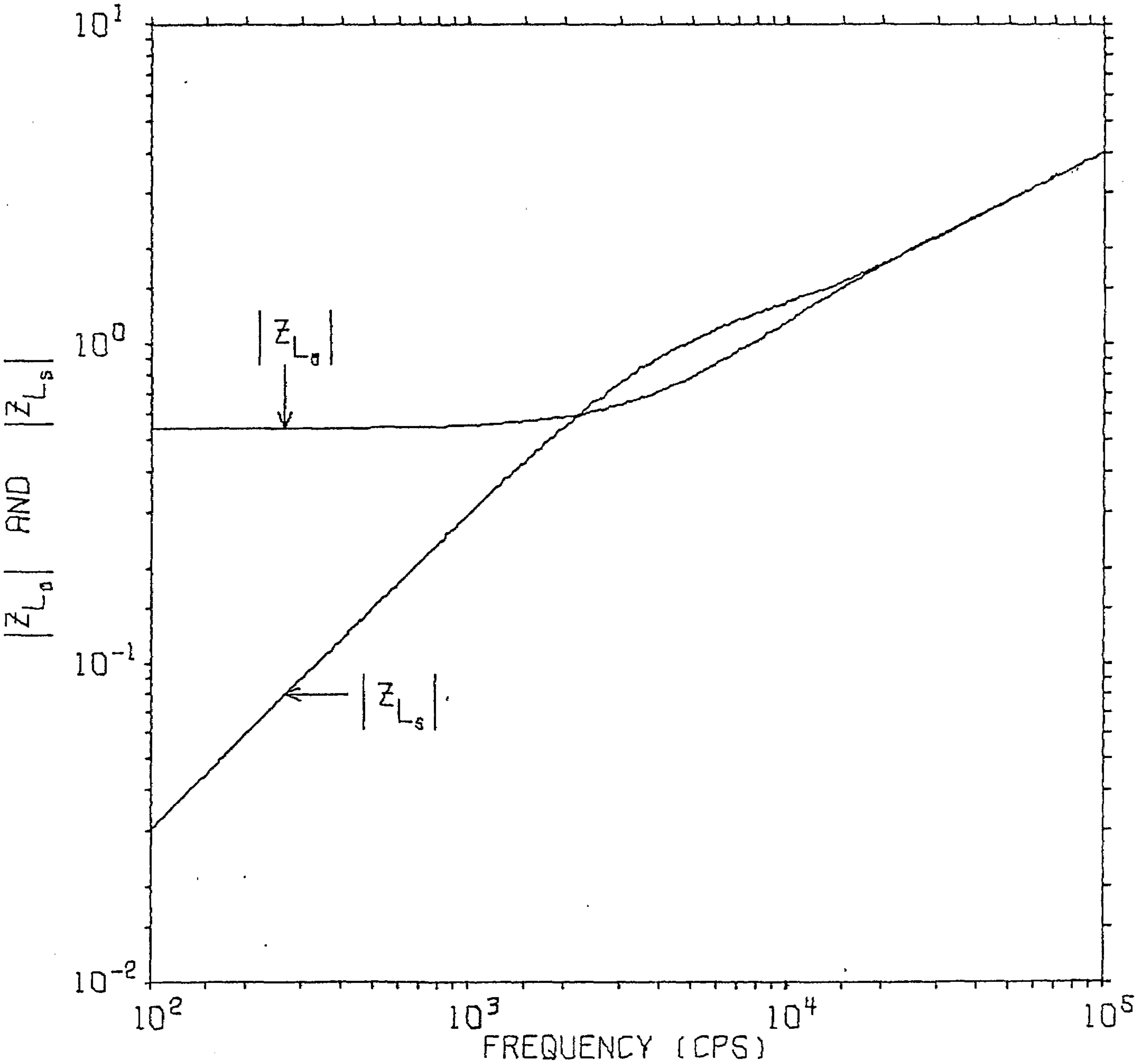
MAGNITUDE OF OPEN-CIRCUITED AND SHORT-CIRCUITED TRANSMISSION LINE IMPEDANCE VERSUS FREQUENCY FOR L = 80.0 METERS, CONDUCTIVITY = 5.00E-03 MHOS/METER FG = .473 (B/A = 1.00)



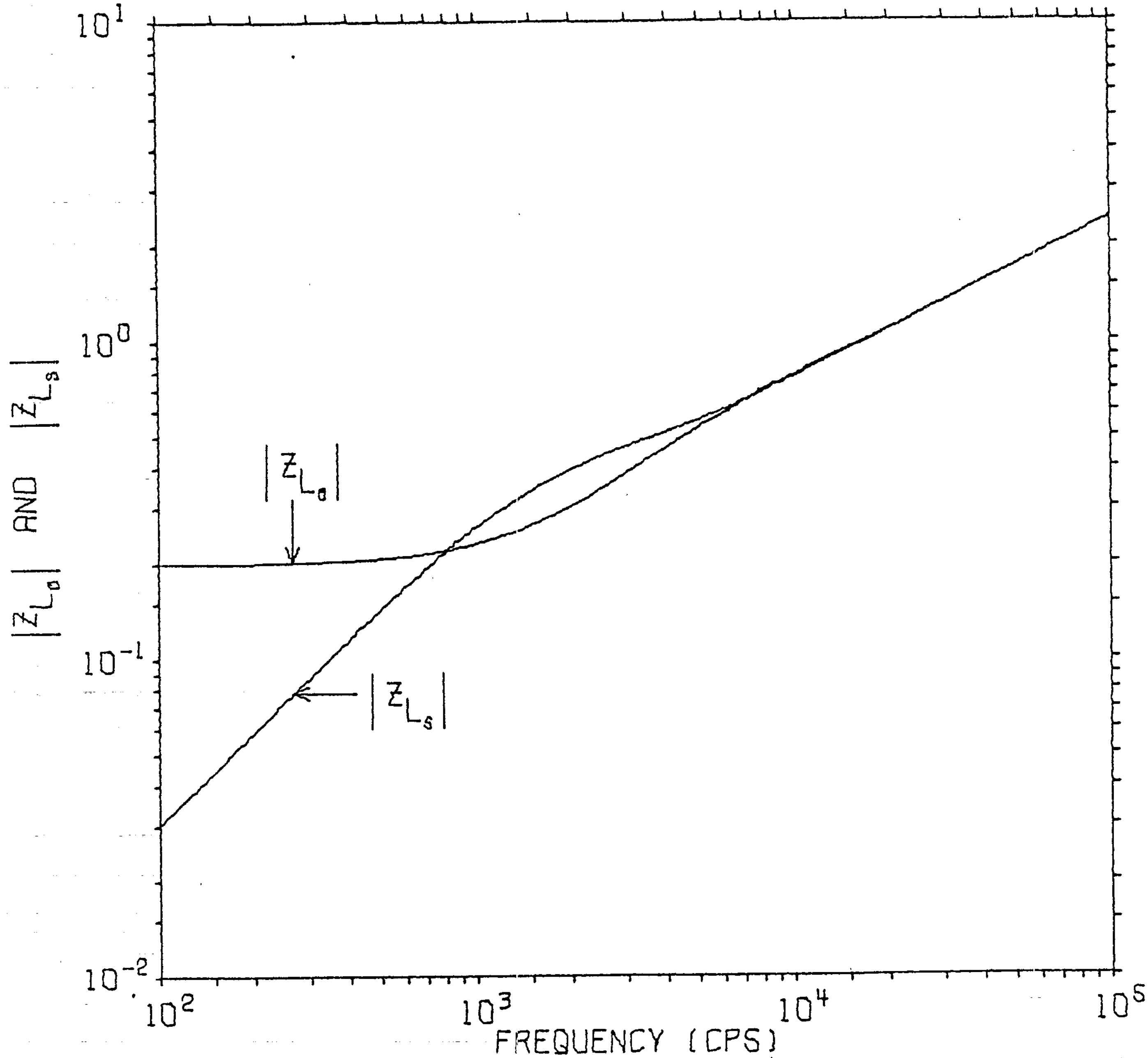
MAGNITUDE OF OPEN CIRCUITED AND SHORT-CIRCUITED TRANSMISSIO
LINE IMPEDANCE VERSUS FREQUENCY FOR
L = 80.0 METERS, CONDUCTIVITY = 8.00E-03 MHOS/METER
FG = .473 (B/A = 1.00)



