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COMPUTER AIDED DESIGN FOR LINEAR CONTROL
STATE VARIABLE SYSTEMS (SVS)

by

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The theory, detailed outline of operating and algorithm procedures of a continuous time-invariant, linear control state variable systems design and analysis computer program is presented. The program, SVS, which is based on Melsa's LINCON, was modified to demonstrate Controllability, Observability, Bode Plot, Root locus plot, Nyquist plot, pole placement, Luenberger observer design, optimal control design, time response plot and some basic matrix manipulations. Worked examples with the program output are included. Some options give only numeric data output; others give both numeric data and high-resolution graphs. The software, which is fully interactive, menu driven and user friendly is written in Turbo Pascal to be run on the IBM-PC microcomputers. All options are presented via option menus and the user will be prompted for all input parameters.

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Computer Aided Design for Linear Control
State Variable Systems (SVS)

by

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Submitted in partial fulfillment of the
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ABSTRACT

The theory, detailed outline of operating and algorithm procedures of a continuous time-invariant, linear control state variable systems design and analysis computer program is presented. The program, SVS, which is based on Melsa's LINCON, was modified to demonstrate Controllability, Observability, Bode Plot, Root locus plot, Nyquist plot, pole placement, Luenberger observer design, optimal control design, time response plot and some basic matrix manipulations. Worked examples with the program output are included. Some options give only numeric data output; others give both numeric data and high-resolution graphs. The software, which is fully interactive, menu driven and user friendly is written in Turbo Pascal to be run on the IBM-PC microcomputers. All options are presented via option menus and the user will be prompted for all input parameters.

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I. LINEAR CONTROL STATE VARIABLE SYSTEMS
(SVS)

A. INTRODUCTION TO THE SVS

SVS is software for the IBM-PC microcomputer in the analysis and design of continuous time, linear control systems. These programs are based on the matrix mathematics of state variables and were first developed by Melsa [Ref. 1] and adapted for batch use at NPS by Desjardins [Ref. 2].

The original intent of this thesis was simply to take Desjardins' adapted version of Melsa's LINCON and modify it for the Turbo Pascal computer language. The features of this thesis are:
- User-friendly as possible
- Menu-driven program. <Q>quit key always returns to the SVS main menu.

The hierarchical menu structure is three levels deep at any point. So the user, before selecting his/her option, can get help at every menu.

SVS was tested with several examples and is now available to any user on the Naval PostGraduate School control laboratory PC's under the SVS directory name.

B. SYSTEM REQUIREMENTS

SVS is a large program and requires at least 512KB of Memory to run. The program will run on any IBM-PC or compatible "MS-DOS" computer and requires a standard IBM color Graphics Adapter (CGA) or IBM Enhanced Graphics Adapter (EGA) card. It will run on either monochrome or color monitor, but all menus are supported by color, for that reason they are easier to work with a color monitor if available. The graphics in the program are in high resolution (640 X 200) mode. They only appear in the white-on-black. The graphics

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can be dumped to an EPSON, IBM-Graphics, or compatible printer by using the Shift + PrtSc key.

The program is written in the Turbo Pascal Language. Turbo Pascal has a 64K data segment and code sizes limitation. Under this restriction, SVS is compiled as five executable programs and nineteen "Chain" files. The main program name is SVS in the disk files. It has extension .COM. The chain files have extension .CHN and they are not themselves executable.

C. FILES ON THE DISK

A complete list of the files and a brief description of these are below.

```
(1) SVS.COM        { The executable main menu module }
(2) INPUT.COM      { The input/change menu module }
(3) MATRIX.COM     { The matrix mathematics menu module}
(4) PLOT.COM       { The graphics menu module }
(5) CHANGE.CHN     { Allows user to change input data
                   { values}
(6) POLYNOM.CHN    { Calculates characteristic
                   { polynomial of A matrix  }
(7) CONTROL.CHN    { Calculates controllability of the
                   { system   }
(8)DETERMIN.CHN    { Calculates determinant of the A
                   { matrix }
(9) EIGEN.CHN      { Shows eigenvalues of the A matrix }
(10)BODE.CHN       { Gives Bode plot of the system }
(11)TIMEPLOT.CHN   { Gives time response of the system}
(12)OBSER.CHN      { Calculates observability of the
                   { system}
(13)LUENBERG.CHN   { Design Luenberger observer to
                   { achieve a closed-loop poles of the
                   { system   }
(14)OPTIMAL.CHN    { Optimal control design program   }
```

```
(15)POLE.COM       ( To calculate feedback coefficients
                   ( to achieve a desired closed-loop
                   ( poles   }
(16)SAVE.CHN       ( Saves data to desired drive   }
(17)RETRIEVE.CHN ( Gets data from desired drive   }
(18)INVERSE.CHN   ( To calculate inverse of the A
                   ( matrix   }
(19)INPUTDAT.CHN ( To permit user to enter the input
                   ( data for whole system   }
(20)HELP1.CHN     ( Help program for SVS main menu
                   ( options}
(21)HELP2.CHN     ( Help information for the
                   ( input/change menu options   }
(22)HELP3.CHN     ( Help information for the matrix
                   ( mathematics menu option   }
(23)HELP4.CHN     ( Help information for graphics menu
                   ( option   }
(24)NYQUIST.CHN   ( to calculate Nyquist (polar) plot
                   ( of the system }
(25)RLOCI.CHN     ( Root locus plotting procedure}
(26)ROOTS.CHN     ( Shows plant characteristic
                   ( equation roots }
```

In addition to these files, there are three "system" files that are needed to run the program. These are 4X6.FON, 8X8.FON and ERROR.MSG files.

D.   STARTING TO THE SVS

This software package has two diskettes. The first step is to get the SVS main menu on your screen. All you have to do is follow these steps:

1. Turn on the power (or, if it's already on, the user reboots the computer).

2. Wait for the operating system prompt. It will
   look like one of the following:
   C:_
   C>_
   C\>_
   C:_
   C:\>_
   <C\>_
   (or some other letter).
   The prompt may look somewhat different, depending
   on the computer and how it has been set up.
3. Type **MD SVS** and press <**ENTER**> key. This opens a
   new directory.
4. Type **CD\SVS** and press <**ENTER**> key. This enters
   the new directory.
5. Insert disk #1 into disk driver A:
   Type **Copy A:*.*** and press <**ENTER**> key.
6. Repeat step 5 for disk #2.
7. Type **SVS** and press <**ENTER**> key.

Now the user is in the SVS main menu and ready to
work. Make a choice for further step.

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II. INPUT/CHANGE MENU

A. INTRODUCTION TO THE INPUT/CHANGE MENU

The first step, of course, is to enter the A, B and C matrices into the computer as a common input. This is the starting point of the program. For our case, the general state variable equations are represented by the following equations.

$$\dot{x}(t) = A\ x(t) + B\ u(t) \qquad (2\text{-}1)$$
$$y(t) = C\ x(t) + D\ u(t) \qquad (2\text{-}2)$$

where A, B, C are given matrices and D is assumed to have a zero elements for this program.

```
┌─────────────────────────────────────────────────────┐
│            *** SVS MAIN MENU ***                      │
├─────────────────────────────────────────────────────┤
│                                                       │
│     (I) Input/Change Plant Matrices Menu              │
│                                                       │
│     (G) Graphics Menu                                 │
│     (C) Controllability                               │
│     (O) Observability                                 │
│     (L) Luenberger Observer Design                    │
│     (D) Design of Optimal Control                     │
│     (P) Pole Placement                                │
│                                                       │
│                                                       │
│     (M) Matrix Mathematics Menu                       │
│                                                       │
│     (H) Help                                          │
│     (Q) Quit the Program                              │
│                                                       │
│                                                       │
│      Make Your Selection_                             │
├─────────────────────────────────────────────────────┤
│   Naval Postgraduate School          Ismail   UNLU    │
│                                                       │
│                                                       │
└─────────────────────────────────────────────────────┘
```
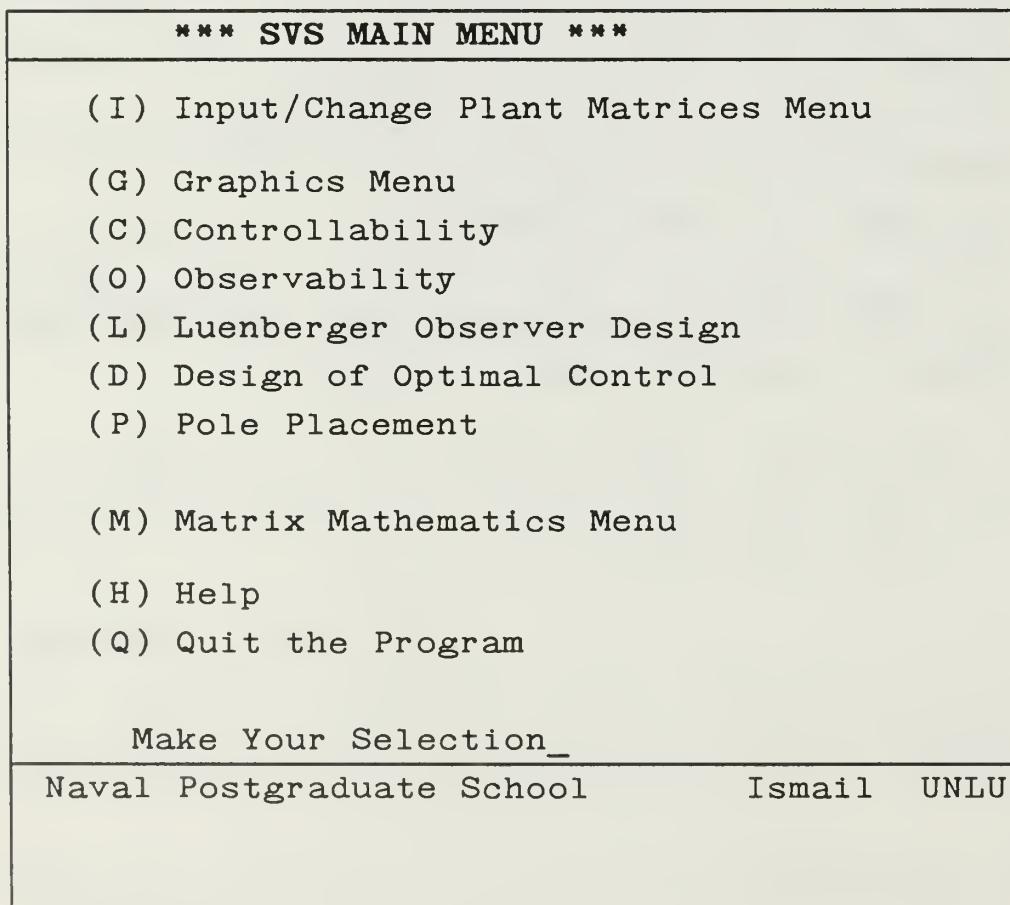
Figure 2.1 The SVS main menu.

From the opening menu of SVS, shown in Figure 2.1, we choose the "Input/Change Plant Matrices Menu" option to bring us to the Input/Change menu shown in Figure 2.2.

```
+----------------------------------------------------+
|         *** INPUT / CHANGE MENU ***                |
|    (I) Input Plant Matrices                        |
|    (C) Change Current Plant Matrices               |
|                                                    |
|    (S) Save Plant Matrices to Disk File            |
|    (L) Load Plant Matrices From Disk File          |
|                                                    |
|                                                    |
|    (H) Help                                        |
|    (Q) Quit to SVS Main Menu                       |
|                                                    |
|                                                    |
| Make Your Selection                                |
|                                                    |
|                                                    |
|                                                    |
+----------------------------------------------------+
```
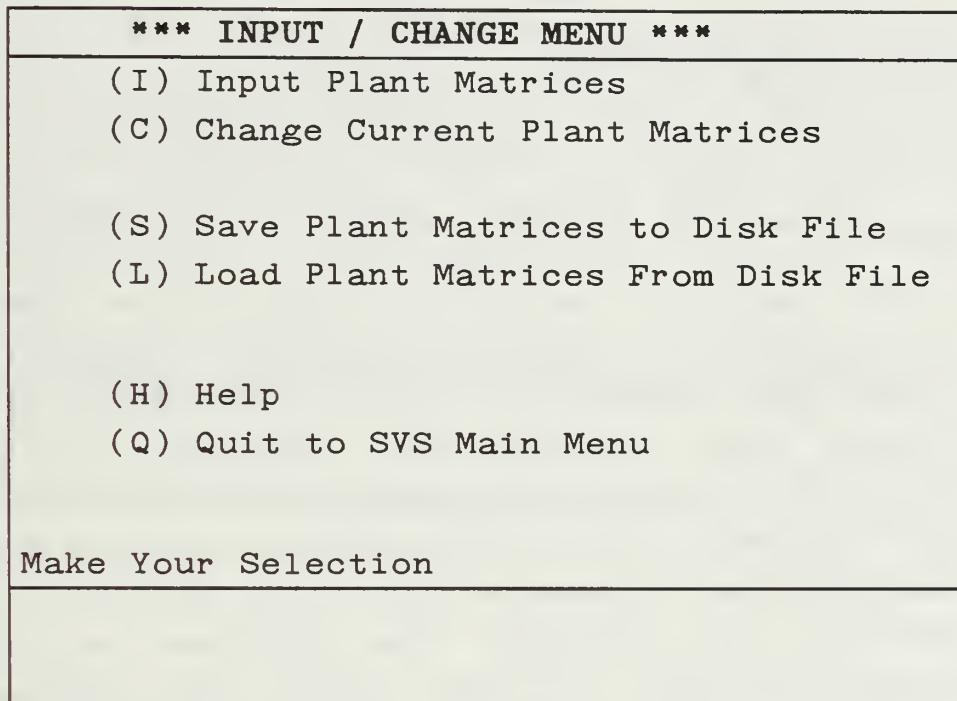
Figure 2.2   The input/change menu.

This input/change menu allows the user to enter common inputs to all programs. These common inputs are the plant or A matrix, the input or B matrix and the output or C matrix. The only restriction is the dimensions of the matrix. It must be no greater than 10. This means that the maximum matrix size has to be 10X10. However, due to a user decision, a dimension size not to exceed 6 is required. The reasoning behind this was due, in part, to the printer. Since the output format to the printer is E11, this naturally limits us to 6 numbers per line. I2 format places are

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normally considered necessary for good accuracy. For systems with order greater than 6, every row of the matrix is continued on the second line. After attempting this, it was decided the results were difficult to read. Otherwise it is appropriate up to a 10th order system.

B. INPUT PLANT MATRICES

This option is used to initially enter the A, B and C matrices of the state variable equations (2-1) and (2-2). For this option, select the "Input plant matrices" from the input/change menu. The screen will prompt the degree of the plant, which is the dimension of the A matrix. The maximum acceptable degree is 10. Then it asks for elements of the A matrix and so forth.

Matrices are entered one element at a time beginning with 1,1 and continuing across the row of the matrix. The next row is then entered, and the process continues until all elements have been entered. After the matrix is entered, the complete matrix is automatically brought to the screen for review and possible element changes. If a change to the matrix is desired the user simply enters the row and column number to change after every prompt. Then the program asks for corresponding matrix elements to change. After being prompted, the change is entered. A review of the matrix is again brought to the screen. The user is again prompted for any more possible changes. This procedure continues until all changes have been done. The same A matrix procedures are repeated for the B and C matrices. This input data can be used for the options without saving to disk file until quitting the program.

