A General-Purpose Scientific and Engineering Plotting Library that Includes Smith Charts

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DISLIN is a **FREE** general-purpose scientific and engineering plotting library for visualizing engineering and scientific data in numerous 2D and 3D graphical formats. This plotting library permits users to work in both 32-bit and 64-bit environments to write programs for visualizing data that was measured in a laboratory environment, or calculated by commercial or privately developed CAE programs. The DISLIN library is available for Unix, Linux, FreeBSD, Windows, Mac OSX, and MS-DOS systems. It supports a variety of public domain and commercial compilers for Go, Perl, Python, Java, Ruby, TCL, Julia, FreeBASIC, Free Pascal, R, C/C++, and Fortran (77, 90, and 95). The documentation for using DISLIN with each programming language is available online at https://www.dislin.de/manuals.html.

The DISLIN graphics library has expanded to satisfy a growing list of scientific and engineering disciplines in its 35-year history. The graphics library was initially created at the Max Planck Institute for Solar System Research beginning in 1985 by Mr. Helmut Michels, which continued through the spring of 2020. Mr. Michels' dedication to maintaining the DISLIN library following his recent retirement from Max Planck Institute for Solar System Research permitted him to found the DISLIN Software (https://dislin.de/) company. This company was created to continue his work for supporting, developing, and distributing the DISLIN graphics library through DISLIN Software (https://dislin.de/).

The critical thing to realize is that DISLIN is a general-purpose scientific and engineering plotting library for visualizing data in numerous graphical formats, so new graphical formats are added when requested by users. This provides users with the ability to visualize data in both general-purpose and self-defined graphical formats. Furthermore, the graphs created by DISLIN can be viewed on a workstation monitor, or saved in various file formats including GKSLIN, CGM, HPGL, PostScript, PDF, WMF, SVG, PNG, BMP, PPM, GIF, and TIFF. This capability permits graphs to be saved and imported into project documents.

RF, Microwave, Millimeter-Wave, and Terahertz Engineering

A majority of the worldwide population of scientists and engineers are working remotely at this time from home, or in an isolated area due to the Coronavirus Pandemic. Working remotely complicates the sharing of CAE resources that are commonly available in an engineering office environment, particularly for data analysis and design projects. Many of these tasks make use of industry-specific graphics as analysis tools for predicting circuit performance. One industry-specific data analysis technique involves visualizing complex impedance and admittance data on a Smith Chart, which is a feature that is not commonly available in plotting software packages.

However, a recent addition to the DISLIN graphics library includes the ability to create Smith Chart plots of complex impedance or admittance data collected through circuit simulations or laboratory measurements. This plotting capability is simple to create using DISLIN, as illustrated in the following discussion. Hence, DISLIN can be used to create data visualization tools that are specific to the RF, Microwave, Millimeter-Wave, and Terahertz Engineering community.

Creating a Smith Chart Using DISLIN

The port reflection and transmission characteristics of RF, Microwave, Millimeter-Wave, and Terahertz circuits are commonly characterized in terms of Scattering Parameters (S-parameters). The Reflection Coefficient of any port in a circuit is represented as $S_{n,n}$, where "n" defines the port at which the data was collected. Therefore, the Reflection Coefficient for Port 1 of an n-port circuit is represented as $S_{1,1}$. $S_{1,1}$ is a complex number, which is commonly calculated or measured in terms of Magnitude and Phase, but may also be recorded in other formats. Any format is acceptable for viewing on a Smith Chart when that format is converted into complex impedance or admittance.

$S_{1,1}$ is calculated or measured at each frequency for Port 1 of an arbitrary circuit in terms of detected power and its associated phase, but this information cannot be plotted directly onto a Smith Chart. The Smith Chart coordinates are in terms of complex impedance or admittance, so $S_{1,1}$ must be converted to complex impedance or admittance to be plotted. For instance, this is accomplished by first converting $S_{1,1}$ Magnitude and Phase data into a complex number containing its real and imaginary parts as follows:

$$A = Magnitude\ of\ S_{1,1}$$
$$B = Phase\ of\ S_{1,1}$$
$$C = Complex\ form\ of\ S_{1,1} = A\left[\cos(B) + j\sin(B)\right]$$

This format permits $S_{1,1}$ to be easily converted to complex impedance ($Z_{1,1}$) as follows:

$$D = \text{Complex form of } Z_{1,1} = \frac{1+C}{1-C}, \text{ where}$$
$$E = \text{Real}(D) = \text{Real}(Z_{1,1}), \text{ and}$$
$$F = \text{Imaginary}(D) = \text{Imaginary}(Z_{1,1}).$$

It is essential to realize that *A*, *B*, *C*, *D*, *E*, and *F* are one-dimensional matrices, where each entry into an array is dependent upon the "*m*" frequencies used for the circuit simulation, calculation, or measurement. The frequency-dependent complex impedance data represented by *E* and *F* are used to plot this frequency-dependent data onto a Smith Chart using DISLIN. Similarly, complex admittance data can also be plotted by remembering that $Y_{1,1} = 1/Z_{1,1}$.

Therefore, a Smith Chart is created using either the $Z_{1,1}$ or $Y_{1,1}$ data with the DISLIN library. Helmut Michels provides both a C and Fortran 90 code demonstrating this plotting capability online at https://dislin.de/gallery_smith_c.html#section_1.

This Smith Chart plotting capability is demonstrated here by creating a Smith Chart plot of the complex impedance and complex admittance data for a monopole antenna, which is provided in tabular format in **Table 1**.

Table 1 – Complex Impedance and Admittance Data for a Monopole Antenna.

Frequency, Hz	Complex Impedance, Ohms	Complex Admittance, S
1.00E+09	0.42 - 0.11j	2.228+0.583j
1.13E+09	0.30+0.15j	2.666-1.333j
1.37E+09	0.63+0.28j	1.325-0.589j
1.52E+09	0.83+0.0j	1.204
1.67E+09	0.67-0.43j	1.057+0.678j

The DISLIN Smith Chart plotting capability is demonstrated by plotting the impedance and admittance data onto two Smith Charts using the Smith5.f90 program that is provided in **Appendix A**. This Fortran 90 program, along with a second Fortran 90 program, and an S-parameter data file are contained in a ZIP file, which can be downloaded to demonstrate this plotting capability from the following URL.

https://www.dropbox.com/s/7p8ac9hgovjdojt/Fortran%2090%20demo%20files%20for%20S-parameter%20and%20Smith%20Chart%20Plots.zip?dl=0

We can start this discussion by looking at Smith5.f90 to learn how a Smith Chart is created using the DISLIN library. A Smith Chart is constructed using 52 lines of code, as shown in **Appendix A**, and many of these lines use the same subroutine multiple times to create these graphs. DISLIN has over 750 subroutines, also referred to as functions, subprograms, methods, procedures, and routines in other supported programming languages, and all of these subroutines are documented in the User's Manual available online in HTML format at https://www.dislin.de/manuals.html. Each line of the Fortran 90 code shown in **Appendix A** is commented to explain why it is being used, and the reader can easily refer to the online User's Manual for more information about each subroutine if necessary.