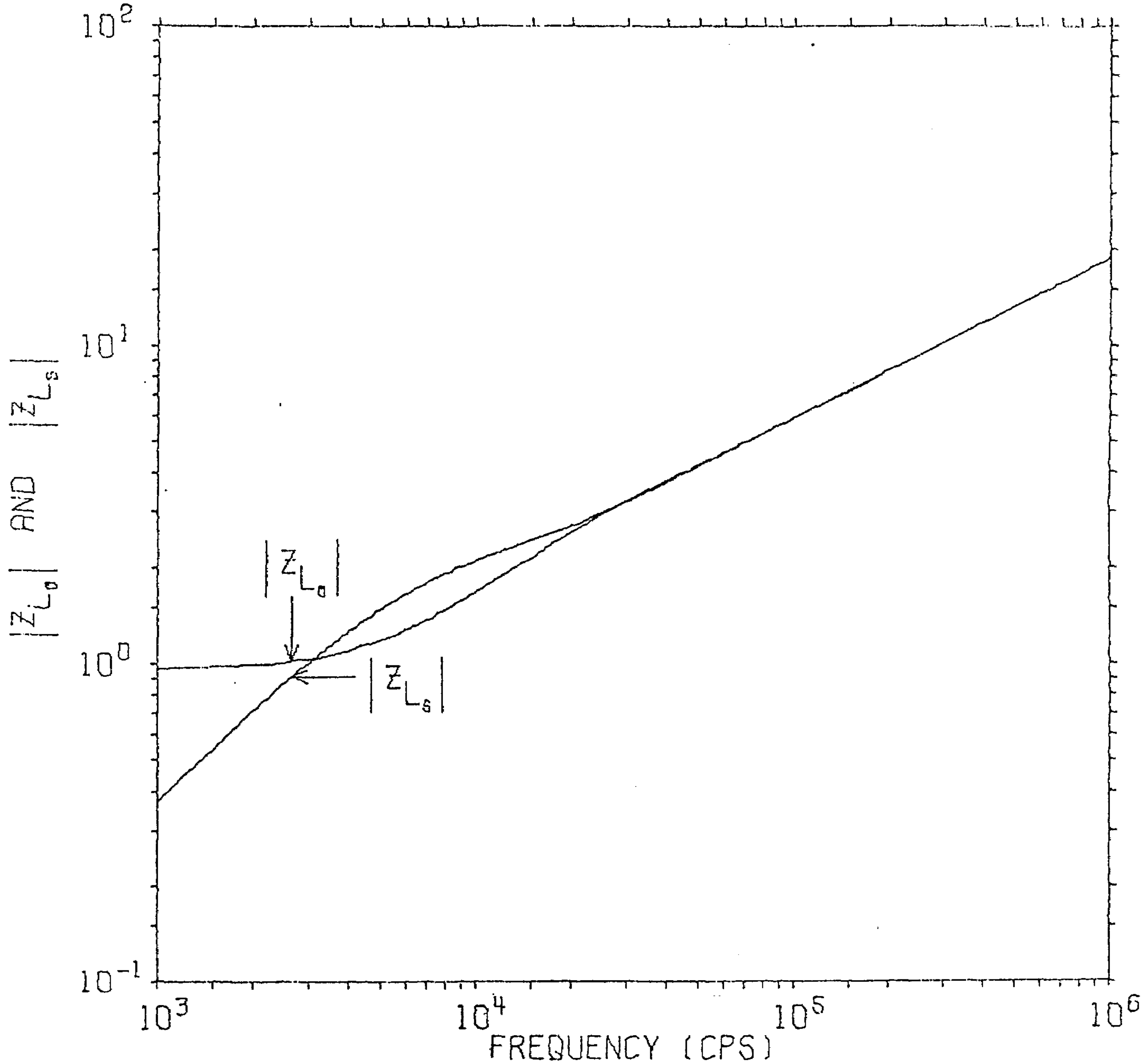
MAGNITUDE OF OPEN-CIRCUITED AND SHORT-CIRCUITED TRANSMISSION LINE IMPEDANCE VERSUS FREQUENCY FOR L = 80.0 METERS, CONDUCTIVITY = 1.10E-02 MHOS/METER FG = .473 (B/A = 1.00)



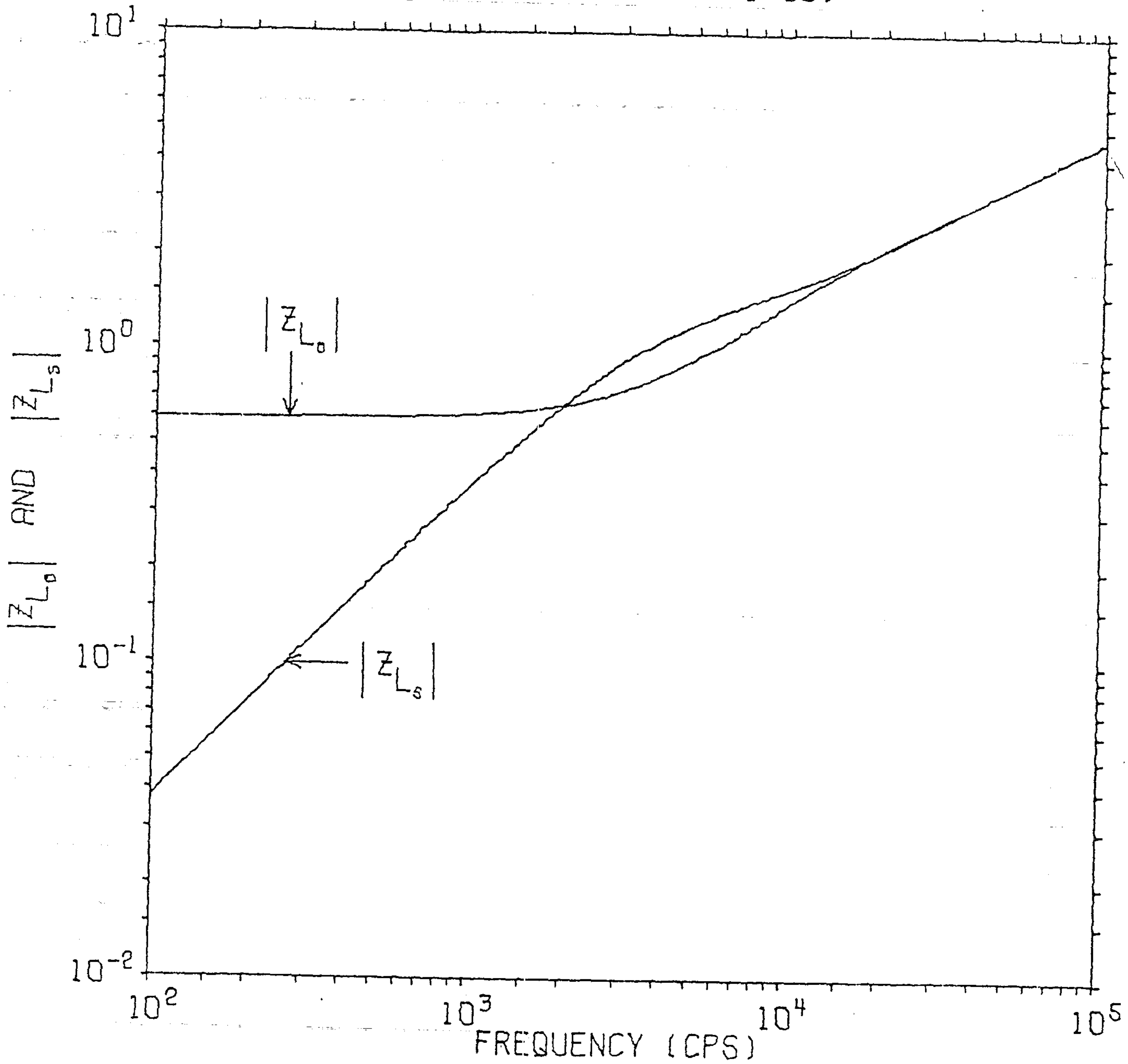
MAGNITUDE OF OPEN-CIRCUITED AND SHORT-CIRCUITED TRANSMISSIO LINE IMPEDANCE VERSUS FREQUENCY FOR L = 80.0 METERS, CONDUCTIVITY = 3.00E-02 MHOS/METER FG = .473 (B/A = 1.00)