C.   CHANGE CURRENT PLANT MATRICES

This option allows the user to change input data A, B and C matrices quickly and easily. The user can change the order and elements of the matrices that were previously entered. This powerful combination facilitates both input correction and changes, especially for higher order matrices during the design process. First Figure 2.3 appears on the screen. The user can choose one matrix at a time for correction. Then the program gives the order and elements of the selected matrix. In the beginning the user can enter a

```
┌──────────────────────────────────────────────────────────┐
│    *** Change Current Plant Matrices Procedure ***       │
│    ====================================================  │
│                                                          │
│   Which matrix do you want to change ?   PLANT (A) A_     │
│                                           INPUT (B)       │
│                                          OUTPUT (C)       │
│                                                          │
│                                                          │
│                                                          │
│                                                          │
│   Press <ESC> to change it!,                             │
│   Then input your choice with <ENTER> key                │
│                                                          │
└──────────────────────────────────────────────────────────┘
```
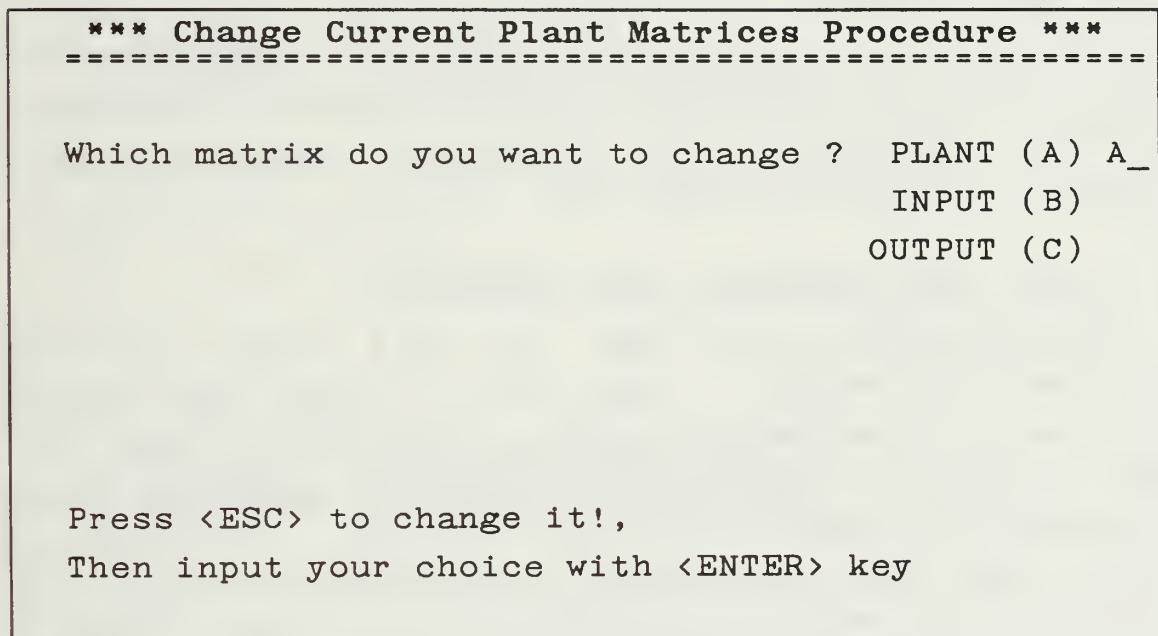
Figure 2.3   Change current plant matrices selection.

correction to the order of the matrix. Then, under the new dimension, can make corrections on elements of the matrix. The program shows the corrected results on the screen. At the end of the program, the user automatically returns to the input/change menu. If the user wants to change more than one matrix, he/she must

choose the "Change Current Plant Matrices" option two or more times. A basic example for this option is illustrated in Figure 2.4.

D. SAVE CURRENT MATRICES TO DISK FILE

This procedure is used to store plant matrices to the hard disk or floppy disk file. First it prompts drive C as a saving drive. Then asks the user for the drive designator (A through E), and filename for the problem to be saved. Eight characters of a MS-DOS filename are allowed; the program gives a filename extension of ".SVS" to each data. This extension is used to limit the disk search for appropriate files. A drive and filename are supplied by the program, which opens the file and stores the data. The procedure stores the data as a text file. A text file consists of ASCII characters, and is usually designed to hold readable information [Ref. 3].

E. LOAD PLANT MATRICES FROM DISK FILE

The procedure first asks the data drive where the problems are stored. After this is done, the program calls another procedure called "Directory" [Ref. 4]. This procedure uses MS-DOS function, calls and shows all available data files on the screen. The user can choose one of the files by moving arrow keys with <RETURN> key. Then the program opens the file and reads it.

The directory displays only the disk files with the extension ".SVS". This eliminates the possibility to read other files.

```
The A matrix is :
   0.0000E+00   1.0000E+00   0.0000E+00   0.0000E+00
   0.0000E+00   0.0000E+00   1.0000E+00   0.0000E+00
   0.0000E+00   0.0000E+00   0.0000E+00   1.0000E+00
   0.0000E+00  -1.5000E+01  -2.3000E+01  -9.0000E+00

The order of the system is:4, Change ? (Y/N)
The order of the system is:3


The A Matrix is :
   0.0000E+00   1.0000E+00   0.0000E+00
   0.0000E+00   0.0000E+00   1.0000E+00
   0.0000E+00   0.0000E+00   0.0000E+00

Do you want to change any element ? (Y/N)
Input row to change : 1
Input column to change : 1

A(1,1)= 10

The A Matrix is :
   1.0000E+01   1.0000E+00   0.0000E+00
   0.0000E+00   0.0000E+00   1.0000E+00
   0.0000E+00   0.0000E+00   0.0000E+00

Do you want to change any element ? (Y/N)
```

Figure 2.4   Change current plant matrices example.

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III. <u>GRAPHICS MENU</u>

A. INTRODUCTION TO THE GRAPHICS MENU

From the opening menu of SVS, shown in Figure 2.1, we choose the " Graphics Menu " option to bring us the Graphics menu shown in Figure 3.1. The Graphics menu contains five basic options. These are the time response plot, Nyquist plot, Root locus plot, characteristic equation roots and Bode plot. This menu is also supported with the "Load plant matrices from disk file" option. This selection allows the user to get data from the disk file quickly instead of going via the SVS main menu route.

```
┌─────────────────────────────────────────────────┐
│            *** GRAPHICS MENU ***                │
├─────────────────────────────────────────────────┤
│                                                 │
│      (L) Load Plant Matrices From disk File     │
│                                                 │
│      (C) Characteristic Equation Roots          │
│      (B) Bode Plot                              │
│      (N) Nyquist Plot                           │
│      (T) Time Response Plot                     │
│      (R) Root Locus Plot                        │
│                                                 │
│      (H) Help                                   │
│      (Q) Quit to SVS Main Menu                  │
│                                                 │
│   Make Your Selection                           │
├─────────────────────────────────────────────────┤
│                                                 │
└─────────────────────────────────────────────────┘
```
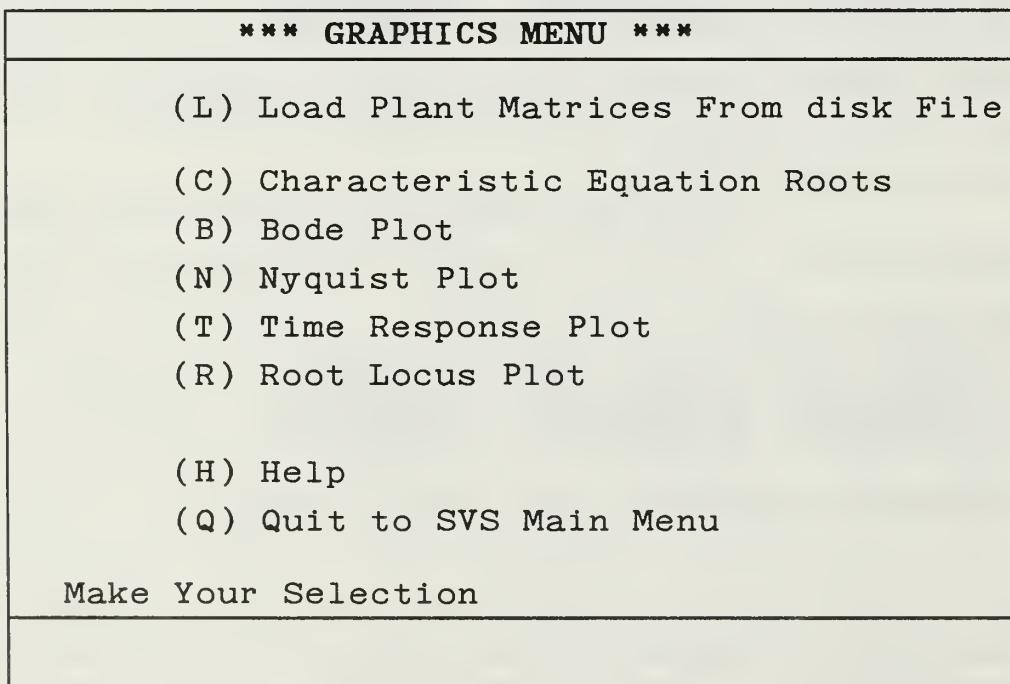
Figure 3.1 The graphics menu.

B. BODE PLOT

Bode plot analysis can be accomplished with the Graphics menu by selecting the <B> Bode plot option. This selection brings Figure 3.2 to the screen. There

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are two selections for the frequency plot: the
open-loop Bode plot and closed-loop Bode plot. Input
data for this option is entered with the Input/change
plant matrices menu selection which is explained in
Chapter II. If the user wants the closed-loop Bode
plot, the program automatically calculates for the
negative unity-feedback condition.

```
*** Bode Plotting Parameters ***
==========================================


Open (O) or Closed (C) Loop Plot?              O

What is the first frequency to be plotted? .1
  (Example: .01, 1, 100, etc. )


How many decades do you want plotted?          4

```

Figure 3.2   Bode plot parameters selection.

The user also must enter the starting frequency and
number of decades for the plotting. The upper
frequency limit is calculated based on the number of
decades. That is, if user selects .1 as the starting
frequency with 4 decades, then the upper frequency will
be 1000 rad/sec.

Bode plot displays two plots at the same time.
These are plots of magnitude and phase versus radian
frequency. Magnitude is converted to the decibels unit
using the relation

$$\text{Magnitude}_{dB} = 20 \log_{10}(\text{magnitude})$$

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and phase is converted to degrees using the relation

$$Phase_{degree} = (180/\pi) \, Phase$$

Magnitude calculations for the single pole or zero can be written as

$$Magnitude = [Realpart^2 + (w-Imaginarypart)^2 \,]^{1/2}$$

and the phase calculation is

$$Phase = Tan^{-1}[(w-Imaginarypart)/Realpart].$$

For the whole system, the magnitude and phase are calculated for each pole or zero. Then the final magnitude is

$$Magnitude_{system} = Magnitude_{zeros}/Magnitude_{poles}$$

and the phase is

$$Phase_{system} = Phase_{zeros} - Phase_{poles}$$

The plots of the magnitude and phase are shown on the same graph. Coordinate values of 0dB magnitude and -180° phase coincide in the graph. We know from control theory that phase margin is read at the zero crossover of the magnitude curve and the gain margin is read at the -180° crossover of the phase curve. These two values can be read directly from the graph. The Bode routine calculates the numbers required for the plots. The procedure "plot-Bode" converts the number to a graphical display. Within the Bode-plot routine is a call to the procedure "graph-menu". Graph-menu is called by all procedures which produce a graph. It provides a small menu offering the user the choice to add a title to the graph, print the graph on the

printer, print the number or   quit   and   return   to the
menu.

       If the   user selects   the title   to graph and it is
completed, the plot is displayed with the title   on the
screen.   The   title   block   can be moved by using the
cursor arrow keys and relocated anywhere on the screen.
When the   title box   is moved where the user wants, the
<enter> key must be pressed.   Then the screen is frozen
in   position   and   the   graph   menu   is recalled on the
screen.

       The   print   numbers   selection   saves   the   current
graphic   screen   and   permits   the   user   to   print the
numbers used   to draw   the graph.   The   numbers may be
printed on   the printer   (this will use a lot of paper)
or to a disk file.   If the disk option is selected, the
user can   scan that   file with   a word   processor or by
using the DOS "type" command and examine the   points of
interest.   This option is illustrated on example 3.1.

EXAMPLE 3.1
       The example   can be   stated as follows: Given plant
transfer function

$$Gp(s) = \frac{100\ (\ 0.02\ S\ +\ 1)}{(s\ +\ 1)\ (\ .1\ s\ +\ 1)\ (.01\ s\ +\ 1)^2} \qquad (3\text{-}1)$$

was rearranged as a state variable equations.

$$\dot{x}(t) = \begin{bmatrix} 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ -100000 & -112000 & -12210 & -211 \end{bmatrix} x(t) + \begin{bmatrix} 0 \\ 0 \\ 0 \\ 1 \end{bmatrix} u(t)$$

$$y(t) = \begin{bmatrix} 10000000 & 200000 & 0 & 0 \end{bmatrix} x(t)$$

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a) Obtain the Bode diagram of the above system.
b) Mark the following on the Bode diagram, recording
   the numerical values.
   1) Gain crossover frequency
   2) Phase margin
   3) Phase crossover frequency
   4) Gain margin
   5) Resonant frequency.

Solution:

   Given data entered to the program by the selecting
of   the   "Input   Plant   Matrices"   option   in   the
input/Change   menu.   Then the   program outputs can be
seen from the Figure 3.3 and Figure 3.4.
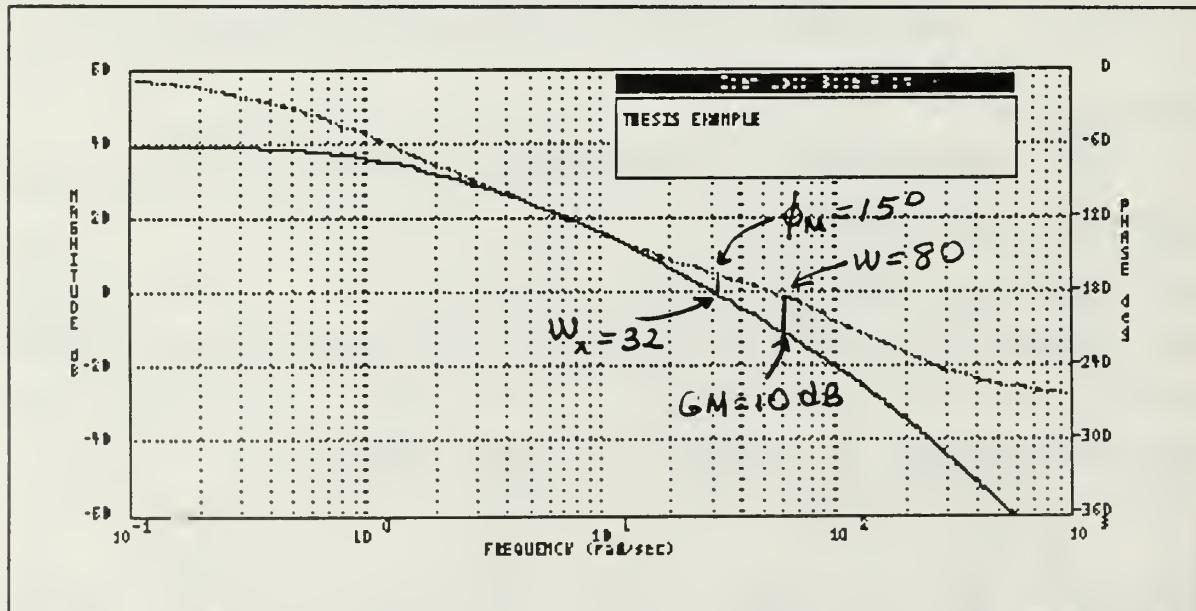
Figure 3.3   Open loop Bode plot for example 3.1.
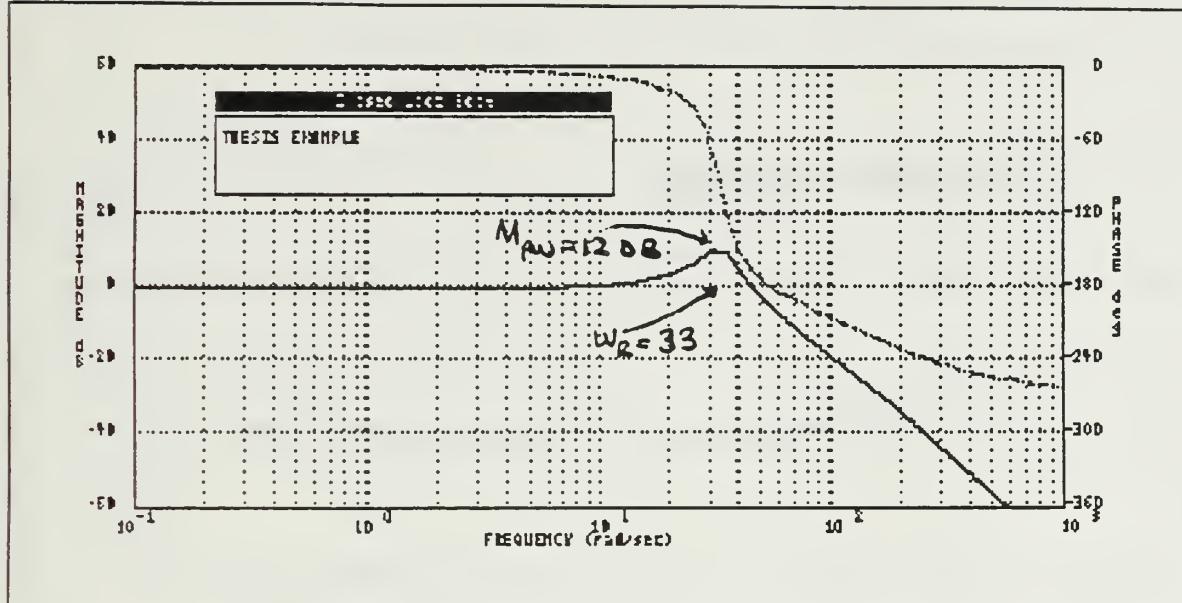
Figure 3.4   Closed loop Bode plot for example 3.1.