The program shown in **Appendix A** begins by entering the Complex Impedance data shown in **Table 1** into the program with lines 11 to 14. Similarly, the Complex Admittance data shown in **Table 1** is entered into the program with lines 16 to 19. The next task undertaken by the code is to create an Impedance Smith Chart, which begins on line 23 and ends on line 83. Line 26 is essential since it defines how the Smith Chart will be displayed, and 'cons' establishes the workstation monitor as the output device. Image formats discussed above may also be entered here for viewing the Smith Chart.

Line 34 is also necessary since it defines the axis for the graph being created as an Impedance Smith Chart, but this may similarly be defined as an Admittance Smith Chart, which is discussed later. Line 46 defines the number of REAL and IMAGINARY grid lines to be plotted on the Smith Chart, and lines 52 to 56 define the REAL impedance circles, while lines 57 to 70 define the positive and negative IMAGINARY impedance arcs to be displayed on the Smith Chart. This completes the formation of a Smith Chart, so data can now be plotted onto this graph.

It is common to use a spline fit to connect the data points on a Smith Chart, which is enabled with lines 72 and 73 of the code. Finally, the Complex Impedance data is plotted in line 75, and markers are added to the data points in lines 77 to 80. The plotting is terminated in lines 82 and 83.

The Complex Impedance Smith Chart created for the data shown in **Table 1** is now displayed in **Figure 1**. Inspection of the markers shown on the Smith Chart reveals that

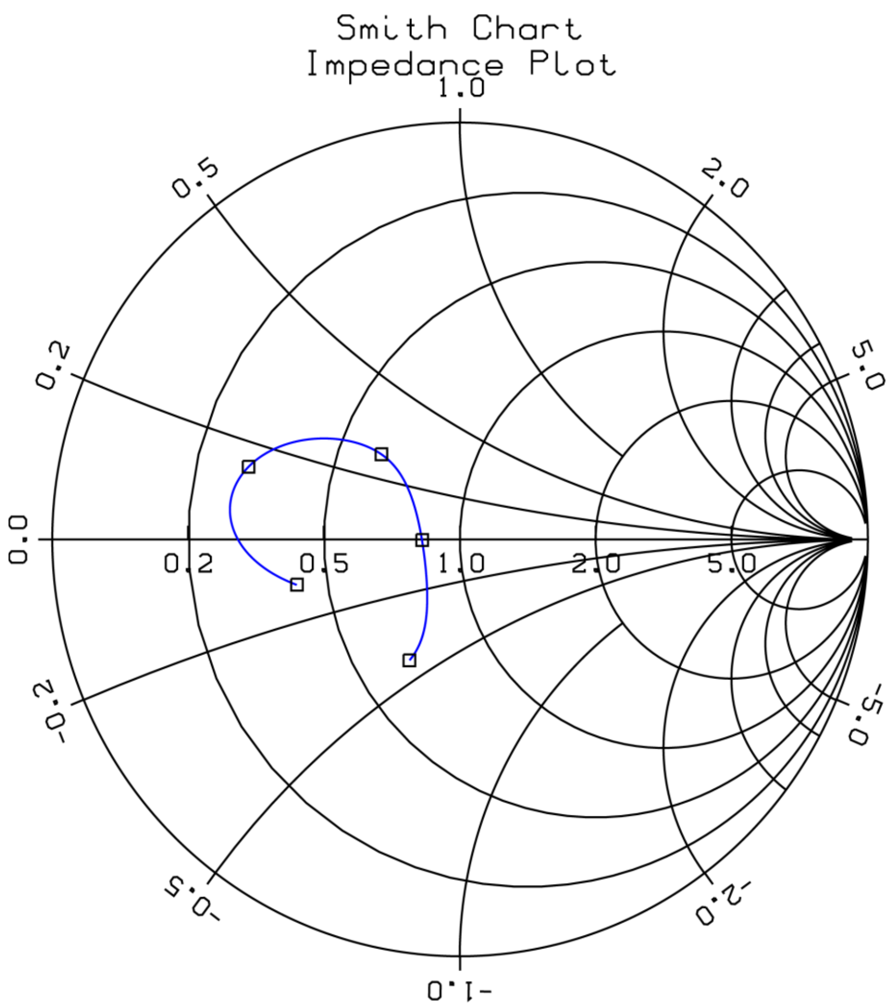

Figure 1 – Impedance Smith Chart for data shown in Table 1.

they are in agreement with the data provided in **Table 1**, so an Impedance Smith Chart has been successfully created using DISLIN.

Similarly, the Admittance Smith Chart plotting algorithm is shown in lines 85 to 146 of the program provided in **Appendix A**, and this code is identical to the code previously discussed for the Impedance Smith Chart with a few exceptions discussed here. Line 96 is edited to convert the graph created for an Impedance Smith Chart into an Admittance Smith Chart, which is shown in **Figure 2**. Inspection of the markers shown on this Smith Chart reveals that they are in agreement with the data provided in **Table 1**, so an Admittance Smith Chart can also be easily created using DISLIN.