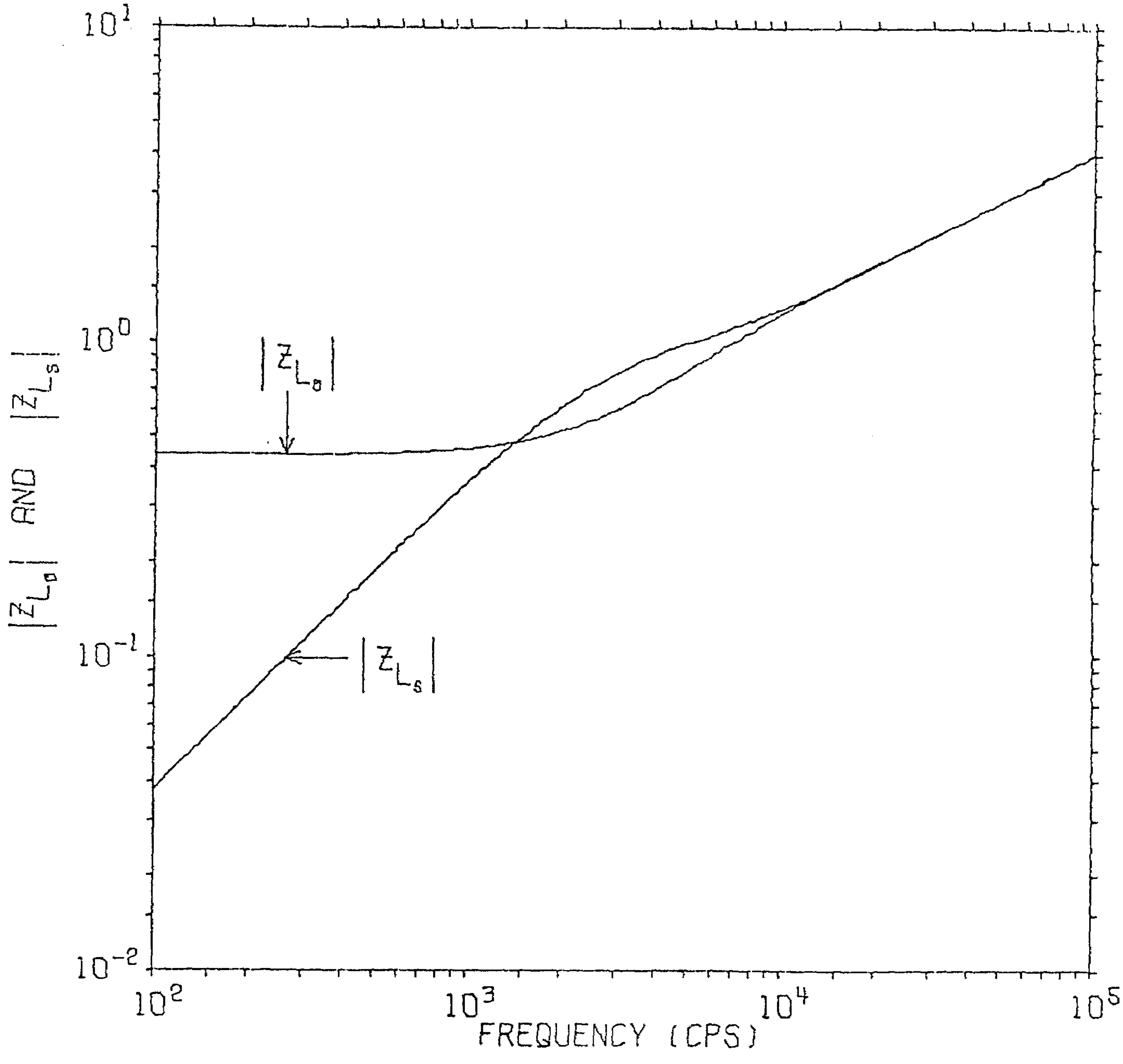
MAGNITUDE OF OPEN-CIRCUITED AND SHORT-CIRCUITED TRANSMISSION LINE IMPEDANCE VERSUS FREQUENCY FOR
L =100.0 METERS, CONDUCTIVITY = 5.00E-03 MHOS/METER
FG = .473 (B/A = 1.00)



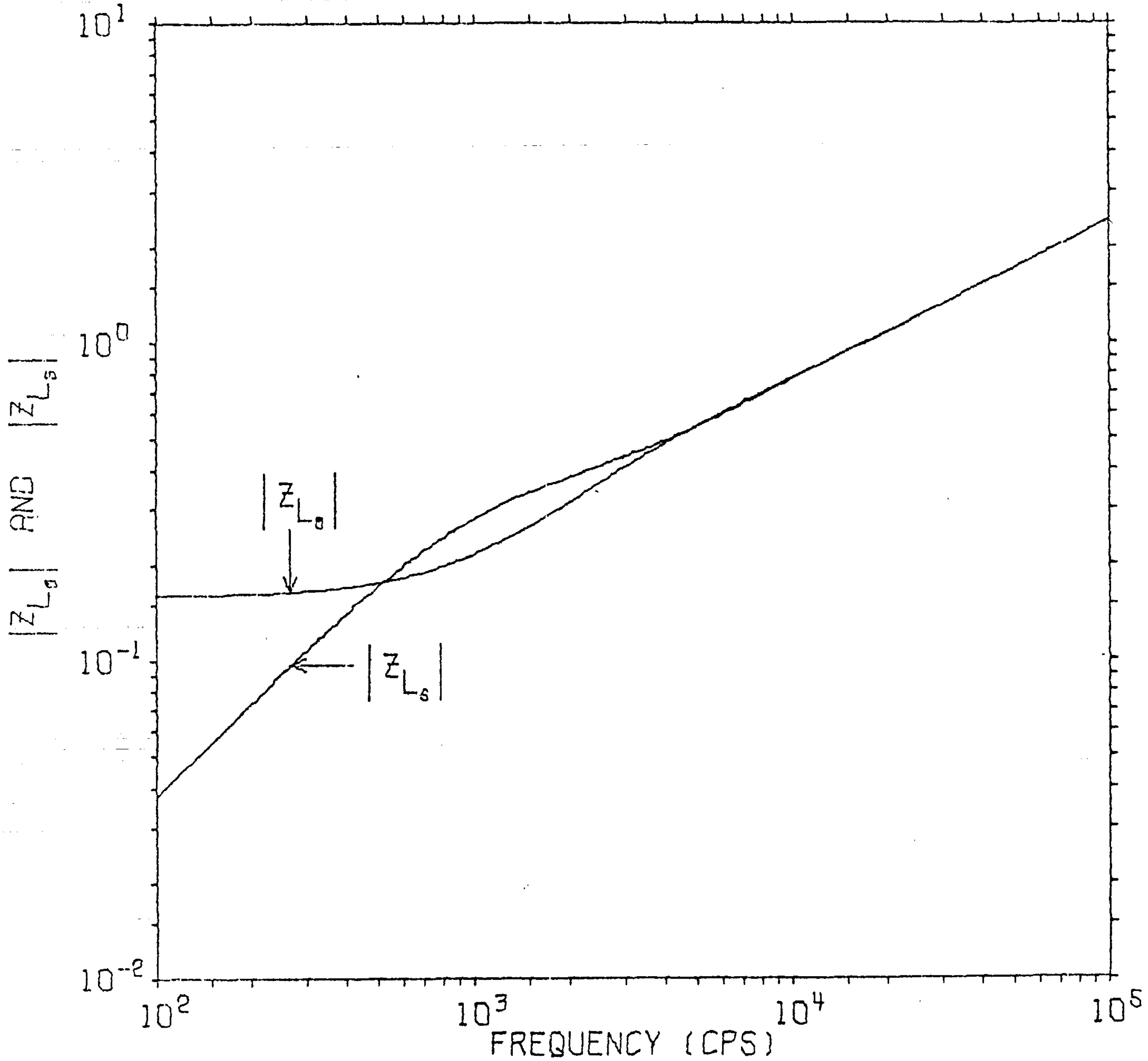
MAGNITUDE OF OPEN-CIRCUITED AND SHORT-CIRCUITED TRANSMISSION LINE IMPEDANCE VERSUS FREQUENCY FOR L =100.0 METERS, CONDUCTIVITY = 8.00E-03 MHOS/METER FG = .473 (B/A = 1.00)



MAGNITUDE OF OPEN-CIRCUITED AND SHORT-CIRCUITED TRANSMISSION LINE IMPEDANCE VERSUS FREQUENCY FOR L =100.0 METERS, CONDUCTIVITY = 1.10E-02 MHOS/METER FG = .473 (B/A = 1.00)



MAGNITUDE OF OPEN-CIRCUITED AND SHORT-CIRCUITED TRANSMISSION LINE IMPEDANCE VERSUS FREQUENCY FOR
L =100.0 METERS, CONDUCTIVITY = 3.00E-02 MHOS/METER
FG = .473 (B/A = 1.00)



Program EXAMN

Program EXAMN accepts parameters from data cards as follows:

Variable Name	Column	Type	Format by Which Variable is Read	Use
STOPRD	1	Alpha-numeric	1A1	Stops reading cycle
FG	2-8	Real	F9.8	Geometric factor
BA	10-15	Real	F5.2	Ratio of the distance between the plates to the plate length (for clarification only)
L	20-25	Real	F7.2	Depth of the plate into the ground
SIGMA	30-35	Real	E9.2	Conductivity of ground

The program generates one graph for each data card that it reads except the last data card which should contain an asterisk (*) in the first column to stop the reading cycle. The graphs drawn by EXAMN are logarithmic vertically and horizontally. The plots measure six inches by six inches.

The domain of the frequency consists of three consecutive decades between 10^2 and 10^7. The program determines this domain in order to calculate values of $|Z_{L_o}|$ and $|Z_{L_s}|$ in an area of interest. The range, R, of $|Z_{L_o}|$ and $|Z_{L_s}|$ is $10^{-1} \le R \le 10^2$ unless $Z_{L_s} = f(F(1))$ is less than 10^{-1} in which case the range is shifted so that $10^{-2} \le R \le 10^1$.

The program generates approximately 50 values of the frequency for each of the three decades and calculates corresponding values for $|Z_{L_o}|$ and

$|Z_{L_s}|$. The numbers are listed by the printer along with the parameters that determine them.

Subroutine ADJUST is called in the event values of $|Z_{L_o}|$ and $|Z_{L_s}|$ fall beyond the upper limit of the range for the selected domain. This routine adjusts the data to the extent of retaining only those points within the upper limits of the graph. The adjusted points are then plotted.