C.   TIME RESPONSE PLOT

It is desirable to see the system's response in the time-domain to a typical input.   Time response can be calculated and plotted with the SVS program as can the system input sinusoid, ramp, step or impulse.   All these inputs have user selectable amplitudes. Figure 3.5 shows the time response parameter screen.

The time response algorithm first converts the A, B and C matrices to the open loop transfer function, then into a discrete-time, state-space equivalent.   The theory of the time response plot is not included here. Users who want more information about the subject should consult reference 4, or any other relevant textbooks.

EXAMPLE 3.2

For the given system in example 3.1, obtain the time response plot and mark the following on the time response plot, recording the numerical values.

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1) Settling time

2) Maximum overshoot for a step input.

Solution:

The program data has already entered for the Bode plot. The selecting "Time response Plot" in the graphics menu gives figure 3.6 as a problem solution.

```
┌─────────────────────────────────────────────────────────┐
│         *** Time Response Plotting Parameters ***        │
│    =================================================     │
│                                                          │
│                                                          │
│  What is your input to the system? STEP (S)   S          │
│                                    RAMP (R)               │
│                               SINE WAVE (W)              │
│                                 IMPULSE (I)              │
│                                                          │
│                                                          │
│  What is your input amplitude?    1                      │
│                                                          │
│                                                          │
│  Input one of these choices, Open (O) or Closed (C) C    │
│                                                          │
│                                                          │
│                                                          │
│  Input your simulation time to the system (99max) 1.4    │
│                                                          │
└─────────────────────────────────────────────────────────┘
```

Figure 3.5 Time response parameters screen.

D. NYQUIST PLOT

This section presents the Nyquist plot option. This selection gives open loop and unity-feedback closed loop Nyquist plot. The program first calculates open loop transfer function of the plant. Then the plot is obtained by calculating the magnitudes and phases angle of the transfer function for a specified

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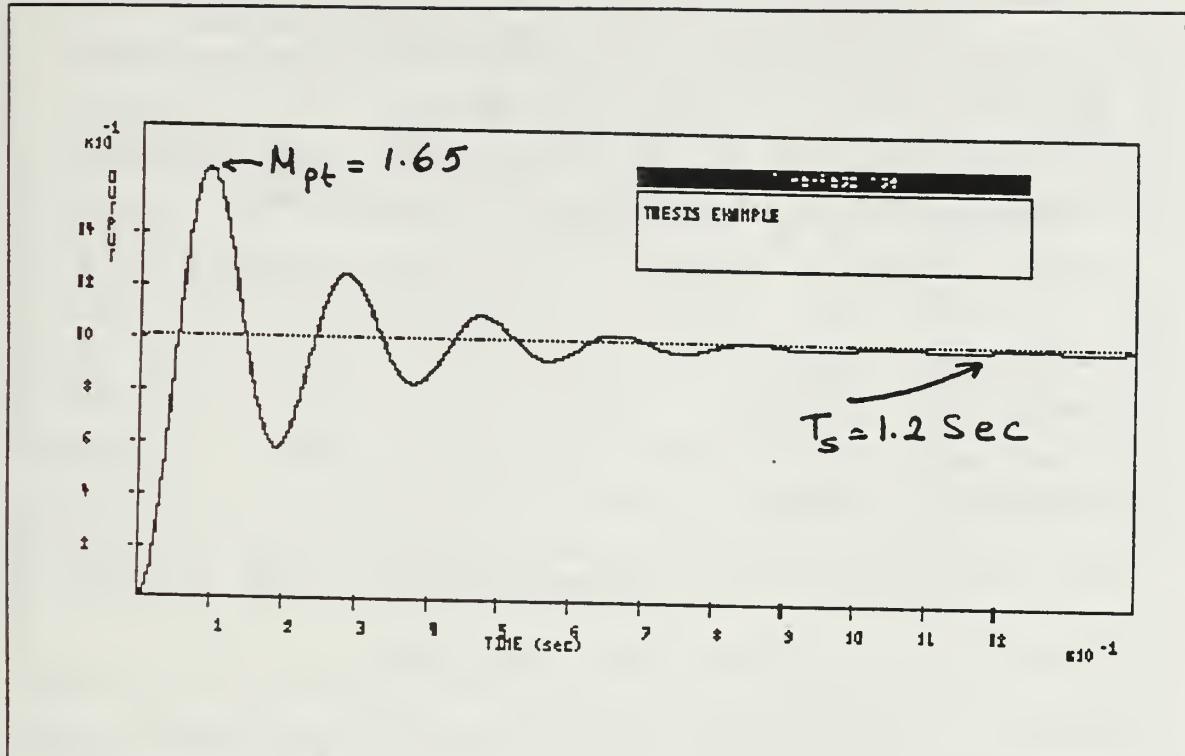
Figure 3.6   Time response plot for example 3.2.

number   of   times   with   a   specified   increment   of w.
Before proceeding   to   the   Nyquist   plot,   the program
prompts the menu of Figure 3.7.   This parameters screen
allows   the   user   to   enter   additional   data   for the
plotting.   The   graphic   window size is given 100X100
scale if the user selects the big picture   option.   The
select own size option asks the user to enter starting
frequency,   number   of   decades   and   X,Y   coordinates
maximum and minimum values for the plot.   After getting
the plot, the procedures are the same as   with the Bode
plot option.   These are   make a   title to the graph,
printer output and listing   numbers (which   are used to
generate a graph) either to the printer or a specified
file with a given drive name.

```
┌─────────────────────────────────────────────────────────┐
│         *** Nyquist Plotting Parameters ***             │
├─────────────────────────────────────────────────────────┤
│                                                         │
│  Open (O) or (C) Closed loop plot?    O                 │
│  Graph window (B) or (S) Select your own size?  S       │
│  Input your first frequency to be plotted?      .1      │
│    (Example: .01, 1, 100, etc. )                        │
│  Input number of decades do you want plotted?    4      │
│                                                         │
│                                                         │
│  X-Maximum      100                                     │
│  X-Minimum     -100                                     │
│  Y-Maximum      100                                     │
│  Y-Minimum     -100                                     │
│                                                         │
│  Any changes to these parameters? ( Y / N )      N      │
│                                                         │
│  Press <F1> to change previous entry                    │
│                                                         │
└─────────────────────────────────────────────────────────┘
```

Figure 3.7   Parameters selection for the Nyquist plot.

EXAMPLE 3.3

   Figure 3.8 shows the Nyquist plot for the example
3.1 A, B and C matrices.
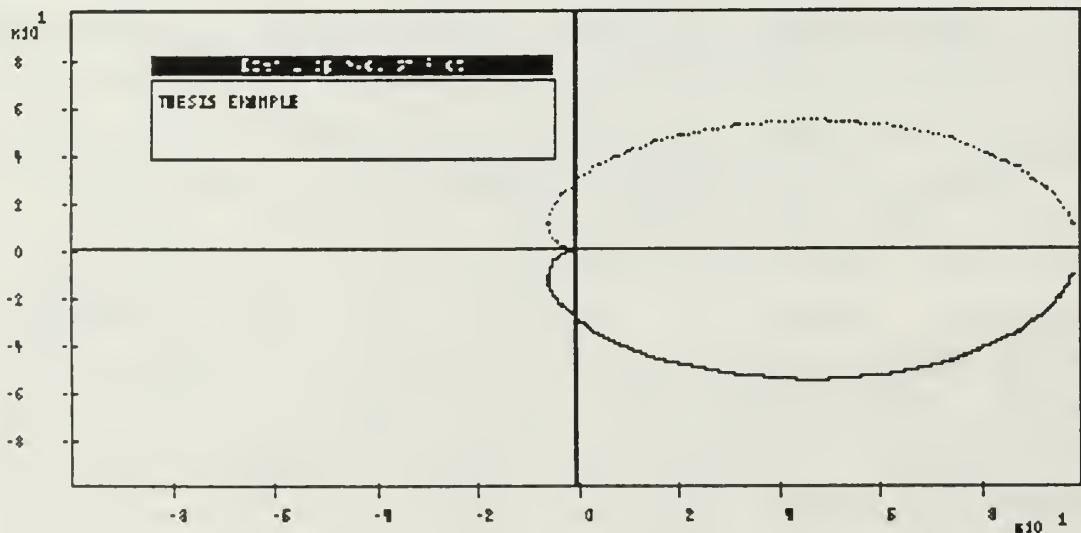
Figure 3.8   Example of the Nyquist plot.

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E. ROOT LOCUS PLOT

This option plots the loci of the closed loop poles of a system with transfer function G(s) = K N(s)/D(s) for varying gain. N(s) and D(s) are polynomials of the plant and the program calculates from the given A, B and C matrices.

The user is prompted to enter the starting and ending gain values, maximum and minimum X,Y coordinate values and to select either positive or negative feedback.   These plotting parameters are shown on Figure 3.9.   After this input routine, the program assumes unity feedback and calculates root locations for varying gain and plots them.

```
┌─────────────────────────────────────────────────────┐
│         *** Root Locus Plotting Parameters ***       │
├─────────────────────────────────────────────────────┤
│                                                       │
│   Input  STARTING value for  the varying gain    Ø   │
│   Input  ENDING value for  the varying gain      1Ø  │
│                                                       │
│                                                       │
│         X-Minimum        -1ØØ                         │
│         X-Maximum         1ØØ                         │
│         Y-Minimum        -1ØØ                         │
│         Y-Maximum         1ØØ                         │
│   Positive or Negative feedback? ( P / N )      N    │
│   Any changes to these parameters?    N              │
│                                                       │
└─────────────────────────────────────────────────────┘
```

Figure 3.9   Parameters screen for the root locus.

EXAMPLE 3.4

Figure 3.1Ø shows the Root locus plot for the given data on the example 3.1.
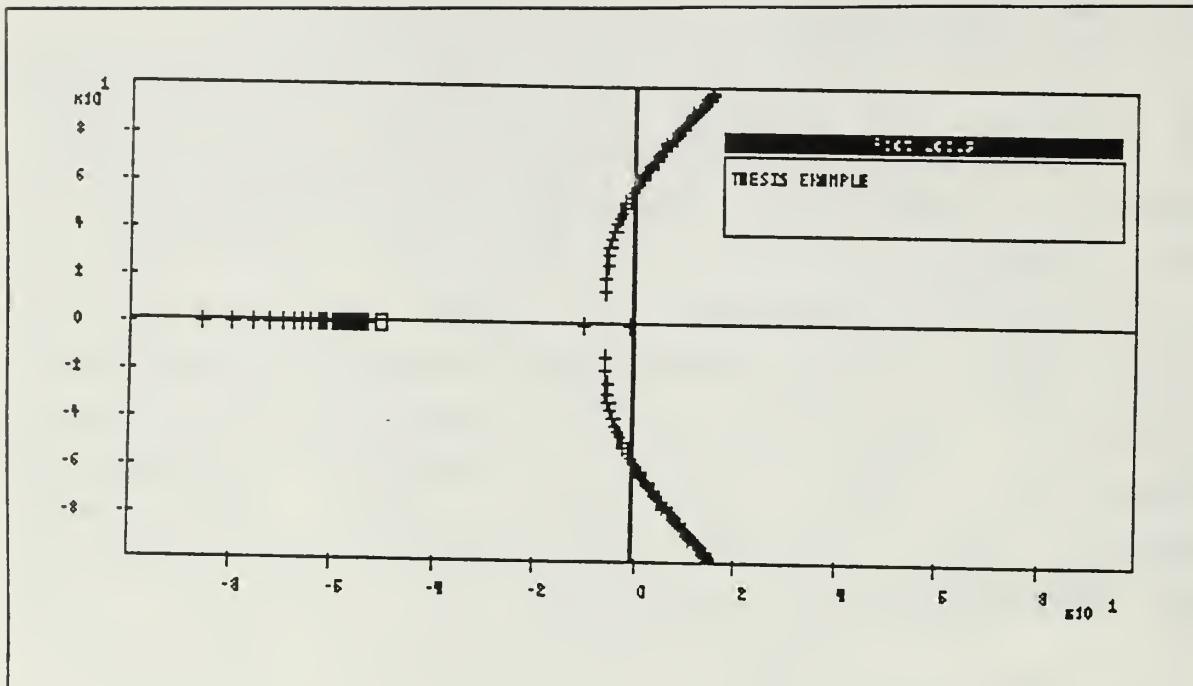
Figure 3.10   Example for the root locus plot.

F.   CHARACTERISTIC EQUATION ROOTS

This option of the graphics menu allows the user to decide whether the system is stable or unstable by looking at the root location of the characteristic equation. The program gives again the unity-feedback closed loop characteristic equation roots of the plant. The illustrative program output of the example 3.1 can be seen in Figure 3.11.

G.   LOAD PLANT MATRICES FROM DISK FILE

This last option of the graphics menu allows the user to get saved data from disk file directly instead of going via to the main menu and input/change menu.

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```
    *** Plant Characteristic Equation Roots ***

ROOTS OF THE NUMERATOR


s[1]= -50.00 +j  0.000


ROOTS OF THE DENOMINATOR

s[1]= -132.032 +j 0.000    s[2]= -69.170 +j 0.000

s[3]= -4.899   +j -32.893 s[4]= -4.899 +j 32.899
```

Figure 3.11   Example of characteristic equation
roots.

IV. <u>SVS MAIN MENU</u>

A.   INTRODUCTION TO THE SVS MAIN MENU

In this chapter six options are presented which may be used for the analysis and design of control systems. These options are supported by the other options which are explained in Chapter II and III.

The observability option is used to determine the observability index of the system.   Another very similar program, controllability is used to determine the controllability   of   the   system.   The matrix mathematics option brings to   the   screen   another menu selections. This   program   calculates   an A matrix determinant, inverse, characteristic polynomial and eigenvalues.   The   last   three options may be used to design optimal linear control systems.   The pole placement option is useful in the design of linear control state variable feedback control systems.   In the pole placement case, the control is computed by multiplying by a gain [K], the difference between the reference input and a weighted (linear) sum of the state variables.   The Luenberger observer design is used to   design a combined observer-controller to achieve a given desired closed loop transfer function when some of the states are not accessible.

Design of optimal control will minimize a given cost function which produces a scalar control.   The program starts to work at the terminal time and works backwards in time.

B.   CONTROLLABILITY

This   option   is   used   to   determine   the controllability of the linear time-invariant system. Consider the following continuous-time system

$$\dot{x}(t) = A\,x(t) + B\,u(t) \qquad (4-1)$$

where

$$x = \text{state vector}$$
$$A = \text{plant matrix}$$
$$B = \text{input matrix}$$
$$u = \text{control input}$$

The system described by the above equation is said to be state controllable at a given initial time if it is possible to construct an unconstrained control signal which will transfer an initial state to any final state in a finite time interval [Ref. 5].

This requires an algebraic condition such that the rank r(C) of the controllability condition matrix

$$C = [B \vdots AB \vdots \ldots \vdots A^{n-1}B] \qquad (4-2)$$

is n, the order of the system.

EXAMPLE 4.1

Consider the matrices A and B,

$$A = \begin{bmatrix} 0 & 1 & -1 \\ 1 & 0 & 1 \\ 0 & 1 & -1 \end{bmatrix} \quad , \qquad B = \begin{bmatrix} 1 & 0 \\ 0 & 1 \\ 0 & 0 \end{bmatrix}$$

Determine if [A, B] is a controllable pair.

Solution: Since A is 3x3 and B is 3x2, matrix C has to be 3x6. The program checked the rank of the controllability condition matrix. The result of the

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program can be seen in Figure 4.1, the system is controllable.