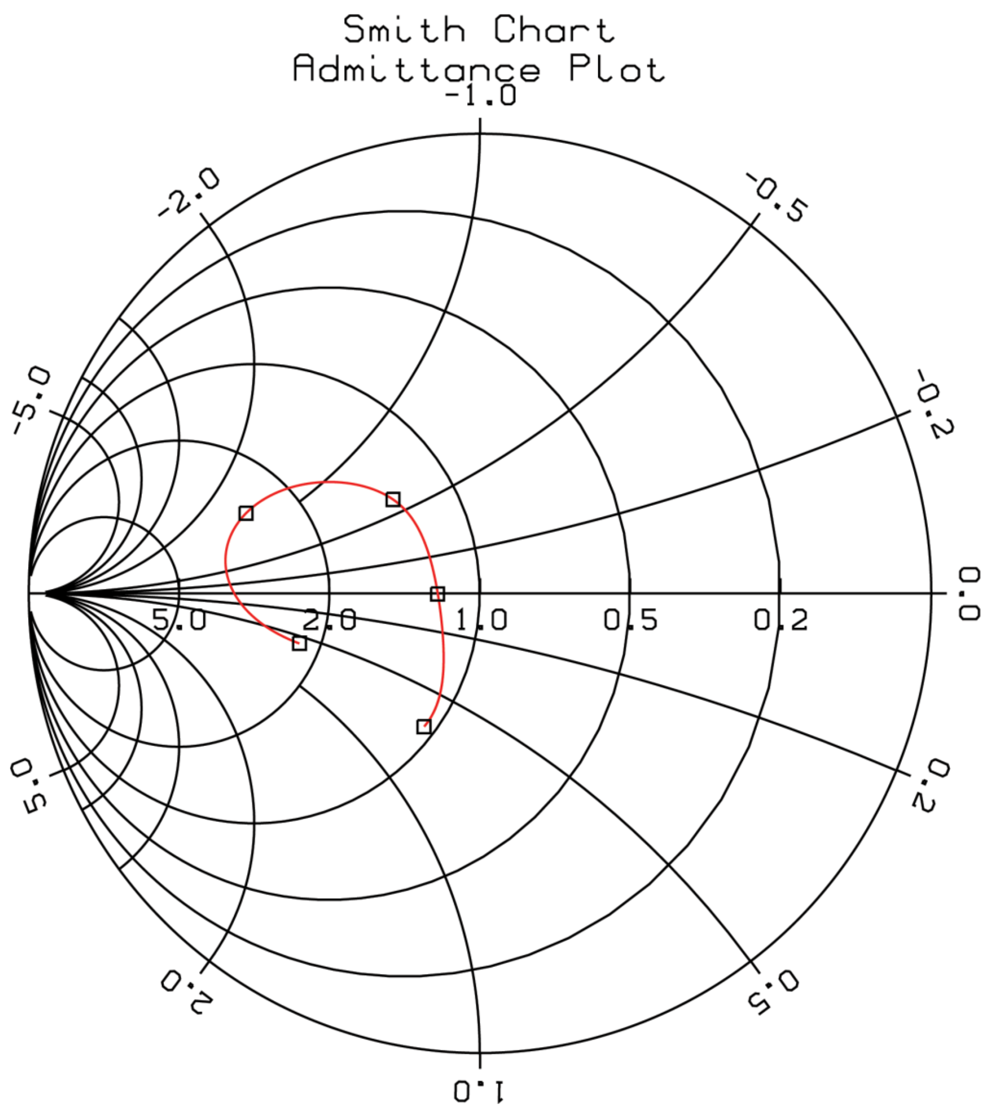

Figure 2 – Admittance Smith Chart for data shown in Table 1.

Now that the code required for creating Impedance and Admittance Smith Charts has been demonstrated, we can look at the other plotting capabilities in DISLIN. These capabilities are shown in a second Fortran 90 program named PLOT SMITH CHART DEMO.f90 shown in **Appendix B**, that uses an S-parameter data file named

GRAPH1.DAT shown in **Appendix C** to create Cartesian plots of $S_{1,1}$ Magnitude and Phase data.

Inspection of the code contained in PLOT SMITH CHART DEMO.f90 reveals that lines 48, 49, and 50 read the S-parameter data stored in GRAPH1.DAT. This program could have been written to read S-parameter data stored in Touchstone file format, so the user can write code to read data files storing data in any format. This S-parameter data can be retrieved by writing code to read the data file contents.

This S-parameter data can be plotted in DISLIN once it is available. The $S_{1,1}$ Magnitude and Phase data saved in GRAPH1.DAT can be graphically displayed using DISLIN. For example, lines 60 to 105 of the Fortran 90 program are used to create a plot of $S_{1,1}$ Magnitude, and lines 107 to 151 are used to plot $S_{1,1}$ Phase. Finally, lines 153 to 226 are used to plot $S_{1,1}$ Magnitude and Phase together on one plot, as shown in **Figure 3**.

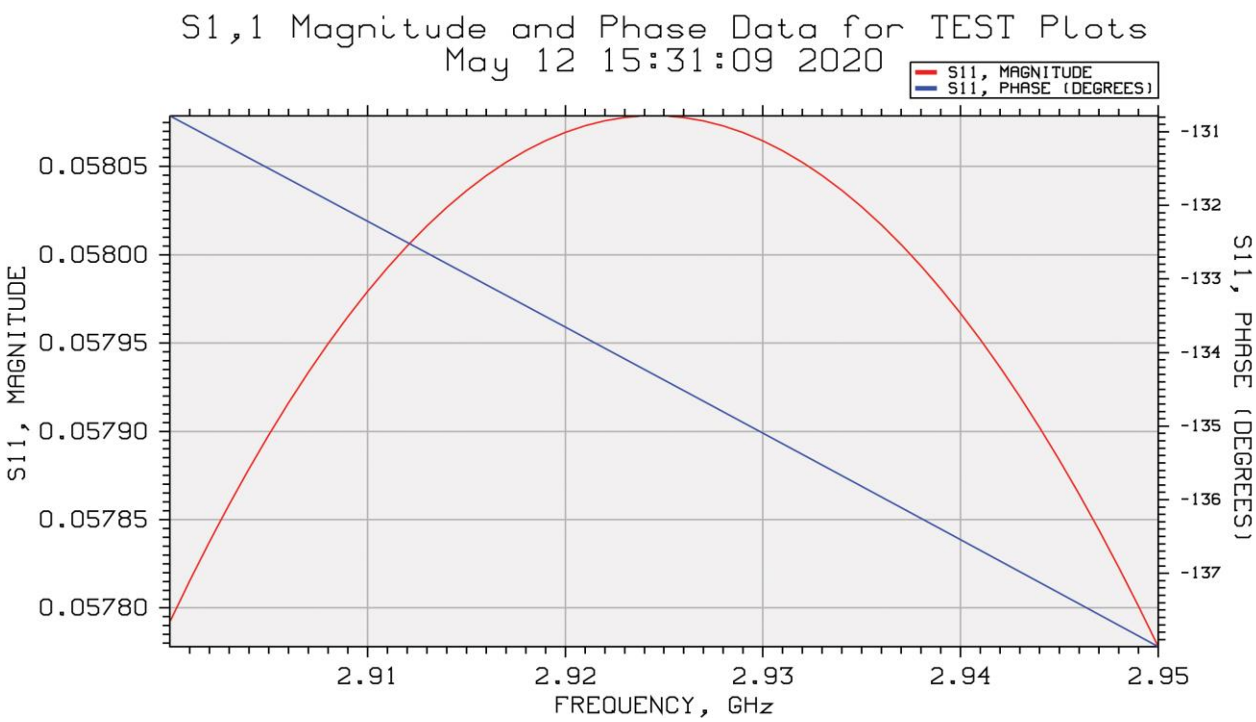

Figure 3 – $S_{1,1}$ Magnitude and Phase for a Test Circuit.

This Fortran 90 program is self-contained, and the reader can easily copy and modified the code for their own S-parameter plotting applications. This is simplified since every line of the code is commented, and the user can reference the online User's Manual (https://www.dislin.de/manuals.html) to obtain detailed information for each DISLIN subroutine.

This is further illustrated by creating a new Smith Chart using a polar axis around the circumference of the plot to illustrate phase-shifting S-parameters by embedding or de-embedding a transmission line from the port. This new Smith Chart is created by first converting the $S_{1,1}$ Magnitude and Phase data shown in **Figure 3** into the Real and

Imaginary parts of $Z_{1,1}$ for each frequency, as shown in lines 228 to 240 of the code. The resulting $Z_{1,1}$ data appears on the Smith Chart shown in **Figure 4**. The polar axis appearing on this Smith Chart is defined in line 286 of the code.