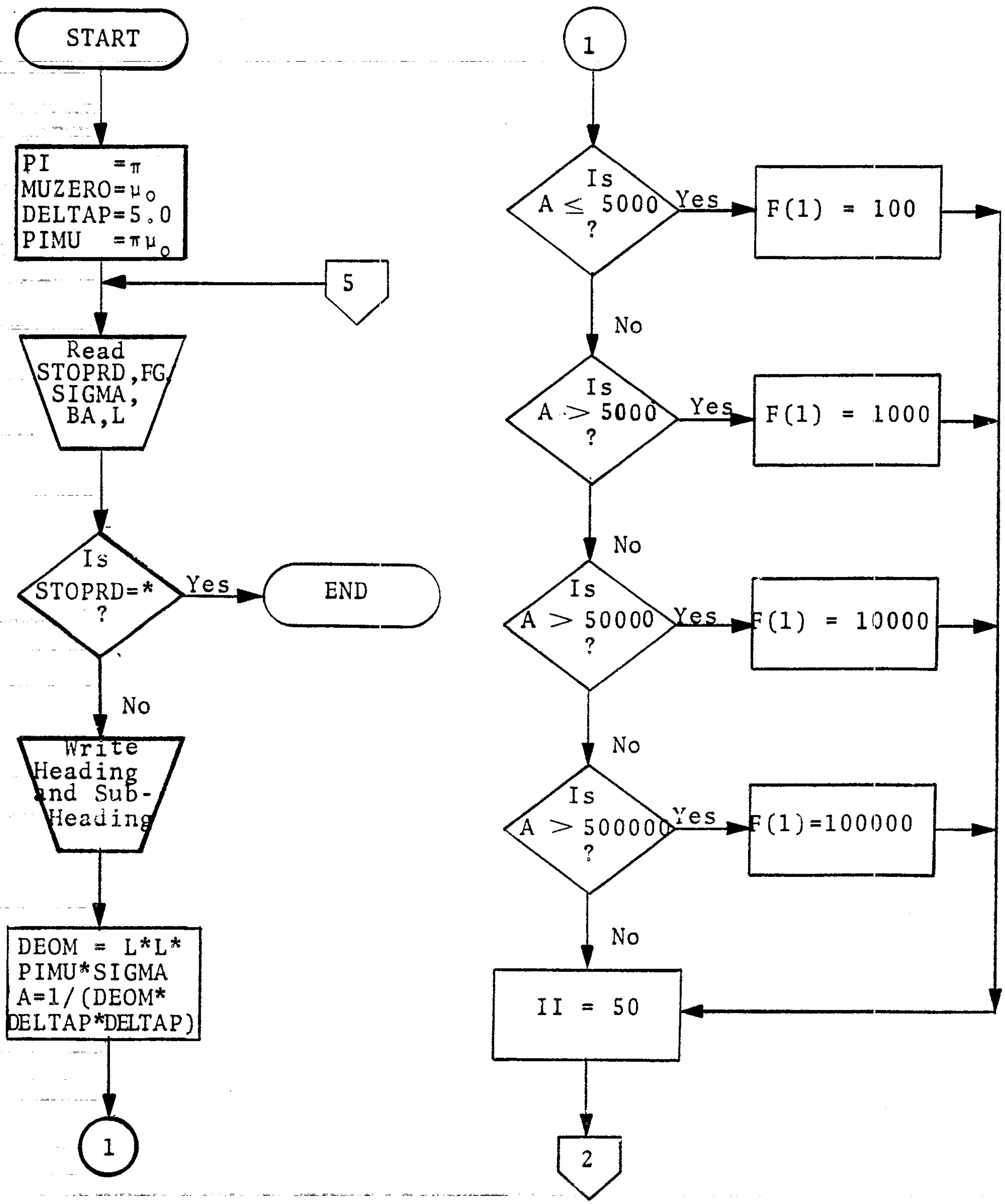
Output to the Calcomp Plotter consists of, for each data card, a log-log graph of f versus $|Z_{L_o}|$ and f versus $|Z_{L_s}|$ along with a heading listing the three parameters. Differentiating tags are positioned at the tenth point plotted for each curve.

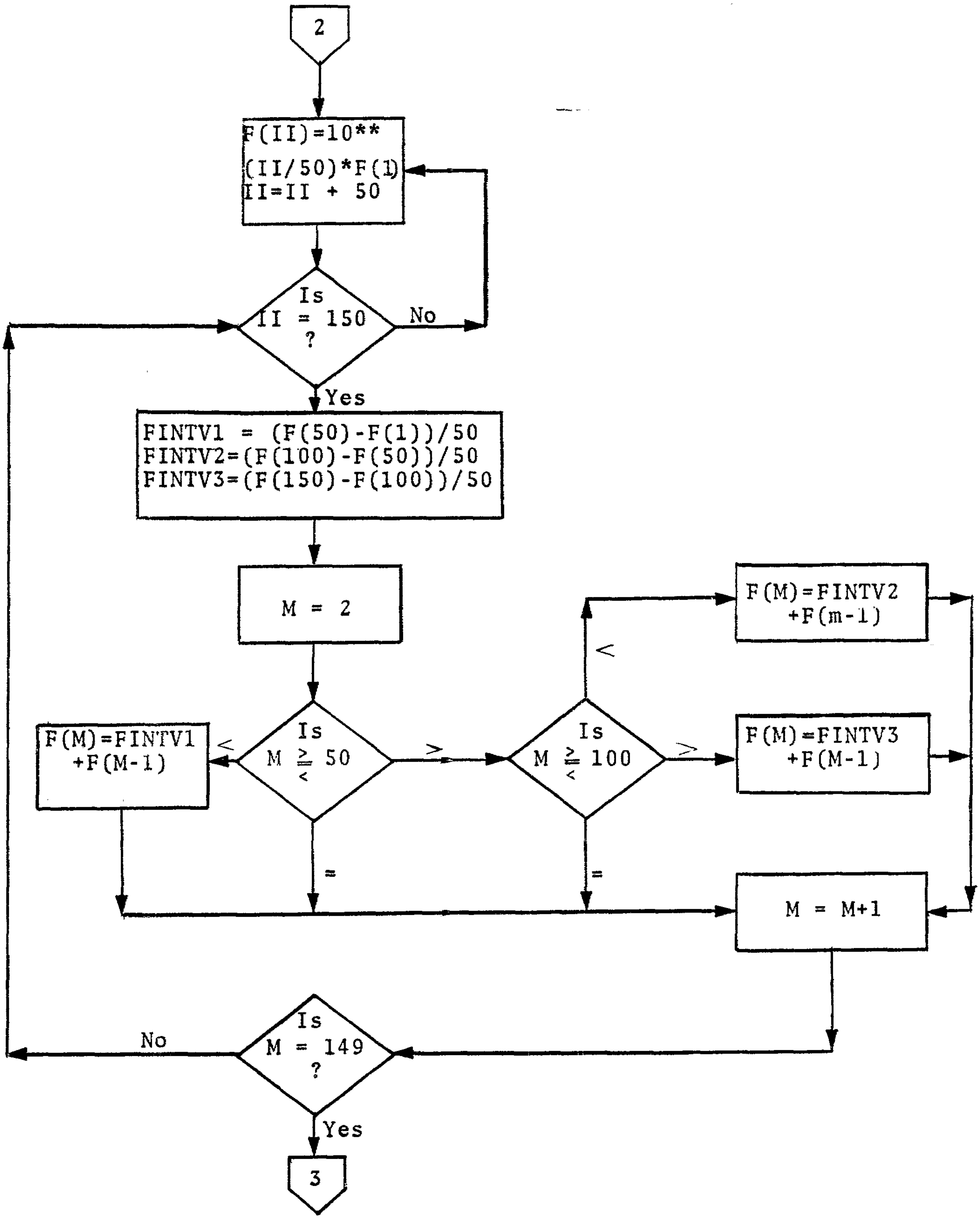
One one-half inch plot tape is required by Program EXAMN. The Calcomp Plotter instructions are written on this tape and it must be specified as a low density tape (200 BPI). The logical designation for this tape is 10 and must appear as such in the control cards.

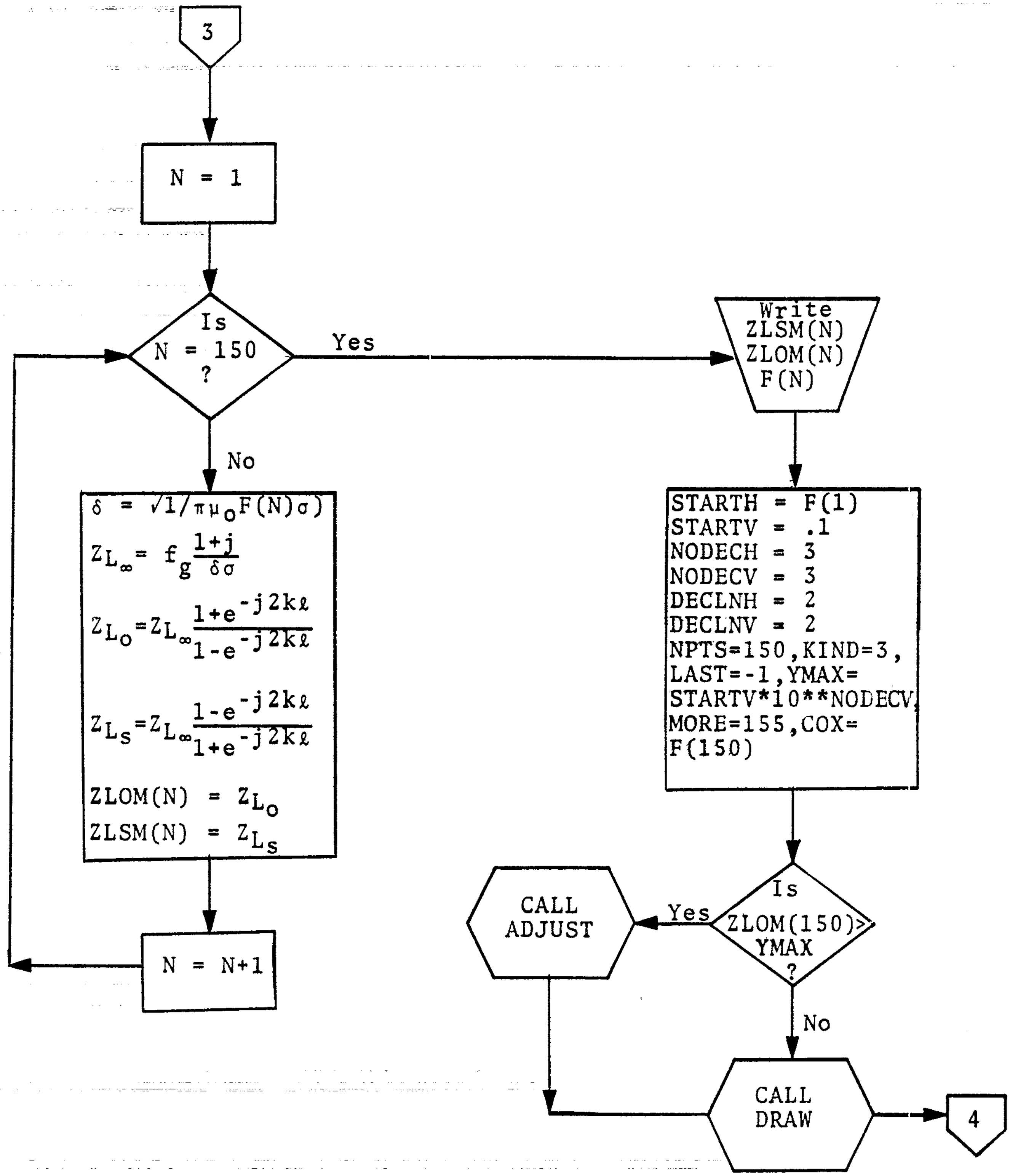
CPU time to compile and produce the first graph is approximately 27 seconds. Each subsequent graph takes less than five seconds. The program will compile and execute in a field of $(53000)_8$. These figures are based on the use of the CDC Chippewa Fortran System on a CDC 6600 computer.