```
                  CONTROLLABILITY      RESULT
The Plant matrix A is :
   0.00000E+00   1.00000E+00   -1.0000E+00
   1.00000E+00   0.00000E+00   1.00000E+00
   0.00000E+00   1.00000E+00   -1.0000E+00

The input Matrix B is :
   1.00000E+00   0.00000E+00
   0.00000E+00   1.00000E+00
   0.00000E+00   0.00000E+00

The system is controllable.
```

Figure 4.1   Controllability program output.

C.   OBSERVABILITY

In this section we determine observability index of the linear systems. Consider the unforced system described by the following equations:

The (unforced) time invariant system

$$\dot{x} = Ax \qquad (4-3)$$

with the observation vector

$$y = Cx \qquad (4-4)$$

The observability index, which is defined as the rank $r(O)$ of the observability condition matrix

$$O = \begin{bmatrix} C \\ CA \\ . \\ \dot{C}A^{n-1} \end{bmatrix} \qquad (4-5)$$

is n, the order of the system.

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The program output for this selection is illustrated in Figure 4.2 with the A matrix as given on example 4.1 and the following C matrix.

$$C = [\ 1 \quad 0 \quad 0\ ] \qquad (4-6)$$

```
                  OBSERVABILITY RESULT

The Plant matrix A is :
   0.00000E+00    1.00000E+00    -1.0000E+00
   1.00000E+00    0.00000E+00     1.00000E+00
   0.00000E+00    1.00000E+00    -1.0000E+00

The Output Matrix C is :
   1.00000E+00    0.00000E+00     0.00000E+00

The system is observable with index 3.
```

Figure 4.2 Observability program output.

D. POLE PLACEMENT

Any single-input single-output linear, time invariant system is described by the following equations:

$$\dot{x}(t) = A\ x(t) + B\ u(t) \qquad (4-7)$$
$$y(t) = C\ x(t) \qquad (4-8)$$

The plant is characterized as a block diagram in Figure 4.3.
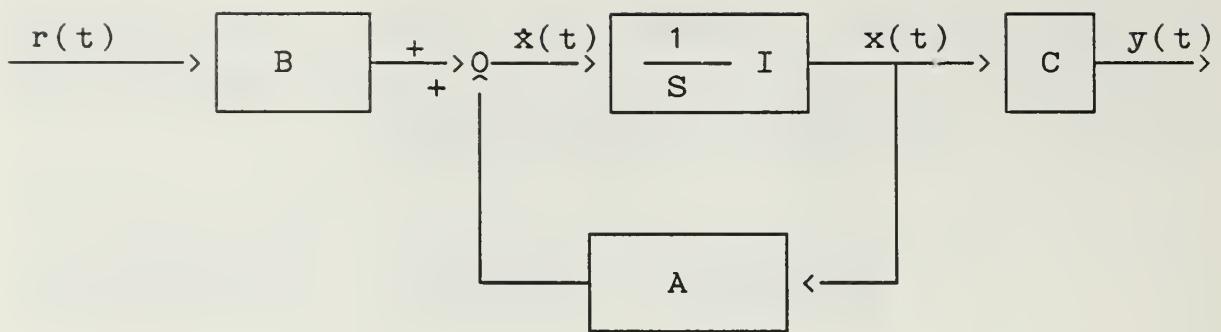
Figure 4.3   Block diagram for the state variable
representation.

The closed   loop nature of the system of Figure 4.4
is showed by   the   presence   of   the   controller.   It
generates the   control signal u from   the knowledge of
the state variables.   So, we   can see   that, except for
the reference input [r],   the state   of the plant x is
the only information needed by the controller.   The
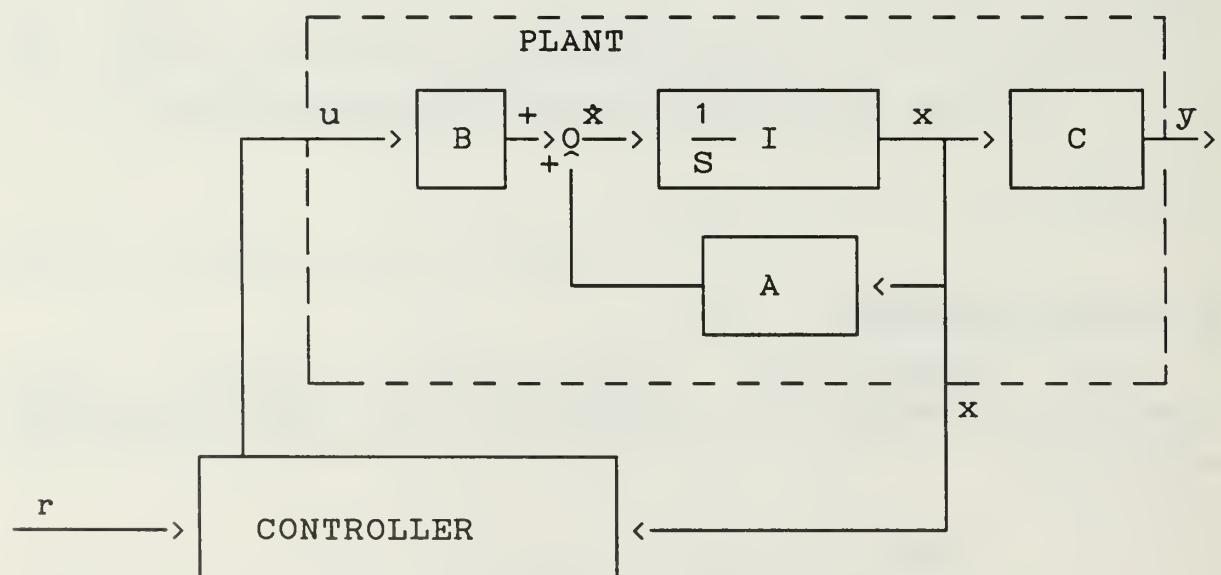
Figure 4.4   General closed loop system with state
variable feedback.

control input is computed by the multiplying by a gain K the difference between the reference input and a weighted (linear) sum of the state variables. As a mathematical expression,

$$u= K [r - (k_1x_1 + k_2x_2 + \ldots + k_nx_n)] \qquad (4-9)$$

where the k_i's are referred to as feedback coefficients. The gain K is referred to as the controller gain. The equation (4-9) may be simplified by making it in the matrix notation

$$u= K [r - k^T x] \qquad (4-10)$$

After all this notation, the graphical representation of the system configuration is shown in Figure 4.5.
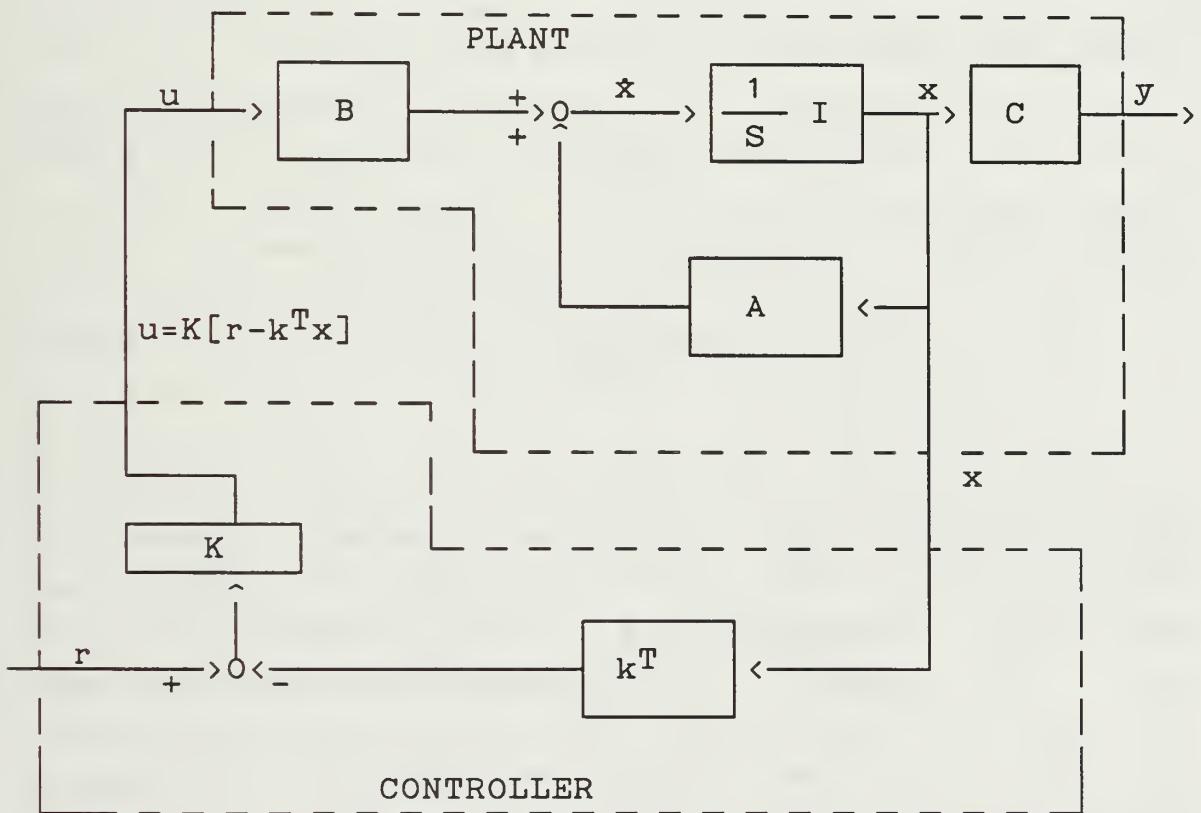
Figure 4.5 Linear state variable feedback system.

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We could obtain the closed loop transfer function $Y(s)/R(s)$ from the state variables. Our approach is to force the system into the configuration shown in Figure 4.6.
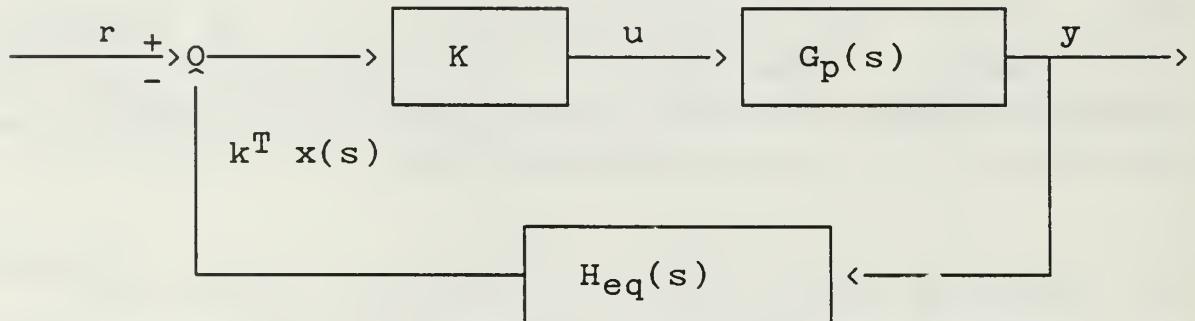
Figure 4.6   Closed loop block diagram representation.

We can see that $H_{eq}(s)$ is given by

$$H_{eq}(s) = \frac{k^T\ x(s)}{y(s)} \tag{4-11}$$

Since $y(s) = C\ x(s)$, this expression becomes

$$H_{eq}(s) = \frac{k^T\ x(s)}{C\ x(s)} \tag{4-12}$$

Here it must be pointed out that the program calculates the gain K, so zero steady state error results from a step input. If the user wants other conditions, he may rescale K and k^T appropriately by hand. For example, assume he wants to desire to have the controller gain, $K = K_1$, but the program output shows that $K = K_0$ with the feedback coefficients k_1, k_2, k_3. The procedure is then to modify the program outputs by setting $K = K_1$ and setting

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$$k^T = \frac{K_\emptyset}{K_1} \; [\; k_1 \; k_2 \; k_3 \;] \qquad\qquad (4\text{-}13)$$

This procedure does not change $Y(s)/R(s)$ and satisfies the condition $K=K_1$. Under these notations and block diagrams, this option gives an open loop transfer function $Y(s)/U(s)$ for the plant, the feedback transfer function $Heq(s)$, the controller gain $[K]$ and the feedback coefficients $[k^T]$ to achieve the desired closed loop characteristic polynomial.

The desired closed loop characteristic polynomial is the denominator of $Y(s)/R(s)$ and must agree with the order of the plant. The user can enter this polynomial either in coefficient form or factored form. If the user wants to enter the coefficient form, the coefficient of the highest degree term must be unity.

The methodology for computing the result is: the coefficients of the denominator polynomial of $Y(S)/R(s)$, which is the polynomial desired by the user, may be adjusted at will by proper selection of k and K. The closed loop zeros are equal to the open loop zeros. In other words, linear state variable feedback has no effect on the zeros of $Y(s)/R(s)$. The program calculates the numerator of $Heq(s)$ to achieve the desired characteristic polynomial. Note that the complete $Heq(s)$ is calculated by taking the numerator of $Heq(s)$ and dividing it by the numerator of $Y(s)/U(s)$. In the program procedures, the coefficients of the characteristic polynomial are computed by the use of the Principle-Minor method. For the matrix inverse calculation, the program uses the diagonalization procedures.

EXAMPLE 4.1

The plant matrices of a third order system are given in the following state variable representation:

$$\dot{x}(t) = \begin{bmatrix} -1.0 & 1.0 & 0.0 \\ 0.0 & 0.0 & 1.0 \\ 0.0 & -3.0 & 0.0 \end{bmatrix} x(t) + \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix} u(t) \qquad (4-14)$$

$$y(t) = [\ 1.0 \quad 1.0 \quad 0.0\ ]\ x(t) \qquad (4-15)$$

Find the feedforward (controller) gain [K] and the feedback coefficients [k^T] required to achieve a closed loop transfer function of

$$\frac{Y(s)}{R(s)} = \frac{2\ (s + 2)}{s^3 + 4s^2 + 6s + 4} \qquad (4-16)$$

The program result for this example is presented in Figure 4.7.

```
                  POLE PLACEMENT RESULT
The Plant matrix A is :
 -1.0000E+00    1.00000E+00    0.00000E+00
  0.00000E+00    0.00000E+00    1.00000E+00
  0.00000E+00   -3.0000E+00    0.00000E+00
The Input matrix B is :
  0.00000E+00
  0.00000E+00
  1.00000E+00

The Output Matrix C is :
  1.00000E+00    1.00000E+00    0.00000E+00

Denominator  of Y(s)/U(s) - Descending powers of S :
  1.0000      1.0000     3.0000     3.0000
```

Figure 4.7 Program output for the pole placement.