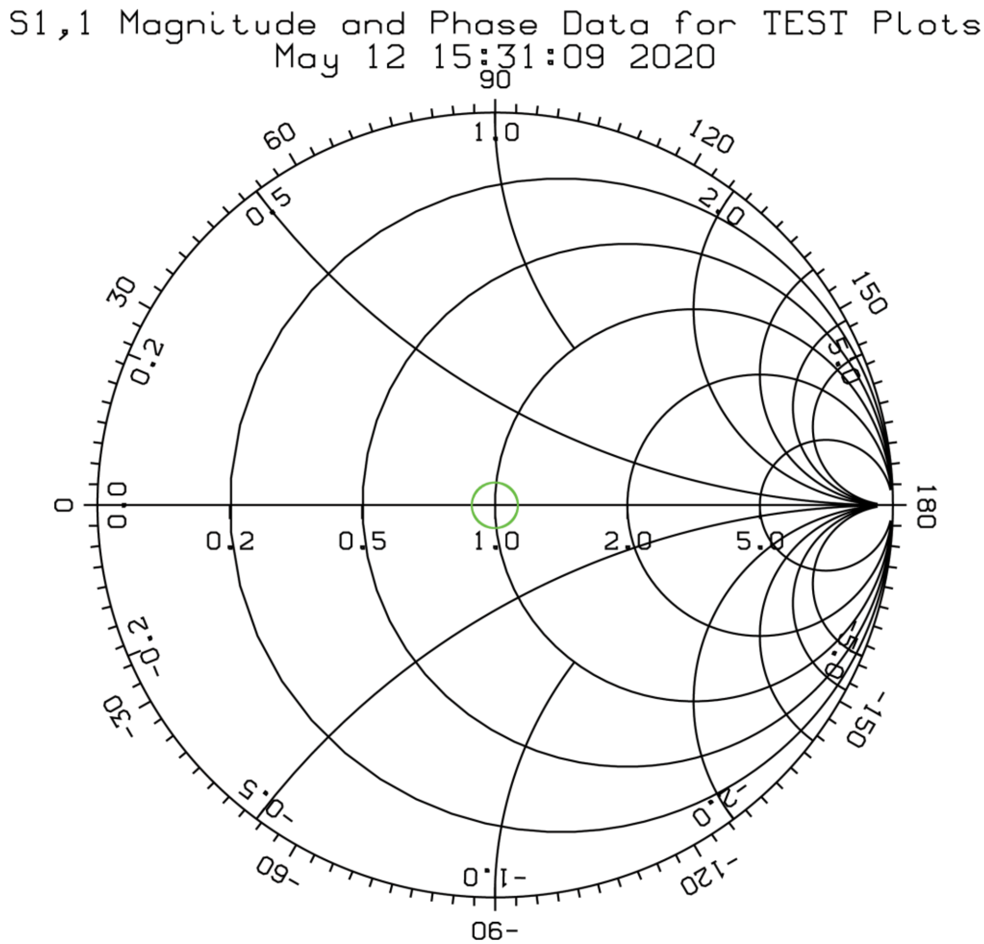

Figure 4 – Smith Chart plot of the Magnitude and Phase data shown in Figure 3.

Finally, the Green Circle in the center of the Smith Chart is formed by a Polynomial Spline Fit of the 51 frequency points contained in the $S_{1,1}$ data file as illustrated in lines 291 and 292 of the code. The code necessary to add a Marker to each data point as it is plotted is contained in lines 297 to 300. Markers can be added to the plot by removing the comment symbol (!) from the beginning of each of these lines so the program can be recompiled to create this new plot.

Path Forward

Helmut Michels is actively adding new features to the DISLIN library as requests are received from individual and corporate users. DISLIN library users can submit plotting feature requests to Helmut Michels, and these feature requests will be addressed over time. For instance, a Compressed Smith Chart (https://www.sciencedirect.com/topics/engineering/smith-chart) may be added to the DISLIN library for the analysis of active components in the future. Stability Analysis Arcs and VSWR Circles can also be added to Smith Chart plots by users today, and zoomed areas of a Smith Chart may be available with a future revision of the DISLIN library. DISLIN can also be used to plot antenna radiation patterns today, so new applications for DISLIN will evolve as users develop new codes using the graphics library.

In conclusion, the DISLIN library is extensive in its plotting capabilities, and it is relatively easy to use if you write your own programs for analyzing either calculated or measured data. This brief paper provides an introduction to the DISLIN library, and the two Fortran 90 programs demonstrate the code necessary to create Cartesian S-parameter plots, as well as Impedance and Admittance Smith Chart plots. This brief introduction to DISLIN should get every RF, Microwave, Millimeter-Wave, and Terahertz engineer started with successfully using the DISLIN library for their projects.