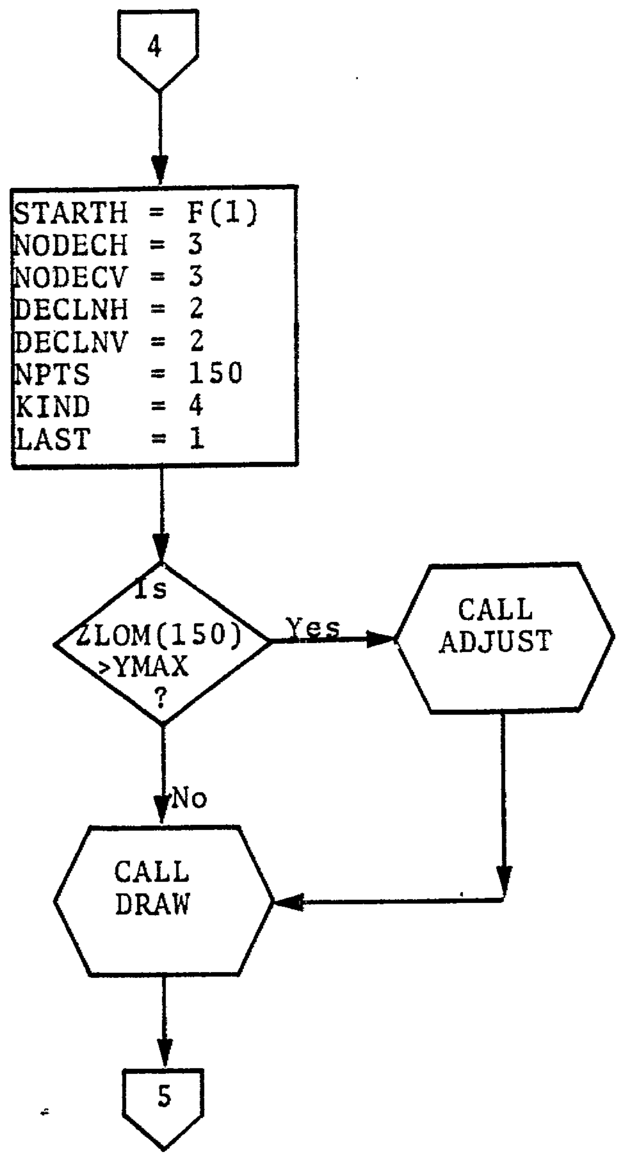
Appendix A

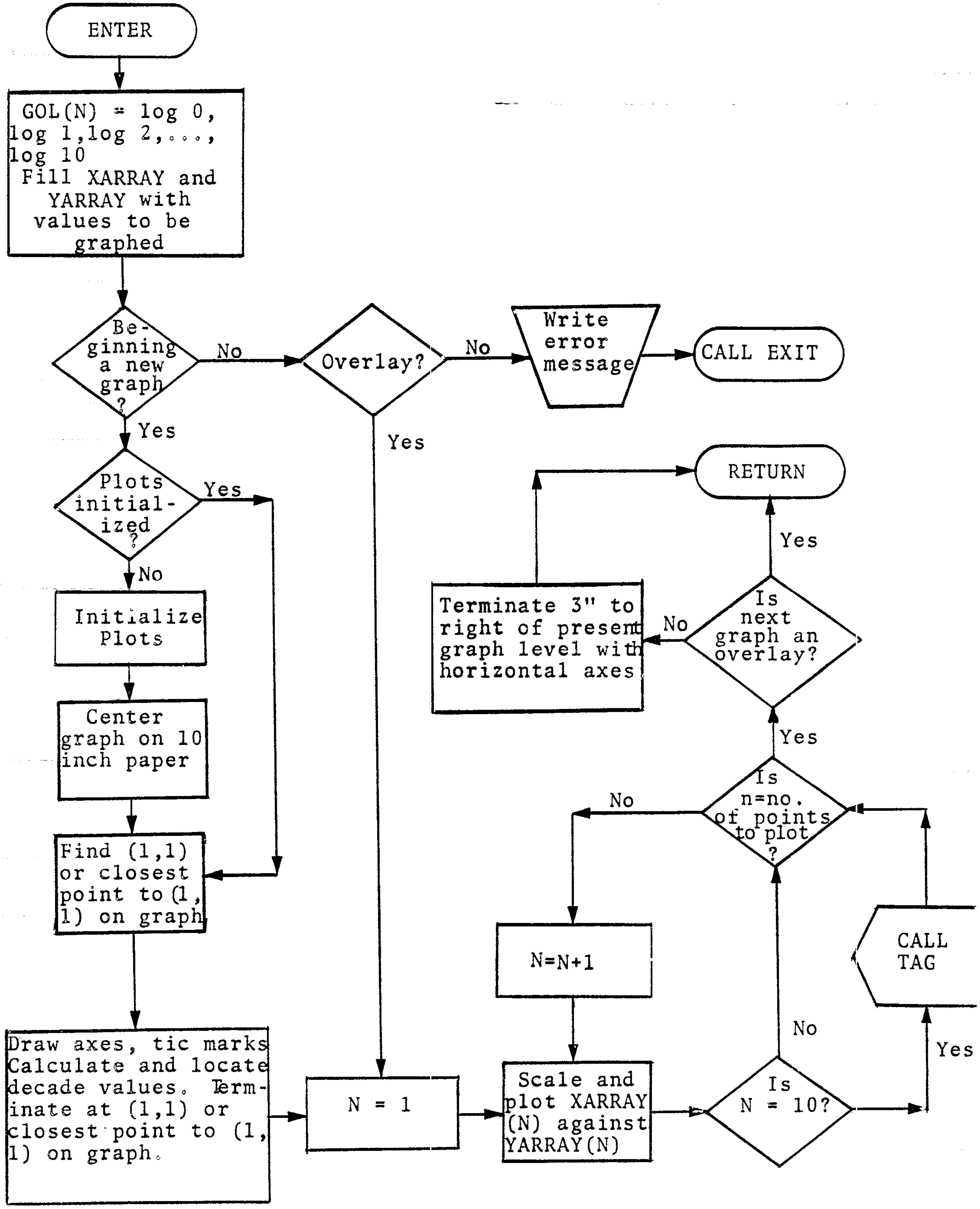
Flow Charts for Program EXAMN


START
PI =π
MUZERO=μo
DELTAP=5.0
PIMU =πμo
5
Read
STOPRD,FG,
SIGMA,
BA,L
Is
STOPRD=*
?
Yes
END
No
Write
Heading
and Sub-
Heading
DEOM = L*L*
PIMU*SIGMA
A=1/(DEOM*
DELTAP*DELTAP)
1
1
Is
A ≤ 5000
?
Yes
F(1) = 100
No
Is
A > 5000
?
Yes
F(1) = 1000
No
Is
A > 50000
?
Yes
F(1) = 10000
No
Is
A > 500000
?
Yes
F(1)=100000
No
II = 50
2


2
F(II)=10**
(II/50)*F(1)
II=II + 50
Is
II = 150
?
No
Yes
FINTV1 = (F(50)-F(1))/50
FINTV2=(F(100)-F(50))/50
FINTV3=(F(150)-F(100))/50
M = 2
F(M)=FINTV1
+F(M-1)
Is
M ≥ 50
<
Is
M ≥ 100
<
F(M)=FINTV2
+F(m-1)
F(M)=FINTV3
+F(M-1)
=
M = M+1
Is
M = 149
?
No
Yes
3