```
The poles of the Y(s)/U(s) are:
                    REAL PART            IMAGINARY PART
                   -1.0000      +j          0.0000
                    0.0000      +j         -1.7321
                    0.0000      +j          1.7321

Numerator of Y(s)/U(s) - Descending powers of S :
   1.0000     2.0000
The zeros  of the Y(s)/U(s) are:
                    REAL PART            IMAGINARY PART
                   -2.0000      +j          0.0000
Desired closed-loop Characteristic polynomial -
Descending powers of S :
    1.0000     4.0000     6.0000     4.0000

The roots of desired closed-loop characteristic
polynomial are:
             REAL PART          IMAGINARY PART
            -2.0000      +j         0.0000
            -1.0000      +j        -1.0000
            -1.0000      +j         1.0000

Numerator of the Heq(s) is - Descending powers of S :
   1.5000     1.5000     0.5000
The roots of the Heq(s) are :
             REAL PART          IMAGINARY PART
            -0.5000      +j        -0.2887
            -0.5000      +j         0.2887
The feedback coefficients [k^T] are :
   0.5000    0.0000    1.5000
The gain [K] is :  2.0000
```

Figure 4.7   Program output for the pole placement
             (continued)

The results shown in Figure 4.7 specify that the
gain of the controller   [K]   is   2.0   and   the   feedback
coefficients are $k_1=0.5$, $k_2=0.0$ and $k_3=1.5$.

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E. LUENBERGER OBSERVER DESIGN

Consider a linear time invariant plant of the form

$$\dot{x}(t) = A\, x(t) + B\, u(t) \qquad (4-17)$$
$$y(t) = C\, x(t) \qquad (4-18)$$

Let a feedback control law for equations (4-17) and (4-18) will be

$$u(t) = K\,[\, r(t) - k^T\, x(t)] \qquad (4-19)$$
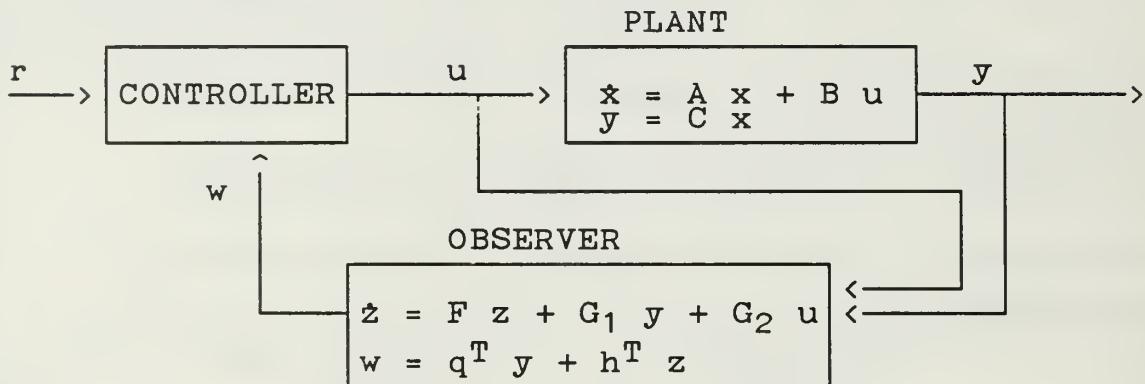
Figure 4.8   Luenberger observer block diagram.

Assume without loss of generality that the plant is controllable and observable. Since the state of equation (4-17) is not directly available to implement equation (4-19), an observer of the form

$$\dot{z}(t) = F\, z(t) + G_1\, y(t) + G_2\, u(t) \qquad (4-20)$$

and replacing the true states with estimates yields

$$u(t) = K\,[\, r(t) - k^T\, z(t)] \qquad (4-21)$$
$$k^T z(t) = h^T\, z(t) + q^T\, y(t) \qquad (4-22)$$

will be designed. The resulting closed loop system is shown in Figure 4.8.

Where

$$x = \text{state vector}$$
$$u = \text{control input}$$
$$y = \text{output}$$
$$r = \text{system forcing input}$$
$$\dot{z} = \text{estimated state vector}$$
$$A = \text{plant matrix}$$
$$B = \text{input matrix}$$
$$F = \text{observer eigenvalues matrix}$$
$$G_1 \text{ and } G_2 = \text{observer gain matrices}$$
$$K = \text{controller gain}$$
$$q^T = \text{output feedback coefficients matrix}$$
$$h^T = \text{observer feedback coefficients matrix}$$

```
      *** Luenberger Observer Design Parameters ***
==========================================================

Input degree of observer (10 max)  2

Input the desired feedback coefficients in
                              Factored <F> Form  C
                     or Coefficient.<C> Form


Input observer characteristic polynomial in
                              Factored <F> Form  C
                     or Coefficient <C> Form



Press <ESC> to change it!,
Then type your input with <ENTER> key
```

Figure 4.9 Luenberger observer design parameters.

The user has to enter the controller gain and the
feedback coefficients which can be found by the use of

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"pole placement" option. The program asks the observer eigenvalues which are represented by the F matrix in the program. The observer degree depends on the observability index. For example, if the observability index r is the minimum integer, then the observer gain matrix [G] has order r. Simply the order of the observer, when the program prompted can be entered, As equal to or greater than (r-1). These input parameters are shown in Figure 4.9.

EXAMPLE 4.2

The example presented here for the fourth degree plant is taken from Desjardin's [Ref. 2]. The plant is represented by the following equations.

$$y(t) = [\ 10\quad 20\quad 0\quad 0\ ]\ x(t) \qquad (4-23)$$

$$\dot{x}(t) = \begin{bmatrix} 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & -15 & -23 & -9 \end{bmatrix} x(t) + \begin{bmatrix} 0 \\ 0 \\ 0 \\ 1 \end{bmatrix} u(t) \qquad (4-24)$$

Solution:

Step1

The x_1 and x_2 are the only measurable states and we want to achieve following closed loop transfer function.

$$\frac{Y(s)}{R(s)} = \frac{1}{s^4 + 6s^3 + 17s^2 + 28s + 20} \qquad (4-25)$$

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The controller gain [K] and the feedback coefficients required are found, as can be seen from Figure 4.10 by the use of the "Pole placement" option in the same menu. Results shown in Figure 4.10 indicates that the feedback coefficients [k^T] are -3, -6, 13, 20 and the controller gain [K] equals unity.

```
                    POLE PLACEMENT RESULT

The Plant matrix A is :
   0.00000E+00   1.00000E+00   0.00000E+00   0.00000E+00
   0.00000E+00   0.00000E+00   1.00000E+00   0.00000E+00
   0.00000E+00   0.00000E+00   0.00000E+00   1.00000E+00
   0.00000E+00  -1.5000E+01   -2.3000E+01   -9.0000E+00

The Input matrix B is :
   0.00000E+00
   0.00000E+00
   0.00000E+00
   1.00000E+00

The Output Matrix C is :
   2.00000E+01   1.00000E+01   0.00000E+00   0.00000E+00

Denominator  of Y(s)/U(s) - Descending powers of S :
    1.0000      9.0000    23.0000     15.0000       0.0000
Numerator of Y(s)/U(s) - Descending powers of S :
   20.0000
Desired closed-loop Characteristic polynomial -
Descending powers of S :
    1.0000      6.0000    17.0000     28.0000     20.0000
Numerator of the Heq(s) is - Descending powers of S :
   -3.0000     -6.0000    13.0000     20.0000
The feedback coefficients [ k ] are :
  20.0000   13.0000    -6.0000    -3.0000
The gain [ K ] is :   1.0000
```

Figure 4.10   Pole placement result for the Luenberger
            observer design.

The observability index is determined using the "Observability" option in the same menu. That results is shown in Figure 4.11.

```
                    OBSERVABILITY RESULT

The Plant matrix A is :
   0.00000E+00    1.00000E+00    0.00000E+00    0.00000E+00
   0.00000E+00    0.00000E+00    1.00000E+00    0.00000E+00
   0.00000E+00    0.00000E+00    0.00000E+00    1.00000E+00
   0.00000E+00   -1.5000E+01   -2.3000E+01   -9.0000E+00

The Output Matrix C is :
   1.00000E+00    0.00000E+00    0.00000E+00    0.00000E+00
   0.00000E+00    1.00000E+00    0.00000E+00    0.00000E+00

The system (A,C) is observable with index 3.
```

Figure 4.11   Observability result for Luenberger.

As can be seen from Figure 4.12, the system is completely controllable.

```
                 CONTROLLABILITY     RESULT
The Plant matrix A is :
   0.00000E+00    1.00000E+00    0.00000E+00    0.00000E+00
   0.00000E+00    0.00000E+00    1.00000E+00    0.00000E+00
   0.00000E+00    0.00000E+00    0.00000E+00    1.00000E+00
   0.00000E+00   -1.5000E+01   -2.3000E+01   -9.0000E+00

The input Matrix B is :
   0.00000E+00
   0.00000E+00
   0.00000E+00
   1.00000E+00

The system (A,B) is controllable.
```

Figure 4.12   Controllability output for Luenberger.

An observability index r=3 (result taken from observability output) allows us to design an observer of order equal to or greater than (r-1)=2. For this

```
                    LUENBERGER OBSERVER RESULT
The plant matrix A is :
  0.00000E+00    1.00000E+00    0.00000E+00    0.00000E+00
  0.00000E+00    0.00000E+00    1.00000E+00    0.00000E+00
  0.00000E+00    0.00000E+00    0.00000E+00    1.00000E+00
  0.00000E+00   -1.5000E+01    -2.3000E+01    -9.0000E+00
The input matrix B is :
  0.00000E+00
  0.00000E+00
  0.00000E+00
  1.00000E+00
The   output Matrix C is:
  1.00000E+00    0.00000E+00    0.00000E+00    0.00000E+00
  0.00000E+00    1.00000E+00    0.00000E+00    0.00000E+00
The desired feedback coefficients are :
  2.00000E+01
  1.30000E+01
 -6.0000E+00
 -3.0000E+00
The Observer characteristic polynomial coefficients
in ascending powers of S
   1.40000E+01   7.50000E+00   1.00000E+00
The F Matrix is :
 -7.5000E+00    1.00000E+00
 -1.4000E+01    0.00000E+00
The G1 Matrix is :
  8.55000E+01    2.92500E+01
  0.00000E+00    0.00000E+00
The G2 Matrix is :
 -3.0000E+00
 -1.5000E+00
The output feedback coefficients are :
  2.00000E+01   8.50000E+00
The compensator feedback coefficients are :
  1.00000E+00   0.00000E+00
```

Figure 4.13   The Luenberger observer design output.

example, we want to design observer eigenvalues of
-3.5 and -4.0.

<u>Step5</u>

    The program results for all this input data is
shown in Figure 4.13. From results, the complete
system can be described as:

$$
\dot{x}(t) = \begin{bmatrix} 0.0 & 1.0 & 0.0 & 0.0 \\ 0.0 & 0.0 & 1.0 & 0.0 \\ 0.0 & 0.0 & 0.0 & 1.0 \\ 0.0 & -15. & -23. & -9. \end{bmatrix} \begin{bmatrix} x_1(t) \\ x_2(t) \\ x_3(t) \\ x_4(t) \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ 0 \\ 1 \end{bmatrix} u(t)
$$

$$
\dot{z}(t) = \begin{bmatrix} -7.5 & -1.0 \\ -14. & 0.0 \end{bmatrix} \begin{bmatrix} z_3(t) \\ z_4(t) \end{bmatrix} + \begin{bmatrix} 85.5 & 29.25 \\ 0.0 & 0.0 \end{bmatrix} \begin{bmatrix} x_1(t) \\ x_2(t) \end{bmatrix}
$$

$$
+ \begin{bmatrix} -3.0 \\ -1.5 \end{bmatrix} u(t)
$$

$$
u(t) = 1.0 \ r(t) - [\ 20.0 \quad 8.5] \begin{bmatrix} x_1(t) \\ x_2(t) \end{bmatrix}
$$

$$
- [1.0 \quad .0] \begin{bmatrix} z_3(t) \\ z_4(t) \end{bmatrix}
$$

F. DESIGN OF OPTIMAL CONTROL

    The system considered is described by the following
state variable equation:

$$
\dot{x}(t) = A \ x(t) + B \ u(t) \tag{4-26}
$$

where

        x = state vector

        u = control input

        A = plant matrix

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$$B = \text{input matrix}$$

The design of optimal control will minimize the following cost function:

$$J(N) = 1/2[\ XT(N)\ Q\ X(N) + \sum_{k=0}^{N-1}[X(k)\ Q\ X(k) + R\ U^2(k)] \tag{4-27}$$

where the following are defined

        Q = noise covariance matrix
        N = time intervals over which the SUM is made
        R = scalar random input
and XT means transpose of X.

   The physical interpretation of J(N) is this: we wish to keep the state near zero without excessive control energy expenditure. The input parameters of the design of optimal control are entered in the beginning of the program. This screen can be seen in Figure 4.14. After entering these parameters and the Q matrix, then the program calculates the feedback gain matrix which, when multiplied by the state vector, yields a scalar control. In the program procedures, the following equations were derived using dynamic programming, starting at the terminal time and working backwards.

```
P(k)=PSIT(k) * P(k-1) * PSI(k) + Q + GT(k) *
                       R * G(k),  P(0)=0            (4-28)
PSI(k)=FI + GAMMA * GT(k),    PSI(0) = 0            (4-29)
GT(k)=-[GAMMAT * P(k-1) * FI]/[GAMMAT * P(k-1) *
                       GAMMA + R],   GT(0)=0    (4-30)
```

```
   *** Design of optimal control procedure ***
===========================================================
Input number of time intervals for SUM procedure?  40
What is your sample interval?      0.1
What is the value of scalar R?     2.0

For the following options which cost function
                              do you want?     0
COST=terminal+fuel+trajectory or
COST=terminal+trajectory                 <0>
COST=terminal+fuel or COST=terminal   <1>
where
      terminal= 1/2 XT(N) Q X(N)
                  N-1
    trajectory= 1/2 ∑ X(k) Q X(k)
                  k=0
                  N-1
         fuel = 1/2 ∑ R U²(k)
                  k=0