Appendix A – Smith5.f90

```
      PROGRAM SMITH5
!      USE DISLIN
      IMPLICIT NONE
      INTEGER, PARAMETER :: N=1000
      INTEGER, PARAMETER :: M=1000
      REAL, DIMENSION (N) :: X, Y
      REAL, DIMENSION (11) :: ZIMG = (/5.0, 2.0, 1.0, 0.5, 0.2, 0.0, &
                              -0.2, -0.5, -1.0, -2.0, -5.0/)
      REAL, DIMENSION (5) :: ZRE =  (/0.2, 0.5, 1.0, 2.0, 5.0/)
!
! Define Complex Impedance (Z) Data (X2,Y2)
!
      REAL, DIMENSION (5) :: X2 = (/0.42, 0.3, 0.63, 0.83, 0.67/), Y2 = (/-0.11, 0.15,
0.28, 0.0, -0.43/)
!
! Define Complex Admittance (Y = 1/Z) Data (X3,Y3))
!
      REAL, DIMENSION (5) :: X3 = (/2.228, 2.667, 1.325, 1.205, 1.057/), &
           Y3 = (/0.583, -1.333, -0.589, 0.0, 0.678/)
!
      INTEGER :: I
!
! Plot Impedance Smith Chart
!
      CALL SCRMOD ('revers')            !Defines White background and Black plot lines.
      CALL METAFL ('cons')              !Create a plot on Console.  Multiple file outputs available.
      CALL DISINI ()                    !Initialize plot.
!
      CALL WINFNT('ARIAL')              !Defines the font to be used for the plot.
!
      CALL TITLIN ('Smith Chart', 3)    !Line 3 of the plot title.
      CALL TITLIN ('Impedance Plot', 4) !Line 4 of the plot title.
!
      CALL AXSTYP ('impedance')         !Defines the y-axis as Impedance
!
      CALL LABTYP ('vert', 'y')         !Defines Vertical y-axis.
      CALL LABTYP ('hori', 'x')         !Defines Horizontal x-axis.
      CALL TICPOS ('labels', 'y')       !Tick marks will be on same side as labels for y-axis.
!
      CALL TICPOS ('reverse', 'x')      !Tick marks will be inside the x-axis.
      CALL LABDIS (20, 'y')             !Defines the distance separating the y-axis from the labels.
!
      CALL HEIGHT (30)                  !Defines the character height.
```

```
      CALL HNAME (30)                 !Defines the axis character height.
!
      CALL GRAFR (ZRE, 5, ZIMG, 11) !Defines the number of REAL and IMAGINARY impedance lines.
      CALL HTITLE (40)                !Defines character height for the title of the plot.
      CALL TITLE ()                   !This plots up to 4 lines of characters for a plot title.
!
! Plot Real and Imagainary Grid for Impedance Smith Chart
!
      CALL GRIDRE(0.2,-50.0,50.0,M)   !Plot 0.2-ohm circle on Smith Chart.
      CALL GRIDRE(0.5,-50.0,50.0,M)   !Plot 0.5-ohm circle on Smith Chart.
      CALL GRIDRE(1.0,-50.0,50.0,M)   !Plot 1.0-ohm circle on Smith Chart.
      CALL GRIDRE(2.0,-50.0,50.0,M)   !Plot 2.0-ohm circle on Smith Chart.
      CALL GRIDRE(5.0,-50.0,50.0,M)   !Plot 5.0-ohm circle on Smith Chart.
      CALL GRIDIM(0.2,0.001,50.0,M)   !Plot +j0.2-ohm arc on Smith Chart.
      CALL GRIDIM(0.5,0.001,50.0,M)   !Plot +j0.5-ohm arc on Smith Chart.
      CALL GRIDIM(1.0,0.001,2.0,M)    !Plot +j1.0-ohm arc on Smith Chart.
      CALL GRIDIM(2.0,0.001,50.0,M)   !Plot +j2.0-ohm arc on Smith Chart.
      CALL GRIDIM(3.0,0.001,50.0,M)   !Plot +j3.0-ohm arc on Smith Chart.
      CALL GRIDIM(4.0,0.001,50.0,M)   !Plot +j4.0-ohm arc on Smith Chart.
      CALL GRIDIM(5.0,0.001,50.0,M)   !Plot +j5.0-ohm arc on Smith Chart.
      CALL GRIDIM(-0.2,0.001,50.0,M)  !Plot -j0.2-ohm arc on Smith Chart.
      CALL GRIDIM(-0.5,0.001,50.0,M)  !Plot -j0.5-ohm arc on Smith Chart.
      CALL GRIDIM(-1.0,0.001,2.0,M)   !Plot -j1.0-ohm arc on Smith Chart.
      CALL GRIDIM(-2.0,0.001,50.0,M)  !Plot -j2.0-ohm arc on Smith Chart.
      CALL GRIDIM(-3.0,0.001,50.0,M)  !Plot  -j3.0-ohm arc on Smith Chart.
      CALL GRIDIM(-4.0,0.001,50.0,M)  !Plot -j4.0-ohm arc on Smith Chart.
      CALL GRIDIM(-5.0,0.001,50.0,M)  !Plot -j5.0-ohm arc on Smith Chart.
!
      CALL POLCRV ('PSPLINE')         !Enables a polar spline fit to data points on a Smith Chart.
      CALL SPLMOD(3,10000) !Defines the order of the polynomial and number of interpolation points for the spline fit.
      CALL COLOR ('blue')             !Defines color of line to be plotted on Smith Chart.
      CALL CURVE (X2,Y2,5)            !Plots the Real and Imaginary Complex Impedance on the Smith Chart.
!
      CALL COLOR('FORE')              !Defines the color of a Marker on the Smith Chart.
      CALL HSYMBL(20)                 !Defines the height of the symbol used as a Marker on the Smith Chart.
      CALL INCMRK(-1)                 !Only symbols are plotted as Markers on the Smith Chart.
      CALL CURVE(X2,Y2,5)             !Plot Markers on the Smith Chart at data point coordinates.
!
      CALL ENDGRF ()                  !Terminates the defined axis system.
      CALL DISFIN()                   !End of plot.
!
! Plot Admittance Smith Chart
!
```

```
      CALL SCRMOD ('revers')              !Defines White background and Black plot lines.
      CALL METAFL ('cons')                !Create a plot on Console.  Multiple file outputs available.
      CALL DISINI ()                      !Initialize plot.
!
      CALL WINFNT('ARIAL')                !Defines the font to be used for the plot.
!
      CALL TITLIN ('Smith Chart', 3)      !Line 3 of the plot title.
      CALL TITLIN ('Admittance Plot', 4)  !Line 4 of the plot title.
!
      CALL AXSTYP ('admittance')          !Defines the y-axis as Admittance
      CALL LABDIS (20, 'y')               !Defines the distance separating the y-axis from the labels.
!
      CALL LABTYP ('vert', 'y')           !Defines Vertical y-axis.
      CALL LABTYP ('hori', 'x')           !Defines Horizontal x-axis.
      CALL TICPOS ('labels', 'y')         !Tick marks will be on same side as labels for y-axis.
!
      CALL TICPOS ('reverse', 'x')        !Tick marks will be inside the x-axis.
      CALL LABDIS (20, 'y')               !Defines the distance separating the y-axis from the labels.
!
      CALL HEIGHT (30)                    !Defines the character height.
      CALL HNAME (30)                     !Defines the axis character height.
!
      CALL GRAFR (ZRE, 5, ZIMG, 11) !Defines the number of REAL and IMAGINARY impedance lines.
      CALL HTITLE (40)                    !Defines character height for the title of the plot.
      CALL TITLE ()                       !This plots up to 4 lines of characters for a plot title.
!
! Plot Real and Imaginary Grid for Admittance Smith Chart
!
      CALL GRIDRE(0.2,-50.0,50.0,M)  !Plot 0.2-ohm circle on Smith Chart.
      CALL GRIDRE(0.5,-50.0,50.0,M)  !Plot 0.5-ohm circle on Smith Chart.
      CALL GRIDRE(1.0,-50.0,50.0,M)  !Plot 1.0-ohm circle on Smith Chart.
      CALL GRIDRE(2.0,-50.0,50.0,M)  !Plot 2.0-ohm circle on Smith Chart.
      CALL GRIDRE(5.0,-50.0,50.0,M)  !Plot 5.0-ohm circle on Smith Chart.
      CALL GRIDIM(0.2,0.001,50.0,M)  !Plot +j0.2-ohm arc on Smith Chart.
      CALL GRIDIM(0.5,0.001,50.0,M)  !Plot +j0.5-ohm arc on Smith Chart.
      CALL GRIDIM(1.0,0.001,2.0,M)   !Plot +j1.0-ohm arc on Smith Chart.
      CALL GRIDIM(2.0,0.001,50.0,M)  !Plot +j2.0-ohm arc on Smith Chart.
      CALL GRIDIM(3.0,0.001,50.0,M)  !Plot +j3.0-ohm arc on Smith Chart.
      CALL GRIDIM(4.0,0.001,50.0,M)  !Plot +j4.0-ohm arc on Smith Chart.
      CALL GRIDIM(5.0,0.001,50.0,M)  !Plot +j5.0-ohm arc on Smith Chart.
      CALL GRIDIM(-0.2,0.001,50.0,M) !Plot -j0.2-ohm arc on Smith Chart.
      CALL GRIDIM(-0.5,0.001,50.0,M) !Plot -j0.5-ohm arc on Smith Chart.
      CALL GRIDIM(-1.0,0.001,2.0,M)  !Plot -j1.0-ohm arc on Smith Chart.
```

```
      CALL GRIDIM(-2.0,0.001,50.0,M)  !Plot -j2.0-ohm arc on Smith Chart.
      CALL GRIDIM(-3.0,0.001,50.0,M)  !Plot -j3.0-ohm arc on Smith Chart.
      CALL GRIDIM(-4.0,0.001,50.0,M)  !Plot -j4.0-ohm arc on Smith Chart.
      CALL GRIDIM(-5.0,0.001,50.0,M)  !Plot -j5.0-ohm arc on Smith Chart.
!
      CALL POLCRV ('PSPLINE')      !Enables a polar spline fit to data points on a Smith Chart.
      CALL SPLMOD(3,10000) !Defines the order of the polynomial and number of interpolation points for the spline fit.
      CALL COLOR ('red')       !Defines color of line to be plotted on Smith Chart.
      CALL CURVE (X3,Y3,5)       !Plots the Real and Imaginary Complex Impedance on the Smith Chart.
!
      CALL COLOR('FORE')       !Defines the color of a Marker on the Smith Chart.
      CALL HSYMBL(20)       !Defines the height of the symbol used as a Marker on the Smith Chart.
      CALL INCMRK(-1)       !Only symbols are plotted as Markers on the Smith Chart.
      CALL CURVE(X3,Y3,5)       !Plot Markers on the Smith Chart at data point coordinates.
!
      CALL ENDGRF ()       !Terminates the defined axis system.
      CALL DISFIN()       !End of plot.
!
      END PROGRAM SMITH5
```