3
N = 1
Is
N = 150
?
Yes
No
δ = √1/πμ₀F(N)σ)
$Z_{L_\infty} = f_g \frac{1+j}{\delta\sigma}$
$Z_{L_o} = Z_{L_\infty} \frac{1+e^{-j2k\ell}}{1-e^{-j2k\ell}}$
$Z_{L_s} = Z_{L_\infty} \frac{1-e^{-j2k\ell}}{1+e^{-j2k\ell}}$
ZLOM(N) = Z_{L_o}
ZLSM(N) = Z_{L_s}
N = N+1
Write
ZLSM(N)
ZLOM(N)
F(N)
STARTH = F(1)
STARTV = .1
NODECH = 3
NODECV = 3
DECLNH = 2
DECLNV = 2
NPTS=150,KIND=3,
LAST=-1,YMAX=
STARTV*10**NODECV,
MORE=155,COX=
F(150)
Is
ZLOM(150)>
YMAX
?
Yes
CALL
ADJUST
No
CALL
DRAW
4


4
STARTH = F(1)
NODECH = 3
NODECV = 3
DECLNH = 2
DECLNV = 2
NPTS = 150
KIND = 4
LAST = 1
Is ZLOM(150) >YMAX ?
Yes
CALL ADJUST
No
CALL DRAW
5


ENTER
GOL(N) = log 0, log 1, log 2,...., log 10
Fill XARRAY and YARRAY with values to be graphed
Be-ginning a new graph ?
No
Overlay?
No
Write error message
CALL EXIT
Yes
Yes
Plots initial-ized ?
Yes
No
Initialize Plots
Center graph on 10 inch paper
Find (1,1) or closest point to (1,1) on graph
Draw axes, tic marks Calculate and locate decade values. Term-inate at (1,1) or closest point to (1,1) on graph.
N = 1
Scale and plot XARRAY (N) against YARRAY(N)
Is N = 10?
No
Yes
CALL TAG
Is n=no. of points to plot ?
No
N=N+1
Yes
Is next graph an overlay?
No
Terminate 3" to right of present graph level with horizontal axes
Yes
RETURN