Press <ESC> to change it!,
Then type your input with <ENTER> key
```

Figure 4.14 Optimal control parameters screen.

For simplicity in programming, the following definitions are defined:

$$\text{Terminal} = 1/2 \ XT(N) * Q * X(N) \qquad (4\text{-}31)$$

$$\text{Trajectory} = 1/2 \sum_{k=0}^{N-1} X(k) * Q * X(k) \qquad (4\text{-}32)$$

$$\text{Fuel} = 1/2 \sum_{k=0}^{N-1} R * U^2(k) \qquad (4\text{-}33)$$

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EXAMPLE 4.3

Given the system equation and parameters described
below find the discrete steady state gains for a sample
interval 0.1, scalar R is 1.0 and number of time
intervals is 40.

$$\dot{x}(t)=\begin{bmatrix} 0 & 1 \\ 5 & 0 \end{bmatrix} x(t) + \begin{bmatrix} 0 \\ 1 \end{bmatrix} u(t) \qquad (4-34)$$

The graphic result of the program is shown in
Figure 4.15 and Figure 4.16, the numerical output is in
the Figure 4.17.
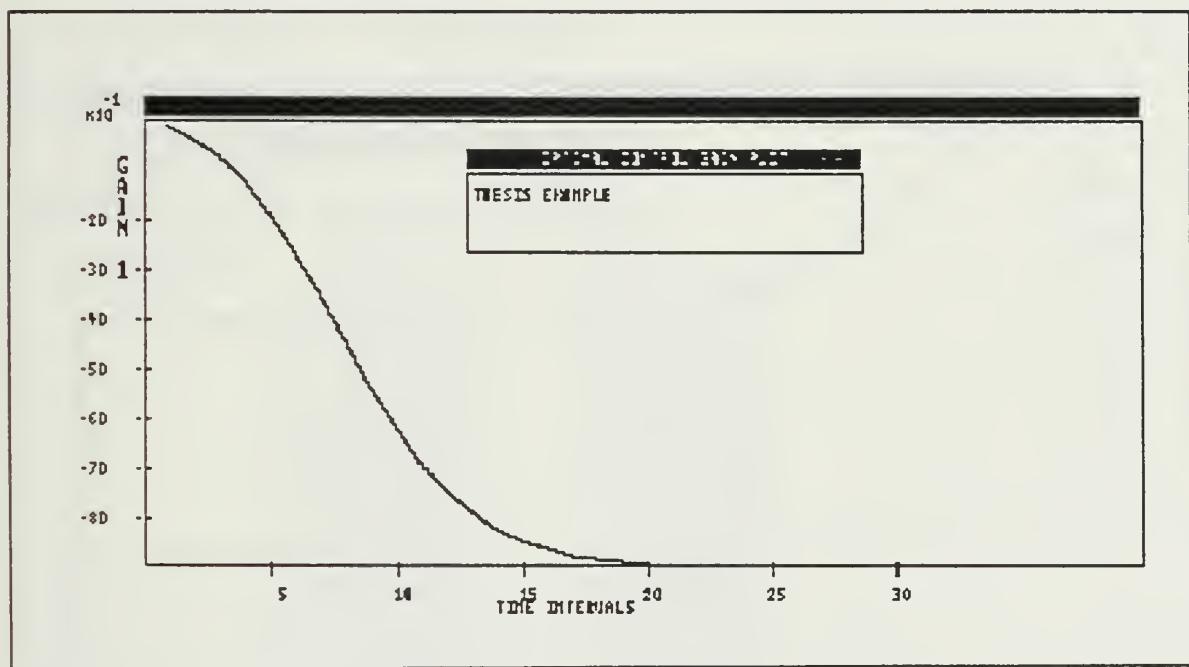
Figure 4.15   Optimal control graphic output #1.

G.   MATRIX MATHEMATICS MENU

This option is used to get various calculations
with the plant matrix A of a given linear control state
variable system.   The selection from the SVS main menu

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brings the matrix mathematics menu. This second menu
consist of following options:
    (1) The determinant of A matrix
    (2) The inverse of A matrix
    (3) The characteristic polynomial of A matrix
    (4) The Eigenvalues of A matrix

    Before selecting this option, the user must select
"Input/Change Plant Matrices" option to enter the
plant matrices.
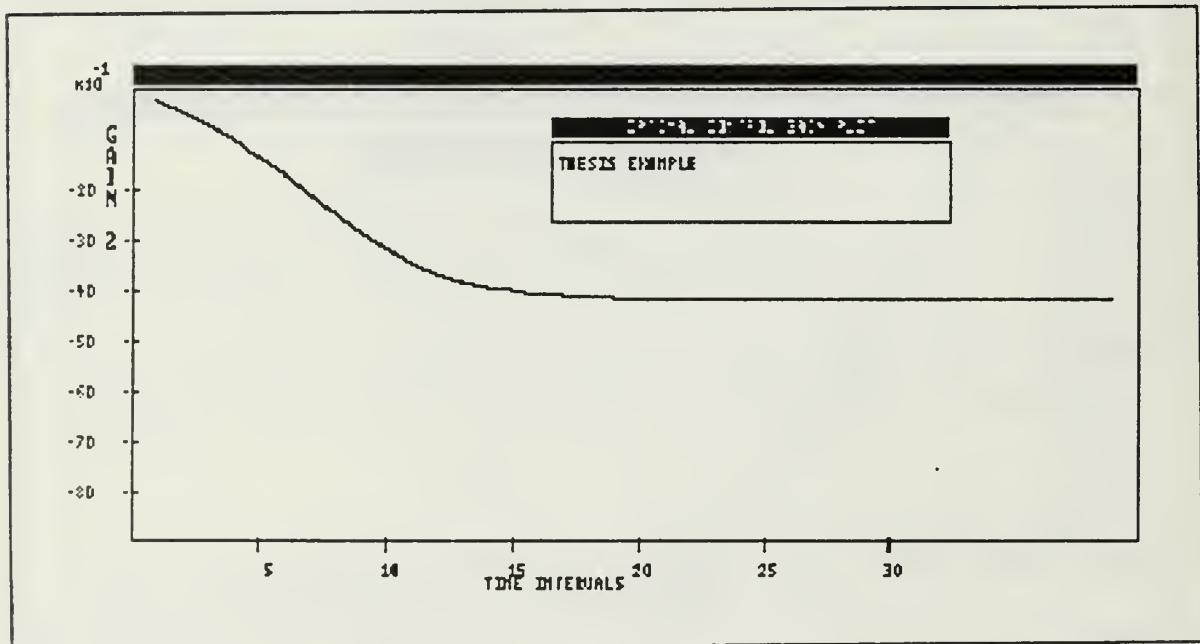
Figure 4.16   Optimal control graphic output #2.

```
                    OPTIMAL CONTROL RESULT
The order of the system is : 2
The number of time intervals is :1.0E-01
The scalar R is : 1.0000
The sample interval is :   40

The A matrix is:

  0.00000E+00   1.00000E+00
  5.00000E+00   0.00000E+00

The B matrix is:

  0.00000E+00
  1.00000E+00

The Q matrix is:

  1.00000E+00   0.00000E+00
  0.00000E+00   2.00000E+00

The FI matrix is:

  1.02510E+00   1.00835E-01
  5.04177E-01   1.02510E+00

The GAMMA matrix is:

  5.02087E-03
  1.00835E-01

MINIMIZATION OVER ALL STAGES

   (stages)       GT:2            GT:2
  ---------    ----------      ----------
      1         -1.047E-01      -2.031E-01
      2         -3.243E-01      -4.211E-01
      3         -6.722E-01      -6.665E-01
      4         -1.164E+00      -9.495E-01
      5         -1.809E+00      -1.275E+00
      6         -2.597E+00      -1.640E+00
      7         -3.494E+00      -2.031E+00
      8         -4.437E+00      -2.424E+00
      9         -5.355E+00      -2.794E+00
     10         -6.185E+00      -3.120E+00
     11         -6.888E+00      -3.390E+00
     12         -7.452E+00      -3.603E+00
     13         -7.886E+00      -3.765E+00
     14         -8.210E+00      -3.883E+00
     15         -8.447E+00      -3.969E+00
     16         -8.617E+00      -4.030E+00
     17         -8.738E+00      -4.073E+00
     18         -8.824E+00      -4.104E+00
     19         -8.884E+00      -4.125E+00
     20         -8.927E+00      -4.140E+00
     21         -8.957E+00      -4.150E+00
     22         -8.978E+00      -4.157E+00
     23         -8.993E+00      -4.163E+00
     24         -9.004E+00      -4.166E+00
     25         -9.011E+00      -4.169E+00
     26         -9.016E+00      -4.170E+00
     27         -9.020E+00      -4.172E+00
     28         -9.023E+00      -4.173E+00
     29         -9.025E+00      -4.173E+00
```

Figure 4.17   Optimal control numerical output.

V. CONCLUSION AND RECOMMENDATIONS

The software, SVS, is written as a teaching learning tool for student use. It can be a nice tool for analysis and design of linear control state variable systems. The program is fully interactive and menu driven. The user does not get lost in the program. The <Q> key always returns to the main menu or CTRL + C key interrupts the program. All options were tested solving several example problems. Hopefully, all "bugs" have been eliminated.

Furthermore, the program can still be easily improved and expanded. These are listed below.

(1) Adding the ability to handle the KALMAN filtering.

(2) Add the capability of the program to handle discrete time systems.

APPENDIX A

UTILITI FILES

A set of Turbo Pascal input and menuing utilities was used widely in the program. These are public domain utilities and was copied from the LCS-CAD source diskettes. These utilities, called TURBO-UT.PAS were written by:

> Donald R. Ramsey
> Larry Romero
> 727 Bunker Hill #70
> Houston, Texas 77029

and distributed through the public domain. The describing documentation are presented on reference 4.

APPENDIX B

PROGRAM LISTING

Appendix B is a listing files of the Turbo Pascal source code. These files make up the major modules of the SVS program. In general, most of the driver programs and including files are listed in the following pages. The source modules from the Borland International Turbo Graphix Toolbox and the input/output utility routines are not listed.

```
Program State Variable System(input,output);
(* **************************************************** *)
(* The following include files contain procedures    *)
(* to handle graphics call from the main procedures*)
(* of this program. These include files are a part  *)
(* of Borland International's Turbo Graphix Toolbox*)
(* Which is a commercially available product.        *)
(* **************************************************** *)

{$I Typedef,SYS}     {type & variable decleration}
{$I Box.INC}         {draw the box for the main menu}

(* **************************************************** *)
(* These are utility procedures and functions to     *)
(* help input. They are public domain programs.      *)
(* **************************************************** *)

{$I Ut-Mod01.INC}    {I/O procedures}
{$I Ut-Mod02.INC}

Procedure MainMenu;
var
  I,Tab                                   : Integer;
  Help1File,InputFile,MatrixFile,
  plotfile,ControlFile,ObserFile,
  LuenbergFile,PoleFile,OptimalFile  : File;
  Description                         : Str80;
  Okchoices                           : Set Of Char;


procedure ProgramExit;
                   {Displays warning about program end}
begin
  Clrscr; Highvideo;
  Msg('Have you  wanted ending the SVS program? ( Y/N )
     ,10,10);
  LowVideo;
  Repeat
    option;
    if not (Ch in ['Y','N']) then Beep(900,350)
  Until Ch in ['Y','N'];
End;

Procedure MenuItem(pick:char;description:str80;
                   color:integer);
        ( allows easy selection of main menu colors}
Begin
  TextColor(color);
  Write(' ':Tab,'('); TextColor(white  ); Write(pick);
  TextColor(color); Writeln(')',description);
End;

Begin ( Main Menu )
  ClrScr;
  TextColor(lightblue);
  Msg('    Naval Postgraduate School              Ismail
     UNLU ',7,24);
  GoToXY(21,4); TextColor(white);
  Writeln('   *** SVS MAIN MENU *** ');
                        ( show main menu )
  Writeln(' ');
  Tab:=23;
  MenuItem('I','Input / Change Plant Matrix Menu',red);
  Writeln;
  MenuItem('G','Graphics Menu',lightgray);
  MenuItem('C','Controllability',yellow);
  MenuItem('O','Observability',yellow);
  MenuItem('L','Luenberger Observer Design',yellow);
```

```
MenuItem('D','Design of Optimal Control',yellow);
MenuItem('P','Pole Placement',yellow);
Writeln;
MenuItem('M','Matrix Mathematics Menu',lightgray);
Writeln;
MenuItem('H','Help',lightmagenta);
MenuItem('Q','Quit the program',lightmagenta);
Box;
if not (block1 in [1..20] ) then
          OKchoices:= [';I','H','Q']
   else          OKchoices:=[';I','C','O','D','M','P',
                   'G','L','H','Q'];

Repeat          {sets legal choices depending on user}
   Option;
   If not (ch in okchoices) then
   Begin
      TextColor(red);
      If block1 <= 0 then
      Begin
         Beep(900,350);
         Msg('WARNING: First  INPUT ,HELP or QUIT!',
                             1,25);
      End;
   End;TextColor(white);
Until Ch in Okchoices;
Case Ch of
   'I': Begin
           Assign(InputFile,'Input.com');
           Execute(InputFile);
        End;
   'M': Begin
           Assign(MatrixFile,'Matrix.com');
           Execute(MatrixFile);
        End;
   'G': Begin
           Assign(Plotfile,'plot.com');
           Execute(plotfile);
        End;
   'C': Begin
           Assign(ControlFile,'Control.chn');
           Chain(ControlFile);
        End;
   'O': Begin
           Assign(ObserFile,'Obser.chn');
           Chain(ObserFile);
        End;
   'L': Begin
           Assign(LuenbergFile,'Luenberg.chn');
           Chain(LuenbergFile);
        End;
   'D': Begin
           Assign(optimalfile,'optimal.chn');
           Chain(optimalfile);
        End;
   'H': Begin
           Assign(Help1File,'Help1.chn');
           Chain(Help1File);
        End;
   'P': Begin
           Assign(PoleFile,'Pole.com');
           Execute(PoleFile);
        End;
   'Q': Begin
           ProgramExit;
           if (ch='Y') or (ch = 'y') then
           Exit := True;
        End;
```

```
    End; {case}
End; {main menu}

(* ****************************************** *)
(*                Program Execution part       *)
(* ****************************************** *)
Begin {svs}
   ClrScr;    {clear screen}
   Exit := False ;{initialize boolean}
   Repeat
     if block1 <> 1 then
     Begin
        Block1 := 0;
     End;
     MainMenu; { call main menu until the user
                 want to exit}
   Until Exit= True;
   Set_Cap_Num(' ',' ',' ');Say Cap_Num;
                 {set caps,insert,and num lock off}
   Block1 := 0;    {reset problem}
End. {svs}
```

```
Program input(input,output);
(* This program allows  the  user  to enter,change,save
and retrieve  the problem  for the whole options on the
other menues. *)

{$I Typedef.SYS} {comman type & variable definitions}

{$I Ut-mod01.INC} {I/O utility routines}
{$I Ut-mod02.INC}
{$I Ut-mod03.INC}

{$I Box.INC} {draws menu box}

var
   inputdatfile,savefile,retrievefile,
   changefile,help2file                : file;

Procedure InputMenu;
var i,Tab           : Integer;
    OKchoices       : Set Of Char ;
    Finished        : Boolean;

Procedure MenuItem(Pick:Char;Description:Str80;
                                  Color:Integer);
                 {displays menu items in color }
Begin
   TextColor(color);
   Write (' ':tab,'('); TextColor(white); Write(pick);
   TextColor(color); Writeln(')',Description);
End;

Begin
   ClrScr; TextColor(white); Finished := False;
   GoToXY(20,4); retriev:=true;
   Write('*** INPUT / CHANGE MENU ***   ');
   for i := 1 to 4 do writeln(' ');
   Tab := 18;
   MenuItem('I','Input Plant Matrices ',red);
   MenuItem('C','Change Current Plant Matrices',yellow);

   Writeln;
   MenuItem('S','Save Plant Matrices to Disk
                  File',yellow);
   MenuItem('L','Load Plant Matrices From Disk
                  File',yellow);
   Writeln;
   MenuItem('H','Help',lightmagenta);
   MenuItem('Q','Quit to SVS Main Menu ',lightmagenta);

   Box; TextColor(white);

   Set Cap num('C',' ',' ');say_cap_num; gotoxy(40,22);
   if block1 <> 1 then OKchoices :=['I','L','H','Q']
            else OKchoices :=['I','C','H','S','L','Q'];

   Repeat {wait for user to input a keyprees}
      option;
      if not (ch in OKchoices) then
      begin
         beep(900,350);TextColor(red);
         if block1 <> 1 then
         begin
            msg('WARNING: First INPUT,RETRIEVE,HELP or
                      QUIT! ',1,25);
      end;
      end;
      TextColor(white);
   until Ch in OKchoices;
```

```
   case ch of
     'I': begin
            Assign(inputdatfile,'inputdat.chn');
            chain(inputdatfile);
          end;
     'L': begin
            Assign(retrievefile,'retrieve.chn');
            Chain(retrievefile);
          end;
     'S': begin
            Assign(savefile,'save.chn');
            Chain(savefile);
          end;
     'C': Begin
            Assign(changefile,'change.chn');
            Chain(changefile);
          End;
     'H': Begin
            Assign(help2file,'help2.chn');
            Chain(help2file);
          End;
     'Q': begin
            Assign(svsFile,'svs.com');
            Execute(svsFile);
          end;
   End; {case}
end;

{ Execution the input/change menu  program. }

Begin  {main program}
   drive:='C';
   repeat
     InputMenu;
   Until Finished = True;
End. {main program}
```

```
Program input_data(input,output);
{To allow  the user  to enter the A,B,C matrix from the
this program}
label 13;label 10;label 11; {label decleration  for the
GOTO statement}

{$I Typedef.sys}  {comman variable declerations}

{$I Ut-mod01.inc}  {I/O routines}
{$I Ut-mod02.inc}

var Ans,Cont                    : Char;
    Out                         : Text;
    Stepping,Step,Steps,
    Temp1,Temp2,i,j             : Integer;
    Result                      : Real;
    inputfile                   : file;

Begin {input_data}
  13:ClrScr; Writeln;
  block1:=1; textcolor(yellow);
  Write('Enter the degree of the plant:  ');
  Readln(size);
  if  (size <= 0) or ( size > 10)  then
  begin
    beep(900,350); goto 13;
  end;
  for steps:=1 to 10 do          {initialize}
    for stepping := 1 to 10 do
      A1A[steps,stepping] := 0.0;