Appendix B – Plot Smith Chart Demo.f90

```
      PROGRAM PLOT
!
!-----------------------------------------------------------------------
!
!   THIS PROGRAM PLOTS FREQUENCY VERSUS S11 MAGNITUDE AND PHASE,
!   AND ALSO PLOTS AN IMPEDANCE SMITH CHART FOR Z11.
!
!   VERSION A MOD 001 MARCH  2020
!
!-----------------------------------------------------------------------
!
      IMPLICIT NONE
!
!--- LOCAL DECLARATIONS ---------------------------------
!
      INTEGER*4 ic , index , INTRGB , k1 , knt , M , N , nfre , NPFRE
      REAL*4 zimg , zre
!
      REAL*4 result1 , result2 , xmax , xorig , safreq , ymax1 , ymax2 , resul18 , resul19,
yorig1 , yorig2
!
      COMPLEX*8 resul20 , resul21
!
      CHARACTER*30 cdate
      CHARACTER*80 cmess
      CHARACTER*80 cmessa
      CHARACTER*160 clegbuf
!
      PARAMETER (NPFRE=2001)
      PARAMETER (N=1000,M=1000)
!
!--- LOCAL DIMENSIONS ----------------------------------
!
      DIMENSION result1(NPFRE) , result2(NPFRE) ,resul18(NPFRE) , resul19(NPFRE)
, resul20(NPFRE) , resul21(NPFRE), safreq(NPFRE)
!
      DIMENSION zimg(11) , zre(5)
!
      DATA zimg/5.0 , 2.0 , 1.0 , 0.5 , 0.2 , 0.0 , -0.2 , -0.5 , -1.0 ,&
        & -2.0 , -5.0/                          !Defines Imaginary Impedance line for Smith Chart.
      DATA zre/0.2 , 0.5 , 1.0 , 2.0 , 5.0/            !Defines Real Impedance line for Smith Chart.
!
!--- 1.0 --- INITIALIZE DISLIN PLOTTING ----------------
!
!
!--- 1.3 --- PLOT DATA ----------------------------------
```

```
!
     OPEN (UNIT=9,FILE='GRAPH1.DAT',ACCESS='SEQUENTIAL',            &  ! Open
the file containing S11 Magnitude and Phase data
          &FORM='FORMATTED',STATUS='OLD')
!
!--- 1.3.2 --- PLOT DATA -------------------------------
!
     READ (9,*) cmess                !Read title of plots.
     READ (9,*) cdate                !Read date that data file was created.
     READ (9,*) nfre                 !Read Number of Frequencies used for data file.
!
     cmessa = cmess(1:60)            !Assign plot title to cmessa.
!
!---PLOT S11, MAGNITUDE ---
!
     READ (9,*) index                !Read data file index, 1=Magnitude, 2=Phase.
     READ (9,*) xorig , xmax         !Read minimum and maximum frequency.
     READ (9,*) yorig1 , ymax1       !Read minimum and maximum Magnitude.
!
     DO k1 = 1 , nfre
       READ (9,*) safreq(k1) , result1(k1)   !Read Frequency and Magnitude data file.
     ENDDO
!
!
     CALL METAFL('CONS')             !Create a plot on Console.  Multiple file outputs available.
     CALL SCRMOD('REVERS')           !Defines White background and Black plot lines.
     CALL DISINI()                   !Initialize plot.
     CALL WINFNT('ARIAL')            !Defines the font to be used for the plot.
!
     CALL AXSPOS(450,1800)           !Defines lower left corner of axis.
     CALL AXSLEN(2200,1200)          !Defines the axis length and height.
!
     CALL NAME('FREQUENCY, GHz','X') !Defines the x-axis title.
     CALL NAME('S11, MAGNITUDE','Y') !Defines the y-axis title.
!
     CALL LABDIG(-1,'X')             !Defines the distance between x-axis labels and ticks.
     CALL TICKS(10,'XY')             !Number of ticks between axis labels.
!
     CALL TITLIN(cmessa,3)           !Defines line 3 of the plot title.
     CALL TITLIN(cdate,4)            !Defines line 4 of the plot title.
!
     ic = INTRGB(0.95,0.95,0.95)     !Defines background color for axis.
     CALL AXSBGD(ic)                 !Defines background color for axis.

     CALL SETSCL(safreq,nfre,'X')    !Defines scaling for x-axis.
     CALL SETSCL(result1,nfre,'Y')   !Defines scaling for y-axis.
```

```
      CALL GRAF(xorig,xmax,xorig,(xmax-xorig)/10.,yorig1,ymax1,yorig1,  &
          & (ymax1-yorig1)/10.)       !Plots the x- and y-axis.
      CALL SETRGB(0.7,0.7,0.7)        !Defines plotting region background.
      CALL GRID(1,1)                  !Defines the plot grid.
!
      CALL COLOR('FORE')              !Defines title color.
      CALL HEIGHT(50)                 !Defines title height.
      CALL TITLE                      !Plots title on graph.
!
      CALL COLOR('RED')               !Defines color of line on graph.
      CALL CURVE(safreq,result1,nfre) !Plots S11 Magnitude on graph.
!
      CALL DISFIN                     !Ends plot of S11 magnitude.
!
!---PLOT S11, PHASE ---
!
      READ (9,*) index                !Read data file index, 1=Magnitude, 2=Phase.
      READ (9,*) xorig , xmax         !Read minimum and maximum frequency.
      READ (9,*) yorig2 , ymax2       !Read minimum and maximum Magnitude.
!
      DO k1 = 1 , nfre
        READ (9,*) safreq(k1) , result2(k1)  !Read Frequency and Phase file.
      ENDDO
!
      CALL METAFL('CONS')             !Create a plot on Console.  Multiple file outputs available.
      CALL SCRMOD('REVERS')           !Defines White background and Black plot lines.
      CALL DISINI()                   !Initialize plot.
      CALL WINFNT('ARIAL')            !Defines the font to be used for the plot.
!
      CALL AXSPOS(450,1800)           !Defines lower left corner of axis.
      CALL AXSLEN(2200,1200)          !Defines the axis length and height.
!
      CALL NAME('FREQUENCY, GHz','X')         !Defines the x-axis title.
      CALL NAME(' S11, PHASE (DEGREES) ','Y') !Defines the y-axis title.
!
      CALL LABDIG(-1,'X')             !Defines the distance between x-axis labels and ticks.
      CALL TICKS(10,'XY')             !Number of ticks between axis labels.
!
      CALL TITLIN(cmessa,3)           !Defines line 3 of the plot title.
      CALL TITLIN(cdate,4)            !Defines line 4 of the plot title.
!
      ic = INTRGB(0.95,0.95,0.95)     !Defines background color for axis.
      CALL AXSBGD(ic)                 !Defines background color for axis.
!
      CALL SETSCL(safreq,nfre,'X')    !Defines scaling for x-axis.
      CALL SETSCL(result2,nfre,'Y')   !Defines scaling for y-axis.
```

```
      CALL GRAF(xorig,xmax,xorig,(xmax-xorig)/10.,yorig2,ymax2,   &
               & yorig2,(ymax2-yorig2)/10.)   !Plots the x- and y-axis.
      CALL SETRGB(0.7,0.7,0.7)   !Defines plotting region background.
      CALL GRID(1,1)             !Defines the plot grid.
!
      CALL COLOR('FORE')         !Defines title color.
      CALL HEIGHT(50)            !Defines title height.
      CALL TITLE                 !Plots title on graph.
!
      CALL COLOR('BLUE')         !Defines color of line on graph.
      CALL CURVE(safreq,result2,nfre) !Plots S11 Magnitude on graph.
!
      CALL DISFIN                !Ends plot of S11 magnitude.
!
!---PLOT S11 MANGINTUDE AND PHASE ON ONE GRAPH--
!
      CALL METAFL('CONS')        !Create a plot on Console.  Multiple file outputs available.
      CALL SCRMOD('REVERS')      !Defines White background and Black plot lines.
      CALL DISINI()              !Initialize plot.
      CALL WINFNT('ARIAL')       !Defines the font to be used for the plot.
!
      CALL AXSPOS(450,1800)      !Defines lower left corner of axis.
      CALL AXSLEN(2200,1200)     !Defines the axis length and height.
!
      CALL NAME('FREQUENCY, GHz','X')     !Defines the x-axis title.
      CALL NAME(' S11, MAGNITUDE ','Y1')  !Defines the left y-axis title.
!
      CALL LABDIG(-1,'X')        !Defines the distance between x-axis labels and ticks.
      CALL TICKS(10,'XY')        !Number of ticks between axis labels.
!