Appendix B

Program Listing

```
C      PROGRAM   EXAMN(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,TAPE10)
C*******************************************************************************
C                                                                              *
C              A  T H R E E   P A R A M E T E R   S T U D Y   O F              *
C                                                                              *
C            S E N S O R   A N D   S I M U L A T I O N   N O T E   2 2         *
C                                                                              *
C           THE OPEN-CIRCUITED AND SHORT-CIRCUITED TRANSMISSION LINE           *
C                  SIMULATION FOR BURIED STRUCTURES IS EXAMINED.               *
C                                                                              *
C                    THIS PROGRAM READS THE GEOMETRIC FACTOR,                  *
C              DEPTH OF TRANSMISSION LINE, AND GROUND CONDUCTIVITY,            *
C                    AND RETURNS GRAPHS OF FREQUENCY VERSUS                    *
C                          MAGNITUDE OF THE IMPEDANCE.                         *
C                                                                              *
C*******************************************************************************
      COMPLEX ETOX,C1,C2,ZIDEAL,ZLO,ZO,ZLS
      REAL MUZERO,L
      DIMENSION F(200), ZLOM(200), ZLSM(200), XF(200), YF(200)
      DATA STAR/1H*/
      PI=3.14159265358979
      MUZERO=.0000012566370614359 1
      PIMU=PI*MUZERO
      DELTAP=1.0
      C1=CMPLX(1.0,1.0)
5     READ (5,10) STOPRD,FG,BA,L,SIGMA
10    FORMAT (1A1,F9.8,2X,F5.2,2X,F7.2,2X,E9.2)
      IF (STOPRD.EQ.STAR) GO TO 105
      WRITE (6,15) L,SIGMA,FG,BA
15    FORMAT (1H1,30X,60HMAGNITUDE OF OPEN-CIRCUITED AND SHORT-CIRCUITED
     1 TRANSMISSION/42X,35HLINE IMPEDANCE VERSUS FREQUENCY FOR/30X,13HPL
     2ATE DEPTH =,F5.1,23H METERS, CONDUCTIVITY =,E9.2,11H MHOS/METER/40
     3X,23HGEOMETRIC FACTOR (FG) =,F6.4,7H (B/A =,F5.2,1H))
      WRITE (6,20)
20    FORMAT (1H0,2X,9HFREQUENCY,4X,4HZLOM,6X,4HZLSM,16X,9HFREQUENCY,4X,
     14HZLOM,6X,4HZLSM,16X,9HFREQUENCY,4X,4HZLOM,6X,4HZLSM)
      DEOM=L*L*PIMU*SIGMA
      A=1.0/(DEOM*DELTAP*DELTAP)
      IF(A.LE.5000.)F(1)=100.
      IF(A.GT.5000.)F(1)=1000.
      IF(A.GT.50000.)F(1)=10000.
      IF(A.GT.500000.)F(1)=100000.
35    DO 40 II=50,150,50
40    F(II)=10**(II/50)*F(1)
      FINTV1=(F(50)-F(1))/50.
      FINTV2=(F(100)-F(50))/50.
      FINTV3=(F(150)-F(100))/50.
      DO 65 M=2,149
      IF (M-50) 45,65,50
```

```
45    F(M)=FINTV1+F(M-1)
      GO TO 65
50    IF (M-100) 55,65,60
55    F(M)=FINTV2+F(M-1)
      GO TO 65
60    F(M)=FINTV3+F(M-1)
65    CONTINUE
      DO 70 N=1,150
      DELTA=SQRT(1.0/(PIMU*F(N)*SIGMA))
      ZIDEAL=FG*C1/(DELTA*SIGMA)
      B=L*(-2.0/DELTA)
      C2=CMPLX(B,B)
      ETOX=CEXP(C2)
      ZLO=ZIDEAL*(1.0+ETOX)/(1.0-ETOX)
      ZLOM(N)=CABS(ZLO)
      ZLS=ZIDEAL*(1.0-ETOX)/(1.0+ETOX)
      ZLSM(N)=CABS(ZLS)
70    CONTINUE
      WRITE (6,75) ((F(NN),ZLOM(NN),ZLSM(NN),F(NN+50),ZLOM(NN+50),ZLSM(N
     1N+50),F(NN+100),ZLOM(NN+100),ZLSM(NN+100)),NN=1,50)
75    FORMAT (1X,3E10.2,13X,3E10.2,13X,3E10.2)
      STARTH=F(1)
      IF(ZLSM(1).LT..1) STARTV=.01
      IF(ZLSM(1).GE..1) STARTV=.1
      NODECH=3
      NODECV=3
      DECLNH=2.
      DECLNV=2.
      NPTS=150
      KIND=3
      LAST=-1
      YMAX=STARTV*10.**(NODECV)
      MORE=155
      COX=F(150)
      IF(ZLOM(150).GT.YMAX) GO TO 80
      GO TO 85
80    CALL ADJUST(F,ZLOM,NPTS,COX,YMAX,XF,YF,MORE,NEWPTO)
      CALL DRAWL(STARTH,STARTV,NODECH,NODECV,DECLNH,DECLNV,NEWPTO,XF,
     1YF,KIND,LAST,BACK)
      GO TO 90
85    CALL DRAWL (STARTH,STARTV,NODECH,NODECV,DECLNH,DECLNV,NPTS,F,ZLOM,
     1KIND,LAST,BACK)
90    STARTH=F(1)
      NODECH=3
      NODECV=3
      DECLNH=2.
      DECLNV=2.
      NPTS=150
      KIND=4
```

```
      LAST=1
      IF(ZLOM(150).GT.YMAX) GO TO 95
      CALL DRAWL (STARTH,STARTV,NODECH,NODECV,DECLNH,DECLNV,NPTS,F,ZLSM,
     1KIND,LAST,BACK)
      GO TO 100
95    CALL ADJUST(F,ZLSM,NPTS,COX,YMAX,XF,YF,MORE,NEWPTS)
      CALL DRAWL(STARTH,STARTV,NODECH,NODECV,DECLNH,DECLNV,NEWPTS,XF,
     1YF,KIND,LAST,BACK)
100   CALL HEAD(6.,6.,L,SIGMA,FG,BA,BACK)
      GO TO 5
105   CONTINUE
      END
```

```
      SUBROUTINE DRAWL (STARTH,STARTV,NODECH,NODECV,DECLNH,DECLNV,NPTS,X
     1ARRAY,YARRAY,KIND,LAST,XT)
C*****************************************************************************
C                                                                            *
C     THIS SUBROUTINE SCALES, DRAWS THE AXIS FOR THE LOG LOG GRAPH, AND      *
C     PLOTS THE DATA WITH ANY NUMBER OF OVERLAYS ON THE CALCOMP PLOTTER.     *
C                                                                            *
C*****************************************************************************
      DIMENSION X(200), Y(200), GOL(11), XARRAY(NPTS), YARRAY(NPTS)
      DATA GOL/0.0,.17609,.30103,.47712,.60206,.69897,.77815,.84510,.903
     109,.95424,1.0/,IFT/2HI2/,CORECY/0./,CORECX/0./,JFT/2HI1/
      DO 5 I=1,NPTS
      X(I)=XARRAY(I)
5     Y(I)=YARRAY(I)
      IHBOKK=KIND
      IF (KIND-3) 15,25,10
10    IF (KIND-4) 15,150,15
15    WRITE (6,20) KIND
20    FORMAT (41H  THE KIND OF GRAPH ASKED FOR IS IN ERROR,I8)
      RETURN
25    IF (IO-2) 30,35,30
30    CALL PLOTS (TB,TB,IO)
      IO=2
      RNODEC=NODECV
      REALH=RNODEC*DECLNV
      YS=(10.-REALH)/2.-.5
      CALL PLOT (0.,YS,-3)
35    K=0
      CALL FLAG (K,STARTH,NODECH)
      K=3*(K-1)
      CALL FLAG (K,STARTV,NODECV)
      GO TO (40,45,50,55,60,65,70,75,80), K
40    CALL FIND1 (STARTH,NODECH,DECLNH,XXX)
      CALL FIND1 (STARTV,NODECV,DECLNV,YYY)
      GO TO 85
45    CALL TOSMAL (STARTV,NODECV,CORECY,YYY,DECLNV)
      CALL FIND1 (STARTH,NODECH,DECLNH,XXX)
      GO TO 85
50    CALL TOLARG (STARTV,NODECV,CORECY,YYY)
      CALL FIND1 (STARTH,NODECH,DECLNH,XXX)
      GO TO 85
55    CALL TOSMAL (STARTH,NODECH,CORECX,XXX,DECLNH)
      CALL FIND1 (STARTV,NODECV,DECLNV,YYY)
      GO TO 85
60    CALL TOSMAL (STARTH,NODECH,CORECX,XXX,DECLNH)
      CALL TOSMAL (STARTV,NODECV,CORECY,YYY,DECLNV)
      GO TO 85
65    CALL TOSMAL (STARTH,NODECH,CORECX,XXX,DECLNH)
      CALL TOLARG (STARTV,NODECV,CORECY,YYY)
```

```
      GO TO 85
70    CALL TOLARG (STARTH,NODECH,CORECX,XXX)
      CALL FIND1 (STARTV,NODECV,DECLNV,YYY)
      GO TO 85
75    CALL TOLARG (STARTH,NODECH,CORECX,XXX)
      CALL TOSMAL (STARTV,NODECV,CORECY,YYY,DECLNV)
      GO TO 85
80    CALL TOLARG (STARTH,NODECH,CORECX,XXX)
      CALL TOLARG (STARTV,NODECV,CORECY,YYY)
85    NODECH=NODECH+1
      NODECV=NODECV+1
      XX=0.
      POWERX=ALOG10(STARTH)
      ILOG=POWERX+SIGN(.000001,POWERX)
      DO 100 I=1,NODECH
      REALI=I-1
      INUM=ILOG+(I-1)
      RR=XX-.12
      RER=XX+.13
      CALL SYMBOL (RR,-.3,.14,2H10,0.,2)
      IF (INUM.GE.0.AND.INUM.LT.10) CALL NUMBER (RER,-.21,.10,INUM,0.,JF
     1T)
      IF (INUM.LT.0.OR.INUM.GE.10) CALL NUMBER (RER,-.21,.10,INUM,0.,IFT
     1)
      CALL PLOT (XX,0.,3)
      IF (I-NODECH) 90,105,90
90    DO 95 J=1,11
      XX=(GOL(J)+REALI)*DECLNH
      CALL PLOT (XX,0.0,2)
      CALL PLOT (XX,-.05,2)
95    CALL PLOT (XX,0.0,2)
100   CONTINUE
105   CONTINUE
      NODEC=NODECV-1
      DO 115 I=1,NODEC
      REALI=I-1
      DO 110 J=1,11
      YY=(GOL(J)+REALI)*DECLNV
      CALL PLOT (XX,YY,2)
      W=XX+.05
      CALL PLOT (W,YY,2)
110   CALL PLOT (XX,YY,2)
115   CONTINUE
      NODEC=NODECH-1
      DO 125 I=1,NODEC
      RELDEC=NODECH-I
      DO 120 J=1,11
      XX=DECLNH*(RELDEC-(1.0-GOL(-J+12)))
      CALL PLOT (XX,YY,2)
```

```
      Z=YY+.05
      CALL PLOT (XX,Z,2)
120   CALL PLOT (XX,YY,2)
125   CONTINUE
      POWERY=ALOG10(STARTV*10.**(NODECV-1))
      JLOG=POWERY+SIGN(.000001,POWERY)
      DO 140 I=1,NODECV
      YADD=YY-.07
      CALL SYMBOL (-.5,YADD,.14,2H10,0.,2)
      RYE=YY+.03
      JNUM=JLOG-(I-1)
      IF (JNUM.GE.0.AND.JNUM.LT.10) CALL NUMBER (-.25,RYE,.10,JNUM,0.,IF
     1T)
      IF (JNUM.LT.0.OR.JNUM.GE.10) CALL NUMBER (-.25,RYE,.10,JNUM,0.,IFT
     1)
      CALL PLOT (XX,YY,3)
      IF (I-NODECV) 130,145,130
130   DO 135 J=1,11
      YY=DECLNV*((NODECV-I)-(1.-GOL(-J+12)))
      CALL PLOT (XX,YY,2)
      W=XX-.05
      CALL PLOT (W,YY,2)
135   CALL PLOT (XX,YY,2)
140   CONTINUE
145   CONTINUE
      CALL PLOT (XXX,YYY,-3)
150   DO 225 I=1,NPTS
      IF (X(I).GE.1.) GO TO 165
      M=0
155   X(I)=X(I)*10.
      M=M+1
      IF (X(I)-1.) 155,160,160
160   REALM=M
      XX=(ALOG10(X(I))-REALM+CORECX)*DECLNH
      GO TO 180
165   N=0
170   IF (X(I).LE.10.) GO TO 175
      X(I)=X(I)/10.
      N=N+1
      GO TO 170
175   REALN=N
      XX=(ALOG10(X(I))+REALN+CORECX)*DECLNH
180   IF(Y(I).GE.1.) GO TO 195
      M=0
185   Y(I)=Y(I)*10.
      M=M+1
      IF(Y(I)-1.) 185,190,190
190   REALM=M
      YY=(ALOG10(Y(I))-REALM+CORECY)*DECLNV
```

```
      GO TO 210
195   N=0
200   IF(Y(I).LE.10.) GO TO 205
      Y(I)=Y(I)/10.
      N=N+1
      GO TO 200
205   REALN=N
      YY=(ALOG10(Y(I))+REALN+CORECY)*DECLNV
210   IF(I-1) 220,215,220
215   CALL PLOT(XX,YY,3)
      CALL PLOT(XX,YY,2)
      GO TO 225
220   CALL PLOT(XX,YY,2)
      IF(I.EQ.10.AND.IHBOKK.EQ.3)CALL TAG(XX,YY,1)
      IF(I.EQ.10.AND.IHBOKK.EQ.4)CALL TAG(XX,YY,-1)
225   CONTINUE
      IF(LAST) 235,230,230
230   RNODEC=NODECH
      XT=-XXX+RNODEC*DECLNH+3.
      CALL PLOT(XT,-YYY,-3)
235   RETURN
      END
```

```
      SUBROUTINE FIND1 (START,NODEC,DECLN,XY)
C***************************************************************************
C                                                                          *