  Writeln('Enter the elements of the A Matrix ');
  writeln;
  for steps := 1 to size do
  Begin
    for stepping := 1 to size do
    Begin
      Write('A(',steps,',',stepping,') = ');
      Readln(A1A[steps,stepping]);
    End;Writeln;
  End;
  Repeat
    ClrScr; Writeln;
    Writeln('The A Matrix is : '); writeln;
    for steps :=1 to size do
    Begin
      for stepping := 1 to size do
      Begin
        Write('  ', A1A [steps,stepping]:11);
      End; Writeln;
    End; writeln;  {prompt to any changes}
    Write('Do you want to change any element of');
    write(' the Matrix ? ( Y / N ) ');
    Read(Kbd,Ans); writeln;   {allows user to change
                              entered data}
    if ( Ans  ='Y') or ( Ans ='y') then
    Begin
      write('Input the row to change : '); readln(i);
      write('Input the column to change : ');
      readln(j);writeln;
      write('A(',i,',',j,')= ');readln(result);
      A1A[i,j]:=result;
    End;
  Until Ans in ['N','n'];

  10:ClrScr;writeln;
  {user inputs B matrix elements from the keyboard}
```

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```pascal
write('How many inputs do you have ?   ');
readln(ni);writeln;
if ( ni < 1 ) or (ni > size) then
begin
   beep(900,350);goto 10;
end;
for steps := 1 to 10 do
   for stepping:=1 to 10 do
      B[steps,stepping] := 0.0;
Writeln('Enter the elements of the B Matrix  ') ;
Writeln;
for steps := 1 to size do
Begin
   for stepping:=1 to ni do
   begin
      Write('B(',steps,',',stepping,') = ');
      Readln( B [ steps,stepping ]);
   end;writeln;
End; Writeln;
Repeat
   ClrScr; Writeln;
   Writeln('The B Matrix is: '); writeln;
   for steps :=1 to size do
   Begin
      for stepping:=1 to ni do
      begin
         Write('   ',B[steps,stepping]:11);
      end; writeln;
   End; Writeln;
   Write('Do you want to change any element of');
   write(' the B Matrix ? ( Y / N ) ');
   Read(Kbd,Ans);
   writeln; {allows user to change B matrix element}
   if ( Ans ='Y') or ( Ans ='y') then
   Begin
      write('Input the row to change : '); readln(i);
      write('Input the column to change : ');
      readln(j); writeln;
      write('B(',i,',',j,')= ');readln(result);
      B[i,j]:=result;
   End;
Until Ans in ['N','n'];

11:ClrScr; Writeln;
{user inputs output data from keyboard}
write('How many outputs do you have ?    ');
readln(no);
if ( no < 1 ) or ( no > size ) then
begin
   beep(900,350);goto 11;
end;
for steps:= 1 to 10 do
   for stepping:=1 to 10 do
      C[steps,stepping]:=0.0;
writeln;
Writeln('Enter the elements of the C Matrix  ');
Writeln;
for stepping := 1 to no do
Begin
   for steps :=1 to size do
   begin
      Write('C(',stepping,',',steps,') = ');
      Readln( C[stepping,steps]);
   end; writeln;
End; writeln;
Repeat
   ClrScr; Writeln;
   Writeln('The C matrix is : '); writeln;
```

```
      for stepping := 1 to no do
      Begin
        for steps:=1 to size do
        begin
          Write('   ',C[stepping,steps]:11);
        end;writeln;
      End; Writeln;
      Write('Do you want to change any element of');
      write(' the C Matrix ? ( Y / N ) ');
      Read(Kbd,Ans); writeln;
      if ( Ans ='Y') or ( Ans ='y') then
      Begin
        write('Input the row to chnage : '); readln(i);
        write('Input the column to change : ');
        readln(j); writeln;
        write('C(',i,',',j,')= ');readln(result);
        C[i,j]:=result;
      End;
  Until Ans in ['N','n'];

  Assign(inputfile,'input.com');
          {re-execute the input/change menu program}
  Execute(inputfile);
End.(input_data)
```

```
Program change data(input,output);
(* **************************************** *)
(* This program allows the user to change A,B, C  *)
(* matrices and their matrix order.               *)
(* **************************************** *)
label 11;label 12;label 14;

{$I Typedef.sys}    {comman type & variable decleration}

{$I Ut-mod01.inc}   {I/O utilities }
{$I Ut-mod02.inc}

var Ans,temp,inputtype       : Char;
    Stepping,Step,Steps,i,j  : Integer;
    Result                   : Real;
    inputfile                : file;
    result_size              : integer;

Begin
    clrscr;writeln; gotoxy(1,22);
    invvideo('Press <ESC> to change it!,                ');
    gotoxy(1,23);
    invvideo('Then input your choice with <ENTER> key');
    gotoxy(1,2);
    textcolor(lightblue);
    writeln('     *** Change Current Plant Matrices
        Procedure ***');
    TextColor(yellow);
    writeln('================================');

    Msg('Which matrix do you want to change ?   ',1,6);
    textcolor(lightmagenta);
    msg('                         PLANT (A) ',39,6);
    msg('                         INPUT (B) ',1,7);
    msg('                         OUTPUT (C) ',1,8);
    repeat
      input('A','A',50,6,2,true,F1,F10);
      temp:=copy(answer,1,1);
      if not (temp in ['A','B','C']) then beep(900,350);

    until temp in ['A','B','C'];
    inputtype:= temp;

    case inputtype of
        'A':begin
            14:ClrScr;
            writeln('The A matrix is :');writeln;
            for steps:=1 to size do
            begin
              for stepping:=1 to size do
              begin
                write('   ',A1A[steps,stepping]:11);
              end;writeln;
            end;writeln;
            Write('The order of the system is:',
                 size,',');
            write(' Change ?'(Y/N)');
            repeat
              read(kbd,ch)
            until ch in ['Y','N','y','n'];
            if (ch='Y') or (ch='y') then
            begin
              writeln;
              write('The order of the system is :');
              readln(result_size);
              if (result_size<1)  or (result_size>10)
            then begin
                beep(900,350); goto 14;
```

```
                    end;
                    size:=result_size;
                end;
                repeat
                  clrscr;writeln;
                  Writeln('The A Matrix is : ');writeln;
                  for steps :=1 to size do
                  Begin
                    for stepping := 1 to size do
                    Begin
                        Write('   ',A1A[steps,stepping]:11);
                    End; Writeln;
                  End;Writeln;
                  Write('Do you want to change any element?
                        ( Y / N )');
                  Read(Kbd,Ans);writeln;
                  if not (Ans in [ 'N','n']) then
                  if ( Ans  ='Y') or ( Ans ='y') then
                  Begin
                    write('Input row to change : ');
                    readln(i);
                    write('Input column to change : ');
                     readln(j); writeln;
                    write('A(',i,',',j,')=');
                     readln(result);
                    A1A[i,j]:=result;
                  End;
                Until Ans in ['N','n'];
             end;
          'B':begin
              11:ClrScr;
              writeln('The B matrix is :');writeln;
              for steps:=1 to size do
              begin
                for stepping:=1 to ni do
                begin
                   write('   ',B[steps,stepping]:11);
                end;writeln;
              end;writeln;
              Write('The number  of input is : ',ni,'  ,
                    Change ?  (Y/N)');
              repeat read(kbd,ch)
              until ch in ['Y','N','y','n'];
              if (ch='Y') or (ch='y') then
              begin
                writeln; {allow the user to change number
                                 of input}
                write('The number of input is:');
                 readln(result_size);
                if (result_size<1)  or (result_size>10)
                then begin
                    beep(900,350); goto 11;
                end;
                ni:=result_size;
              end;
              repeat
                clrscr;writeln;
                Writeln('The B Matrix is : ');writeln;
                for steps :=1 to size do
                Begin
                  for stepping := 1 to ni do
                  Begin
                     Write('   ',B[steps,stepping]:11);
                  End; Writeln;
                End;Writeln;
                {prompt the user for changes  on B matrix}
```

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```
                    Write('Do you  want to change any element
                         ? ( Y / N )');
                    Read(Kbd,Ans);writeln;
                    if not (Ans in [ 'N','n']) then
                    if ( Ans  ='Y') or ( Ans ='y') then
                    Begin
                      write('Input row to change : ');
                       readln(i);
                      write('Input column to change : ');
                       readln(j);
                      writeln;write('B(',i,',',j,')=');
                       readln(result);
                       B[i,j]:=result;
                    End;
                 Until Ans in ['N','n'];
              end;
        'C':begin
            12:ClrScr;
            writeln('The C matrix is :');writeln;
            for steps:=1 to no do
            begin
              for stepping:=1 to size do
              begin
                write('  ',C[steps,stepping]:11);
              end;writeln;
            end;writeln;
           {allow the user to change number of outputs}
            Write('The number of output is :  ',no,');
            write(', Change ? (Y/N)');
            repeat read(kbd,ch)
              until ch in ['Y','N','y','n'];
            if (ch='Y') or (ch='y') then
            begin
              writeln;
              write('The Number of Output is :');
              readln(result_size);
              if (result_size<1)  or (result_size>10)
              then begin
                beep(900,350); goto 12;
              end;
              no:=result_size;
            end;
            repeat
              clrscr;writeln;{show C matrix elements}
              Writeln('The C Matrix is : ');writeln;
              for steps :=1 to no do
              Begin
                for stepping := 1 to size do
                Begin
                   Write('  ',C[steps,stepping]:11);
                End; Writeln;
              End;Writeln;
             {prompt the user for changes on C matrix }

              Write('Do you  want to change any element
                     ? ( Y / N )');
              Read(Kbd,Ans);writeln;
              if not (Ans in [ 'N','n']) then
              if ( Ans  ='Y') or ( Ans ='y') then
              Begin
                write('Input row to change : ');
                 readln(i);
                write('Input column to change : ');
                 readln(j);
                writeln;write('C(',i,',',j,')=');
                 readln(result);
                 C[i,j]:=result;
              End;
```

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```
            Until Ans in ['N','n'];
          end;
      end;
    Assign(inputfile,'input.com');    {re-execute input
                                 program}
    Execute(inputfile);
End.{change}
```

```pascal
Program save_data;

{$I Typedef.SYS}
{$I Ut-mod01.INC}
{$I Ut-mod02.inc}

var
   filename  : str20;
   blockfile  :text;
   i,j        : integer;
   inputfile  :file;
begin {save data}
   clrscr; HighVideo;
   {let user to change drive if necessary}
   Msg('** Your Data Drive is    . Press <esc> to change
       it!**',10,11);
   repeat
     input('A',copy(drive,1,1),32,11,2,true,F1,F10);
     ch:= copy(answer,1,1);
     if not(ch in ['A','B','C','D','E'])  then
        beep(350,150);
   until ch in ['A','B','C','D','E'];
   Drive := concat(ch,':');
   clrscr;       {prompt for filename to store data}
   msg('Input name of file to save data in File',1,10);
   writeln; writeln;
   writeln('*** Your DATA disk must be in drive
   ',Drive,' ***');
   input('A','',45,10,8,true,F1,F10);
   filename:= concat(Drive,copy(answer,1,8),'.svs');

   Assign(Blockfile,filename); {Open file }
   rewrite(Blockfile);
   Writeln(Blockfile,size);
   Writeln(Blockfile,ni);
   Writeln(Blockfile,no);
   for i:= 1 to size do
     for j:=1 to size do
       write(blockfile,A1A[i,j]);
   for i:=1 to size do
     for j:= 1 to ni do
       writeln(blockfile,B[i,j]);
   for i:=1 to no do
     for j:=1 to size do
       write(blockfile,C[i,j]);

   close(Blockfile);  {close the file}
   Assign(inputfile,'input.com');{re-execute
                    input/change menu program}
   Execute(inputfile);
end.{save_data}
```

```pascal
Program  retrieve_data;
{$I Typedef.SYS} -{variable decleratios}

{$I Ut-mod01.INC} {I/O routines}
{$I Ut-mod02.INC}
{$I Ut-mod03.INC}

{$I Directry.INC}  {shows available data files}

var
   readfile         : text;    {The text file user will use}
   filename           : str20;
   readerror         : boolean;
   linecounter,i,j    : integer;  { A counter for the
                      lines we read}
   inputfile,PlotFile: file;

begin   { procedure retrieve_data}
   ClrScr;HighVideo;
       { Allow change of disk drive if desired}
   block1:=1;
   Msg('** Your data drive is   . Press <ESC>  to change
       it! **',10,11);
   Repeat
     Input('A',copy(drive,1,1),32,11,2,true,F1,F10);
     Ch:= copy(answer,1,1);
     If not(ch in ['A','B','C','D','E']) then
     beep(900,350);
   Until ch in ['A','B','C','D','E'];
   Drive:= concat(ch,':');
       { Call directory to display eligible files}
   Directory(drive,extension,filename,readerror);
   If not(readerror) then
   Begin
     Assign(readfile,filename);
       { Open the file and read contents}
     Reset(readfile);
     Linecounter:=0;               {count the lines }
     While not EOF(readfile) do
         {The built-in function EOF returns true}
     Begin{if the end of a file has been reached}
       Linecounter:=linecounter+1;{Count the next line}
       Readln(readfile,size);
           { Read it into variable line }
       Readln(readfile,ni);
       Readln(readfile,no);
       For i:=1 to size do
         For j:= 1 to size do
           Read(readfile,A1A[i,j]);
       For i:=1 to size do
         For j:=1 to ni do
           Readln(readfile,B[i,j]);
       For i:= 1 to no do
         For j:=1 to size do
           Read(readfile,C[i,j]);
     End; Close(readfile);
   End
   Else
   Begin
     Delay(1500);
       { Wait for directory error message and continue}
     Window(1,1,80,25);
     Clrscr;
   End;
   if not (retriev) then
   begin
     Assign(plotfile,'Plot.COM');
     Execute(PlotFile);
```

```
   end
   else
   begin
       Assign(inputfile,'input.com');{re-execute
                          input/change menu program}
       Execute(inputfile);
   end;
End. {retrieve_data}
```

```
Program Plot;
{ Program  plot  contains  graphic  programs.  They are
written  by  WOOD  Roy,  Jr.  and  modified  for  this
program.  }

{$I Typedef.SYS}{type and variable decleration routine}

{$I Ut-mod01.INC}      {I/O routines }
{$I Ut-mod02.INC}
{$I Ut-mod03.INC}

{$I Box.INC}            {drawing menu box }

var
   i,j                                    : Integer;
   help4file,Retrievefile,Nyquistfile,
   timeplotfile,bodefile,rlocifile,rootsfile  : File;
Procedure GraphicsMenu;
var
   i,Tab                                  : Integer;
   Okchoice                               : Set Of Char ;
   Finished                               : Boolean;

Procedure MenuItem(Pick:Char;Description:Str80;
          Color:Integer);
          {gives easy selection of input menu colors}
Begin
   TextColor(color);
   Write (' ':tab,'('); TextColor(white); Write(pick);
   TextColor(color); Writeln(')',Description);
End;

Begin
   ClrScr;TextColor(white);
   Finished := False;GoToXY(20,4);
   Writeln('  *** GRAPHICS MENU ***  ');
                              {display graphics menu}
   Writeln;
   Tab := 18;
   MenuItem('L','Load Plant Matrices From Disk
       File',red);
   Writeln;
   MenuItem('C','Characteristic Equation Roots',yellow);

   MenuItem('B','Bode Plot ',yellow);
   MenuItem('T','Time Response Plot',yellow);
   MenuItem('N','Nyquist plot',yellow);
   MenuItem('R','Root Locus Plot',yellow);
   writeln;
   MenuItem('H','Help',lightmagenta);
   MenuItem('Q','Quit to SVS Main Menu ',lightmagenta);
   TextColor(green);
   Box; Writeln;
   TextColor(white); retriev:=false;
   GoToXY (40,22);
   repeat              { read user choice from keyboard}
     option;
   until ch in ['R','L','B','T','N','H','Q','C'];
   case ch of
      'R' :begin
             assign(rlocifile,'rloci.chn');
             chain(rlocifile);
           end;
      'L': Begin
             Assign(retrievefile,'retrieve.chn');
             Chain(retrievefile);
           end;
```

```
        'T': begin
                Assign(timeplotfile,'timeplot.chn');
                Chain(timeplotfile);
            end;
        'B': begin
                Assign(Bodefile,'Bode.chn');
                Chain(bodefile);
            end;
        'N': begin
                Assign(nyquistfile,'Nyquist.chn');
                Chain(Nyquistfile);
            end;
        'C': Begin
                Assign(rootsfile,'roots.chn');
                Chain(rootsfile);
            End;
        'H': Begin
                Assign(Help4File,'Help4.CHN');
                Chain(Help4File);
            End;
        'Q': begin
                Assign(svsFile,'svs.com');
                Execute(svsFile);
            end;
    End;
End;

Begin {plot}
   drive:='C';
   {initialize drive selection for load procedure}
   repeat
     GraphicsMenu; {repeadely call graphics menu until
                          user selects to quit}
   Until Finished = True;
End. {plot}
```

```
(    BODE   PLOT   is   the   driver   program   for   the Bode
plotting   routines.   It simply invokes Bode plot, when
finished, returns back to the graphics menu. )

Program Bode;

{$I Typedef.sys}      {graphics routines}
{$I Graphix.sys}
{$I Kernel.sys}
{$I Windows.sys}
{$I Polygon.hgh}
{$I Axis.hgh}

{$I Ut-mod01.inc }    {I/O routines}
{$I Ut-mod02.inc }
{$I Ut-mod03.inc }

{$I GrapMenu.inc}     {graph options menu}
{$I PlotBode.inc}     {Bode plotting routine}
{$I Boxuser.inc}

type
     ary4  = array [1..11] of real;
     ary6  = array [1..21] of integer;

var
     plotfile  :file;

{$I Polynom.inc}          {Polynomial routine}
{$I Rootfind.inc)         {Polynomial roots finder routine}

($I Bodeplot.inc)        {Bode routine}

begin
     BODEPLOT;    {call the Bode calculation routine}

     Assign(plotfile,'PLOT.COM');
            {re-execute the graphics menu routines}
     Execute(plotfile);

end.
```

```
Program time response;
label 13;  {label decleration for GOTO statement}

{$I Typedef.sys}    {graphics routines}
{$I Graphix.sys}
{$I Kernel.sys}
{$I Windows.sys}
{$I Axis.hgh}
{$I Polygon.hgh}

{$I Ut-mod01.inc}   {I/O routines}
{$i UT-mod02.inc}
{$I Ut-mod03.inc}

{$I GrapMenu.inc}   {graph option menu procedure}

type
  ary4     = array [1..11] of real;
  ary6     = array [1..11] of integer;

var
  Psi,Phi,A,Atemp                      : ary1s;
  temp, inputtype                      : char;
  Offset,Slope,Tmax,
  RowSum,MaxRowSum,T,
  T1,OldMaxRowSum,
  Plottime,Uinput,PhiX,
  hold,Ymax,Ymin,TPlot,
  Amplitude, Freq,y                    : real;
  Factorial,Plotindex,
  Nincr,code,i,
  ij,j,l,m,n,kk,cnpoles,sizezero       : integer;
  DumpGraph,GoodNumbers,
  ClosedLoop,quit                      : boolean;
  C1,Xold,Xnext,Gamma                  : ary3s;
  GraphArray,Inputarray                : plotarray;
  List                                 : text;
  numcoeff,dencoeff,cdencoeff          : ary4;
  kk1                                  : integer;
  plotfile                             : file;

{$I Polynom.inc}   {characteristic equation procedure}
{$I Boxuser.inc}


Procedure PrintGraphData;
  {this procedure dumps time-response data to printer}
Begin
  LeaveGraphic;Clrscr;
  repeat
    Textcolor(white); gotoxy(20,10);
    writeln('   *** PROGRAM OUTPUT OPTIONS ***   ');
    gotoxy(20,13);
    writeln('<P> Printer output                  ');
    Textcolor(yellow);   gotoxy(20,14);
    writeln('     Check Your Printer!             ');
    Textcolor(white);    gotoxy(20,15);
    writeln('<F> List to File name               ');
    gotoxy(20,16);
    writeln('      on the current drive          ');
    gotoxy(20,17);
    writeln('<Q> Quit                            ');
    gotoxy(42,15);textcolor(yellow);write('"TIME.RES"');

    gotoxy(28,17);
    read(kbd,ch);
      If (ch='F') or (ch='f') or (ch='P') or (ch='p')
      then
```

```
      begin
        if (ch = 'F') or (ch = 'f') then
        begin
          gotoxy(24,15);textcolor(red);
          write('PRINTING....                          ');
          assign(list,'Time.RES');
          rewrite(list);
        end
        else
        begin
          gotoxy(24,13);textcolor(red);
          write('PRINTING...;.......                   ');
          assign(list,'LST:');
          rewrite(list);
        end;
        writeln(list,'                    TIME RESPONSE PLOT
                  RESULT ');
        writeln(list);
        writeln(list,'        TIME (Sec)                        Y
              (input)'( output)                       R
                  (input)');

        writeln(list,'------------------------------');
        writeln(list);
        for i := 1 to 200 do
        writeln(list,'      ',GraphArray[i,1]:10:5,'      ',
                GraphArray[i,2]:12:4,' ',
          InputArray[i,2]:12:4);
      end;
    until ch in ['Q','q'];
    EnterGraphic;
    swapscreen;
    close(list);
end;

Procedure Matrix_Mult(Matrix1,Matrix2:ary1s;
                      var AnswerMatrix:ary1s;
                      Order:integer);
var i,j    : integer;

begin
  for i:=1 to order do
    for j:=1 to order do
      AnswerMatrix[i,j] := 0;
          (initialize the answer matrix)

  for i:= 1 to order do
    for j:= 1 to order do
      for L := 1 to order do
        AnswerMatrix[i,j] := AnswerMatrix[i,j] +
                    Matrix1[i,L]*Matrix2[L,j];
end;

Procedure Scalar_Mult(Matrix1 : ary1s; scalar : real;
                      var AnswerMatrix:ary1s;
                  Order:integer);
var i,j    : integer;

begin
  for i:= 1 to order do
    for j:=1 to order do
      AnswerMatrix[i,j]:= AnswerMatrix[i,j] * scalar;
end;

Procedure Matrix_Vector_Mult(Matrix1 :ary1s;
                             Vector : ary3s;
                             var AnswerVector:ary3s;
                             order:integer);
```