      CALL TITLIN(cmessa,3)      !Defines line 3 of the plot title.
      CALL TITLIN(cdate,4)       !Defines line 4 of the plot title.
!
      ic = INTRGB(0.95,0.95,0.95)  !Defines background color for axis.
      CALL AXSBGD(ic)              !Defines background color for axis.
!
      CALL SETSCL(safreq,nfre,'X')     !Defines scaling for x-axis.
      CALL SETSCL(result1,nfre,'Y1')   !Defines scaling for left y-axis.
!
!--PLOT S11 MAGNITUDE
      CALL SETGRF('NAME','NAME','TICKS','NONE')   !Initializes dual y-axis.
      CALL GRAF(xorig,xmax,xorig,(xmax-xorig)/10.,yorig1,ymax1,   &
               & yorig1,(ymax1-yorig1)/10.)   !Plots the x- and left y-axis.
      CALL SETRGB(0.7,0.7,0.7)   !Defines plotting region background.
      CALL GRID(1,1)             !Defines the plot grid.
!
```

```
! Plot Legend for dual y-axes
!
      CALL legini(clegbuf, 2, 21)   !Initializes legend for dual y-axes.
      CALL legtit("")               !Initializes blank legend title for dual y-axes.
!
      CALL leglin(clegbuf, 'S11, MAGNITUDE', 1)        !Legend title for left y-axis.
      CALL leglin(clegbuf, 'S11, PHASE (DEGREES)', 2)  !Legend itle for right y-axis.
!
      CALL color("RED")               !Assigns color for left y-axis legend.
      CALL legpat(0, 3, -1, -1, -1, 1)  !Assigns legend attributes for left y-axis.
      CALL color("BLUE")              !Assigns color for right y-axis legend.
      CALL legpat(0, 3, -1, -1, -1, 2)  !Assigns legend attributes for right y-axis.
      CALL color("WHITE")             !Assigns legend background color.
      CALL height(24)                 !Assigns legend text height.
      CALL legopt(2.0, 0.3, 1.0)      !Defines legend attributes.
      CALL legend(clegbuf, 3)         !Defines legend buffer and position.
!
      CALL COLOR('RED')               !Assigns color to S11 Magnitude line.
      CALL CURVE(safreq,result1,nfre) !Plots S11 Magnitude line.
      CALL ENDGRF()                   !Ends S11 Magnitude plot.
!--PLOT S11 PHASE
!
      CALL NAME(' S11, PHASE (DEGREES)  ','Y2') !Defines the right y-axis title.
      CALL SETSCL(result2,nfre,'Y2')        !Defines scaling for right y-axis.
      CALL COLOR('FORE')                    !Defines right y-axis color.
!
      CALL AXSBGD(-1)                       !Defines background color for axis.
!
      CALL SETGRF('NONE','NONE','NONE','NAME')  !Initializes right y-axis.
      CALL GRAF(xorig,xmax,xorig,(xmax-xorig)/10.,yorig2,ymax2,   &
               & yorig2,(ymax2-yorig2)/10.)   !Plots the x- and right y-axis.
      CALL SETRGB(0.7,0.7,0.7)                !Defines plotting region background.
!
      CALL COLOR('FORE')         !Defines plot title color.
      CALL HEIGHT(50)            !Defines plot title height.
      CALL TITLE                 !Plots plot title on graph.
!
      CALL COLOR('BLUE')              !Assigns color to S11 Phase line.
      CALL CURVE(safreq,result2,nfre) !Plots S11 Phase line.
      CALL ENDGRF()                   !Ends plot of S11 phase.
!
      CALL DISFIN                !End of plot.
!
!---CONVERT S11 TO Z11 FOR SMITH CHART PLOT ---
!
      DO k1 = 1 , nfre
```

```
        resul20(k1) = CMPLX(result1(k1)*COS(result2(k1)),        &
                  & result1(k1)*SIN(result2(k1)))
        resul21(k1) = CMPLX(1.0+resul20(k1))/((1.0-resul20(k1)))
!
! --- REAL(Z11) = RESUL18(K1); IMAG(Z11) = RESUL19(K1) ---
!
        resul18(k1) = REAL(REAL(resul21(k1)))
        resul19(k1) = REAL(AIMAG(resul21(k1)))
!
      ENDDO
!
!--- SMITH CHART LAYOUT BY HELMUT MICHELS ---
!
      CALL METAFL('CONS')          !Create plot on Console.
      CALL SCRMOD('REVERS')        !Defines White background and Black plot lines.
      CALL DISINI                  !Initialize plot.
      CALL WINFNT('ARIAL')         !Defines the font to be used for the plot.
!
      CALL TITLIN(cmessa,3)        !Line 3 of the plot title, which is a character string.
      CALL TITLIN(cdate,4)         !Line 4 of the plot title, which is a date for this program.
!
      CALL LABTYP('HORI','X')      !Defines Horizontal x-axis.
      CALL LABTYP('VERT','Y')      !Defines Vertical y-axis.
      CALL LABDIS(-50,'Y')         !Defines the distance separating the y-axis from the labels.
!
      CALL HEIGHT(30)              !Defines the character height.
      CALL HNAME(30)               !Defines the axis character height.
      CALL TICPOS('REVERS','Y')    !Tick marks will be inside the y-axis.
!
      CALL GRAFR(zre,5,zimg,11)    !Defines the number of REAL and IMAGINARY impedance lines for Smith Chart.
      CALL HTITLE(40)              !Defines character height for the title of the plot.
      CALL TITLE()                 !This plots up to 4 lines of characters for a plot title.
!
      CALL GRIDRE(0.2,-50.0,50.0,M)  !Plot 0.2-ohm circle on Smith Chart.
      CALL GRIDRE(0.5,-50.0,50.0,M)  !Plot 0.5-ohm circle on Smith Chart.
      CALL GRIDRE(1.0,-50.0,50.0,M)  !Plot 1.0-ohm circle on Smith Chart.
      CALL GRIDRE(2.0,-50.0,50.0,M)  !Plot 2.0-ohm circle on Smith Chart.
      CALL GRIDRE(5.0,-50.0,50.0,M)  !Plot 5.0-ohm circle on Smith Chart.
      CALL GRIDIM(0.5,0.001,50.0,M)  !Plot +j0.5-ohm arc on Smith Chart.
      CALL GRIDIM(1.0,0.001,1.0,M)   !Plot +j1.0-ohm arc on Smith Chart.
      CALL GRIDIM(2.0,0.001,50.0,M)  !Plot +j2.0-ohm arc on Smith Chart.
      CALL GRIDIM(3.0,0.001,50.0,M)  !Plot +j3.0-ohm arc on Smith Chart.
      CALL GRIDIM(4.0,0.001,50.0,M)  !Plot +j4.0-ohm arc on Smith Chart.
      CALL GRIDIM(5.0,0.001,50.0,M)  !Plot +j5.0-ohm arc on Smith Chart.
      CALL GRIDIM(-0.5,0.001,50.0,M) !Plot -j0.5-ohm arc on Smith Chart.
      CALL GRIDIM(-1.0,0.001,1.0,M)  !Plot -j1.0-ohm arc on Smith Chart.
```

```
      CALL GRIDIM(-2.0,0.001,50.0,M)  !Plot -j2.0-ohm arc on Smith Chart.
      CALL GRIDIM(-3.0,0.001,50.0,M)  !Plot -j3.0-ohm arc on Smith Chart.
      CALL GRIDIM(-4.0,0.001,50.0,M)  !Plot -j4.0-ohm arc on Smith Chart.
      CALL GRIDIM(-5.0,0.001,50.0,M)  !Plot -j5.0-ohm arc on Smith Chart.
!
      CALL LABDIS (20, 'Y')          !Defines the distance separating the y-axis from the labels.
      CALL TICPOS ('LABELS', 'Y');   !Tick marks will be on the same side as labels for the y-axis.
      CALL LABDIG (-1, 'Y');         !Defines the number of digits after the decimal point for the y-axis.
      CALL TICKS (10, 'Y');          !Defines number of tick marks between y-axis labels
      CALL YPOLAR (180.0, -180.0, 180.0, -30.0, ' ', 0); !Defines polar axis for the Smith Chart.
!
!--- PLOT Z11 ---
!
      CALL COLOR('GREEN')            !Defines color of line to be plotted on Smith Chart.
      CALL POLCRV('PSPLINE')         !Enables a polar spline fit to data points on a Smith Chart.
      CALL SPLMOD(3,10000) !Defines the order of the polynomial and number of interpolation points for the spline fit.
      CALL CURVE(resul18,resul19,nfre)  !Plots Z1,1 on the Smith Chart
!
!--- PLOT MARKERS FOR Z11 ---
!
!      CALL COLOR('FORE')            !Defines the color of a Marker on the Smith Chart.
!      CALL HSYMBL(20)               !Defines the height of the symbol used as a Marker on the Smith Chart.
!      CALL INCMRK(-1)               !Only symbols are plotted as Markers on the Smith Chart.
!      CALL CURVE(resul18,resul19,nfre)  !Plot Markers on the Smith Chart.
!
       CALL DISFIN                   !End of plot.
!
!
      READ (9,*) index
!
      END PROGRAM PLOT
```