C       THIS SUBROUTINE LOCATES 1 ON THE VERTICAL OR HORIZONTIAL AXIS.     *
C                                                                          *
C***************************************************************************
      STARR=START
      DO 15 I=1,NODEC
      N=I
      IF (ABS(STARR-1.0)-1.0E-6) 20,20,5
5     IF (STARR-1.00) 10,20,20
10    STARR=STARR*10.
15    CONTINUE
20    REALN=N-1
      XY=REALN*DECLN
      RETURN
      END
```

```
      SUBROUTINE TOSMAL (START,NODEC,CORECS,XY,DECLN)                    TS   1
C***********************************************************************************
C                                                                                 *
C       TOSMAL DETERMINES THE NUMBER OF DECADES DIFFERENCE BETWEEN 1 AND          *
C                        THE LARGEST VALUE LESS THAN 1.                           *
C                                                                                 *
C***********************************************************************************
      CORECS=0.0                                                         TS   2
      XYMAX=START*10.0**NODEC                                            TS   3
      RELNOD=NODEC                                                       TS   4
      XY=RELNOD*DECLN                                                    TS   5
5     IF (ABS(XYMIN-1.0)-1.0E-6) 20,20,10                                TS   6
10    IF (XYMAX-1.00) 15,20,20                                           TS   7
15    CORECS=CORECS+1.                                                   TS   8
      XYMAX=XYMAX*10.                                                    TS   9
      GO TO 5                                                            TS  10
20    RETURN                                                             TS  11
      END                                                                TS  12-
```

```
      SUBROUTINE TOLARG (START,NODEC,CORECL,XY)
C***********************************************************************
C                                                                      *
C       TOLARG DETERMINES THE NUMBER OF DECADES DIFFERENCE BETWEEN 1 AND *
C                     THE SMALLEST VALUE GREATER THAN 1.               *
C                                                                      *
C***********************************************************************
      XY=0.
      CORECL=0.0
      XYMIN=START
5     IF (ABS(XYMIN-1.0)-1.0E-6) 20,20,10
10    IF (XYMIN-1.0) 20,20,15
15    CORECL=CORECL-1.0
      XYMIN=XYMIN*.1
      GO TO 5
20    RETURN
      END
```

```
      SUBROUTINE FLAG (K,SHV,NODEC)
C************************************************************************
C                                                                       *
C          SUBROUTINE FLAG DETERMINES WHAT COMBINATION OF SUBROUTINES   *
C                 FIND1, TOLARG AND TOSMAL SHOULD BE CALLED.            *
C                                                                       *
C************************************************************************
      IF (ABS(SHV-1.)-1.0E-6) 25,25,5
5     IF (SHV-1.00) 10,25,30
10    ZHVT=SHV*10.**NODEC
      IF (ABS(ZHVT-1.0)-1.0E-6) 20,20,15
15    IF (ZHVT-1.0) 20,20,25
20    K=K+2
      RETURN
25    K=K+1
      RETURN
30    K=K+3
      RETURN
      END
```

```
      SUBROUTINE HEAD (GL,GH,L,SIGMA,FG,BA,BACK)
C***********************************************************************************
C                                                                                 *
C                     THIS SUBROUTINE PRINTS THE HEADING AND                      *
C                      CORRESPONDING NUMBERS ON THE GRAPH.                        *
C                                                                                 *
C***********************************************************************************
      CALL PLOT (-BACK,0.,-3)
      GLO2=GL/2.
      X1=GLO2-3.6
      X2=GLO2-2.16
      X3=GLO2-3.06
      X4=GLO2-1.38
      X5=GLO2-.9
      Y1=GH+1.06
      Y2=GH+.78
      Y3=GH+.5
      Y4=GH+.22
      Y5=-.5
      CALL SYMBOL (X1,Y1,.14,60HMAGNITUDE OF OPEN-CIRCUITED AND SHORT-CI
     1RCUITED TRANSMISSION,0.,60)
      CALL SYMBOL (X2,Y2,.14,35HLINE IMPEDANCE VERSUS FREQUENCY FOR,0.,3
     15)
      CALL SYMBOL (X3,Y3,.14,51HL =        METERS, CONDUCTIVITY =
     1 MHOS/METER,0.,51)
      CALL SYMBOL (X4,Y4,.14,22HFG =       (B/A =      ),0.,22)
      CALL SYMBOL (X5,Y5,.14,15HFREQUENCY (CPS),0.,15)
      XN1=X3+.36
      XN2=X3+3.7
      XN3=X4+.38
      XN4=X4+2.04
      CALL NUMBER (XN1,Y3,.14,L,0.,4HF5.1)
      CALL NUMBER (XN2,Y3,.14,SIGMA,0.,4HE9.2)
      CALL NUMBER (XN3,Y4,.14,FG,0.,4HF5.3)
      CALL NUMBER (XN4,Y4,.14,BA,0.,4HF4.2)
      Y6=(GH-1.75)/2.+.1
      CALL SYMBOL (-.80,Y6,.14,12HZ    AND   Z,90.,12)
      XS1=-.7
      YS1=Y6+.12
      DO 5 I=1,2
      CALL SYMBOL (XS1,YS1,.14,1HL,90.,1)
5     YS1=YS1+1.32
      XS2=-.80+.15
      YS2=Y6+.23
      CALL SYMBOL (XS2,YS2,.07,1HO,90.,1)
      YS2=YS2+1.32
      CALL SYMBOL (XS2,YS2,.07,1HS,90.,1)
      DO 15 I=1,2
      ABSIGN=Y6-.05
```

```
      DO 10 J=1,2
      CALL PLOT (-.95,ABSIGN,3)
      CALL PLOT (-.65,ABSIGN,2)
10    ABSIGN=ABSIGN+.4
15    Y6=Y6+1.32
      CALL PLOT (BACK,0.,-3)
      RETURN
      END
```

```
       JBROUTINE TAG (X,Y,ISCRI)
C***  *************************************************************************
C                                                                               *
C        SUBROUTINE TAG POINTS OUT AND LABELS THE CURVES ON THE GRAPH.          *
C                                                                               *
C***  *************************************************************************
       ALL PLOT (X,Y,3)
       F (ISCRI) 15,5,20
5      RITE (6,10)
10     DRMAT (10X,33HARGUMENT ERROR IN SUBROUTINE TAG.)
       ALL EXIT
15     X=X+.1
       Y=Y-.04
       ALL PLOT (XX,YY,2)
       Y=Y+.04
       ALL PLOT (XX,YY,3)
       ALL PLOT (X,Y,2)
       X=X+.4
       ALL PLOT (XX,Y,2)
       Z=XX+.2
       Z=Y-.07
       ) TO 25
20     X=X+.04
       Y=Y+.1
       ALL PLOT (XX,YY,2)
       X=X-.04
       ALL PLOT (XX,YY,3)
       ALL PLOT (X,Y,2)
       Y=Y+.4
       ALL PLOT (X,YY,2)
       Z=X-.06
       Z=Y+.55
25     ALL SYMBOL (XZ,YZ,.14,1HZ,0.,1)
       L=XZ+.12
       L=YZ-.1
       ALL SYMBOL (XL,YL,.14,1HL,0.,1)
       OS=XZ+.23
       OS=YZ-.15
       F (ISCRI) 30,5,35
30     ALL SYMBOL (XOS,YOS,.07,1HS,0.,1)
       O TO 40
35     ALL SYMBOL (XOS,YOS,.07,1HO,0.,1)
40     X=XZ-.1
       Y=YZ-.15
       ALL PLOT (XX,YY,3)
       Y=YY+.35
       ALL PLOT (XX,YY,2)
       X=XZ+.35
       ALL PLOT (XX,YY,3)
```

```
      YY=YY-.35
      CALL PLOT (XX,YY,2)
      CALL PLOT (X,Y,3)
      RETURN
      END
```

```
      SUBROUTINE ADJUST(X,Y,NPTS,XM,YM,XE,YE,MORE,L)
C*******************************************************************************
C                                                                              *
C       THIS SUBROUTINE ADJUSTS ALL DATA POINTS IN THE FIRST QUADRANT THAT     *
C     OVERFLOW THE GIVEN LIMITS OF THE BOUNDARY TO THE BOUNDARY WITHOUT THE    *
C        LOSS OF THE SLOPE FROM THE INTERIOR POINT TO THE EXTERIOR POINT      *
C                                                                              *
C*******************************************************************************
      DIMENSION X(NPTS), Y(NPTS), XE(MORE), YE(MORE)
      L=0
      I=0
5     I=I+1
      IF (I-NPTS) 10,35,45
10    K=0
      IF (X(I).GT.XM.AND.X(I+1).GT.XM) GO TO 5
      IF (Y(I).GT.YM.AND.Y(I+1).GT.YM) GO TO 5
      IF (X(I).GT.XM.OR.X(I+1).GT.XM) K=1
      IF (Y(I).GT.YM.OR.Y(I+1).GT.YM) K=K+2
      IF (K) 15,40,15
15    C=X(I)
      D=Y(I)
      E=X(I+1)
      F=Y(I+1)
      CALL EDGE (C,D,E,F,K,KK,XM,YM)
      IF (KK) 5,20,20
20    L=L+1
      GO TO (25,30,30), KK
25    XE(L)=C
      YE(L)=D
      GO TO 5
30    XE(L)=C
      YE(L)=D
      L=L+1
      XE(L)=E
      YE(L)=F
      GO TO 5
35    IF (X(I).LE.XM.AND.Y(I).LE.YM) GO TO 40
      GO TO 45
40    L=L+1
      XE(L)=X(I)
      YE(L)=Y(I)
      GO TO 5
45    RETURN
      END
```

```
      SUBROUTINE EDGE (X1,Y1,X2,Y2,K,KK,XM,YM)
C*******************************************************************************
C                                                                              *
C       SUBROUTINE EDGE CALCULATES THE INTERSECTION OF THE LINE ADJOINING     *
C                 TWO POINTS AND THE LINES X=XM, Y=YM OR BOTH                  *
C                                                                              *
C*******************************************************************************
      IF (X1-X2) 5,95,5
5     SLOPE=(Y2-Y1)/(X2-X1)
      B=Y1-SLOPE*X1
      M=1
10    GO TO (15,55,80), K
15    IF (X2-X1) 25,20,20
20    X2=XM
      Y2=SLOPE*XM+B
      KK=2
      GO TO (50,30,40), M
25    X1=XM
      Y1=SLOPE*XM+B
      KK=1
      GO TO (50,30,40), M
30    IF (Y1.GT.YM.OR.Y2.GT.YM) GO TO 35
      RETURN
35    K=2
      M=2
      GO TO 10
40    IF (Y1.GT.YM.AND.Y2.GT.YM) GO TO 45
      K=2
      M=2
      GO TO 10
45    KK=-1
50    RETURN
55    IF (Y2-Y1) 65,60,60
60    Y2=YM
      X2=(YM-B)/SLOPE
      KK=2
      GO TO (75,70), M
65    Y1=YM
      X1=(YM-B)/SLOPE
      KK=1
      GO TO (75,70), M
70    KK=3
75    RETURN
80    IF (SLOPE) 85,90,90
85    K=1
      M=3
      GO TO 10
90    K=1
      M=2
```

```
      GO TO 10
95    IF (Y2-Y1) 105,100,100
100   Y2=YM
      KK=2
      RETURN
105   Y1=YM
      KK=1
      RETURN
      END
```