Appendix C – $S_{1,1}$ Magnitude and Phase Data File

```
'S1,1 Magnitude and Phase Data for TEST Plots        '
 'May 12 15:31:09 2020      '
          51
 1
   2.90000010       2.95000005
   5.77780530E-02   5.80786504E-02
   2.90000010       5.77921309E-02
   2.90100002       5.78152575E-02
   2.90200019       5.78373969E-02
   2.90300012       5.78585491E-02
   2.90400004       5.78787178E-02
   2.90499997       5.78979030E-02
   2.90599990       5.79161122E-02
   2.90700006       5.79333417E-02
   2.90799999       5.79495952E-02
   2.90899992       5.79648763E-02
   2.91000009       5.79791851E-02
   2.91100001       5.79925254E-02
   2.91199994       5.80048971E-02
   2.91299987       5.80163039E-02
   2.91399980       5.80267496E-02
   2.91499996       5.80362305E-02
   2.91599989       5.80447540E-02
   2.91699982       5.80523200E-02
   2.91800022       5.80589324E-02
   2.91900015       5.80645874E-02
   2.92000008       5.80692962E-02
   2.92100000       5.80730513E-02
   2.92199993       5.80758639E-02
   2.92300010       5.80777265E-02
   2.92400002       5.80786504E-02
   2.92499995       5.80786280E-02
   2.92600012       5.80776706E-02
   2.92700005       5.80757745E-02
   2.92799997       5.80729432E-02
   2.92899990       5.80691807E-02
   2.92999983       5.80644868E-02
   2.93099999       5.80588616E-02
   2.93199992       5.80523089E-02
   2.93299985       5.80448322E-02
   2.93400002       5.80364317E-02
   2.93500018       5.80271110E-02
   2.93600011       5.80168702E-02
   2.93700004       5.80057129E-02
   2.93799996       5.79936393E-02
   2.93900013       5.79806492E-02
```

```
  2.94000006     5.79667501E-02
  2.94099998     5.79519421E-02
  2.94200015     5.79362251E-02
  2.94300008     5.79196028E-02
  2.94400001     5.79020791E-02
  2.94499993     5.78836501E-02
  2.94599986     5.78643233E-02
  2.94700003     5.78440987E-02
  2.94799995     5.78229763E-02
  2.94899988     5.78009598E-02
  2.95000005     5.77780530E-02
 2
  2.90000010     2.95000005
 -137.997604    -130.783646
  2.90000010    -130.783646
  2.90100002    -130.926636
  2.90200019    -131.069672
  2.90300012    -131.212769
  2.90400004    -131.355911
  2.90499997    -131.499115
  2.90599990    -131.642349
  2.90700006    -131.785660
  2.90799999    -131.929001
  2.90899992    -132.072403
  2.91000009    -132.215851
  2.91100001    -132.359344
  2.91199994    -132.502899
  2.91299987    -132.646500
  2.91399980    -132.790146
  2.91499996    -132.933853
  2.91599989    -133.077606
  2.91699982    -133.221420
  2.91800022    -133.365280
  2.91900015    -133.509201
  2.92000008    -133.653168
  2.92100000    -133.797195
  2.92199993    -133.941269
  2.92300010    -134.085388
  2.92400002    -134.229568
  2.92499995    -134.373810
  2.92600012    -134.518097
  2.92700005    -134.662445
  2.92799997    -134.806839
  2.92899990    -134.951279
  2.92999983    -135.095795
  2.93099999    -135.240356
```

2.93199992	-135.384964
2.93299985	-135.529633
2.93400002	-135.674362
2.93500018	-135.819138
2.93600011	-135.963974
2.93700004	-136.108871
2.93799996	-136.253815
2.93900013	-136.398819
2.94000006	-136.543884
2.94099998	-136.688995
2.94200015	-136.834167
2.94300008	-136.979401
2.94400001	-137.124680
2.94499993	-137.270020
2.94599986	-137.415421
2.94700003	-137.560883
2.94799995	-137.706390
2.94899988	-137.851974
2.95000005	-137.997604
999	