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```pascal
var i,j   : integer;
begin
  for i:= 1 to order do
  begin
    hold:= 0;
    for j:= 1 to order do
      hold:= hold + Matrix1[i,j]*Vector[j];
      AnswerVector[i]:= hold;
  end;
end;

Begin
  Initgraphic;leavegraphic;
  Boxuser;
  Characteristic Equation(A1A,size,Dencoeff);
                {calculating denominator coefficient}

  for i:=1 to size do  PSI[i,size]:=B[i,1];
  for jj:=2 to size do
  begin
    for i:=1 to size do
    begin
      j:=size-jj+1;
      kk1:=j+1;
      PSI[i,j]:=Dencoeff[kk1] * B[i,1];
      for l:=1 to size do
        PSI[i,j]:= PSI[i,j] +A1A[i,l] * PSI[l,kk1];
    end;
  end;

  for i:=1 to size do
              {calculating numerator coefficients }
  begin
    Numcoeff[i]:= 0.0;
    for j:=1 to size do
      Numcoeff[i]:= Numcoeff[i] + PSI[j,i] * C[1,i];
  end;
  for i:=1 to size do  {calculating numerator order }
  begin
    m:=size+1-i;
    if Numcoeff[m] <> 0.0 then goto 13;
  end;
  13:sizezero:=m-1;
  Clrscr;

  TextColor(lightblue);
  writeln('          *** Time Response Plotting
  Parameters ***');
    TextColor(yellow);writeln('==================');
  Msg('What is your input to the system?  STEP (S)
                                        ',1,6);
  Msg('                                    RAMP (R)
                                        ',1,7);
  Msg('                               SINE WAVE (W)
                                        ',1,8);
  Msg('                                 IMPULSE (I)
                                        ',1,9);
  repeat
    Input('A','S',50,6,2,true,F1,F10);
    temp := copy(answer,1,1);
    if not (temp in ['S','R','W','I']) then
                  Beep(350,150);
  until temp in ['S','R','W','I'];
  InputType := temp;
  Msg('What is your input amplitude? ',1,11);
  Input('N','1',35,11,5,true,F1,F10);
  val(answer,Amplitude,code);
```

```pascal
case InputType of
  'R': begin
          Msg('What is your DC value? ',1,13);
          Input('N','0',28,13,5,true,F1,F10);
          val(answer,Offset,code);
          msg('What is your slope? ',1,15);
          Input('N','1',23,15,5,true,F1,F10);
          val(answer,slope,code);
      end;
  'W': begin
          Msg('What is your frequency?
                 (rad/sec)',1,13);
          Input('N','',35,13,5,true,F1,F10);
          val(answer,Freq,code);
      end;
end;
Msg('Open (O) or Closed (C) Loop Plot ? ',1,17);

repeat
   Input('A','C',40,17,2,true,F1,F10);
   temp := copy(answer,1,1);
   if not (temp in ['O','C']) then beep(350,150);
until temp in ['O','C'];
if temp = 'C' then ClosedLoop:= true
              else ClosedLoop:= false;
Msg('Input your  simulation time for the system (99
                 max)',1,20);
repeat
   Input('N','',55,20,5,true,F1,F10);
   val(answer,Tmax,code);
   if Tmax > 99 then beep(350,150);
until (Tmax <= 99) and ( Tmax > 0) ;

Boxuser;

if ClosedLoop then
begin
   for i:=1 to maxorder do CDenCoeff[i] := 0.0;
                    (initialize)
   for i:=1 to sizeZero + 1 do
      CDenCoeff[i] := Numcoeff[i] ;
     (C.L. denominator  equals the sum of open loop
        denominator and  O.L. numerator  )

   for i:=1 to SIZE + 1 do
       CDenCoeff[i] := CDenCoeff[i] + Dencoeff[i];
   if size > sizezero then CNpoles:= size
                      else CNPoles:= SizeZero;
       (Nploes shold always be greater,but to be safe)

end
else
begin
   CNpoles:=Size;
   for i:=1 to size do
     CDenCoeff[i]:=Dencoeff[i];
end;

{ Calculation of new A matrix}

for i:= 1 to CNPoles-1 do
begin
   for j:=1 to CNPoles do
   begin
      if j = i+1 then A[i,j]:= 1.0
                 else A[i,j]:= 0.0;
   end;
end;
```

```
{Calculation of new C matrix }

for j:= 1 to CNPoles do
begin
   A[CNPoles,j] := -CDenCoeff[j];
end;
for i:= 1 to CNPoles do
begin
   if i > SizeZero + 1 then C1[i]:= 0.0
                    else C1[i]:= NumCoeff[i];
   if SizeZero = CNPoles then
        C1[i] := C1[i] +  NumCoeff[SizeZero+1]*
           A[CNPoles,i];
end;

{ Selection of sampling time interval }

Nincr := 1000;
T := (Tmax/Nincr);
Atemp :=A;
Psi :=  A; {initialize psi to the value of the
    infinite series after the first}

Scalar_Mult(Psi,T/2,Psi,CNPoles);
for i:= 1 to CNPoles do {two terms I + A*T / 2!}
   Psi[i,i]:=Psi[i,i] + 1.0;
Factorial := 2;  T1 := T;  Oldmaxrowsum:= 0.0;
repeat
   begin
      Factorial := Factorial * (i+1);  T1 := T1 * T;
      Matrix_Mult(A,ATemp,Phi,CNPoles);
           {phi is used at temp}
      ATemp:= Phi;  {holding matrix to large array}
      Scalar_Mult(Phi,(T1/Factorial),Phi,CNPoles);

      for j:=1 to CNpoles do
      begin
         for m:= 1 to CNpoles do
         begin
            Psi[j,m]:=Psi[j,m] + Phi[j,m];
         end;
      end;
      Maxrowsum:= 0.0;
     {computes maxrowsum as measure of change in last}
      for j:= 1 to CNpoles do{series term to be added.}

      begin
         rowsum:= 0.0;
         for m:=1 to CNPoles do
          rowsum:= rowsum + Psi[j,m];writeln;
         if rowsum > maxrowsum then maxrowsum := rowsum;

      end;
      if (abs(maxrowsum-oldmaxrowsum)/maxrowsum)< 0.001

                          then finished := false
         {quit when .1%change} else finished := true;

      oldmaxrowsum := maxrowsum;
   end;
until Finished;
Scalar_Mult(Psi,T,Psi,CNPoles);
Matrix_Mult(A,Psi,Phi,CNPoles);
for i := 1 to CNPoles do
   Phi[i,i] := Phi[i,i] + 1.0;
for i:= 1 to CNPoles do
   Gamma[i] := Psi[i,CNPoles];
  {single input system with B vector:  }
```

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```
                { B= [ 0 0 0 0 ... 0 1]  (transpose)}
    Plottime := 0.0; PlotIndex := 1;  {initialize}
    for i:= 1 to CNPoles do Xold[i]:= 0.0;
                        {init. prev. state}
       Ymax := 0.0; Ymin := 0.0;

    Boxuser;

    for N := 1 to Nincr do
           {begin calculating next state and y}
    begin
                   {compute input at time Plottime}
      case Inputtype of
        'S' : Uinput := Amplitude;
        'R' : Uinput := Plottime * slope + offset;
        'I' : if plottime = 0 then Uinput := amplitude
                               else Uinput := 0.0;
        'W' : Uinput := Amplitude * sin(freq * plottime);

      end; {case}
      Matrix_Vector_Mult(Phi,Xold,XNext,CNpoles);
                           {compute new states}
      for i:= 1 to CNpoles do
        Xnext[i]:= Xnext[i] + Gamma[i]*Uinput;
      y:= 0.0;
      for i:= 1 to CNPoles do
      begin
        if abs(y) < 1.0E07 then y:= y + C1[i] * Xnext[i]
                    else y:= 1.0E07;  {max y limit}
      end;
      if SizeZero = CNPoles then
          y := y +  NumCoeff[SizeZero+1] * Uinput;
      if y > Ymax then Ymax:= y;
      if y < Ymin then Ymin:= y;
      if N mod 5 = 0 then  {plot every 5th point}
      begin
        GraphArray[Plotindex,1] := Plottime;
        GraphArray[Plotindex,2] := y;
        InputArray[Plotindex,1] := Plottime;
        InputArray[Plotindex,2] := Uinput;
        Plotindex := Plotindex + 1;
      end;
      Plottime := Plottime + T; Xold := Xnext;
    end;
    Ymax := 1.1 * Ymax;

    Initgraphic;

    SelectWindow(1);

    drawtext(20,20,1,'O');
    drawtext(20,26,1,'U');
    drawtext(20,32,1,'T');
    drawtext(20,38,1,'P');
    drawtext(20,44,1,'U');
    drawtext(20,50,1,'T');

    drawtext(250,195,1,'TIME(sec)');

    NiceAxes(0,tmax,ymin,ymax,'');
    Selectworld(WorldNdxGlb); SelectWindow(WindowNdxGlb);

    DrawPolygon(GraphArray,1,-(Plotindex-1),0,0,0);
    NiceAxes(0,tmax,ymin,ymax,'');
    SetLineStyle(1);  {dashed line for input signal}
    DrawPolygon(InputArray,1,-(Plotindex-1),0,0,0);
    SetLineStyle(0);
```

```
    repeat until keypressed;
    quit := false;
    repeat
      Graph_Menu('Time-Response',DumpGraph,quit);
                            (calls print/title menu)
      If DumpGraph then  PrintGraphData;
    until quit;
    LeaveGraphic;

    assign(plotfile,'plot.com');
            (re-execution graphics menu program )
    execute(plotfile);
end.
```

```pascal
Program Nyquist;
label 1; {label decleration for goto statement}

{$I Typedef.sys}   {graphics routines}
{$I Graphix.sys}
{$I Kernel.sys}
{$I Windows.sys}
{$I Polygon.hgh}
{$I Axis.hgh}

{$I Ut-mod01.inc }   {I/O routines}
{$I Ut-mod02.inc }
{$I Ut-mod03.inc }

{$I GrapMenu.inc}    {graph options menu}
{$I Plotnyqs.inc}    {Nyquist plotting routine}
{$I Boxuser.inc}

type
     ary4  = array [1..11] of real;
     ary6  = array [1..21] of integer;

{$I Polynom.inc}        {Polynomial routine}
{$I Rootfind.inc}       {Polynomial roots finder routine}


var
  Code,I,Count,NumberDecades,
  StartDecade,EndDecade,one           : integer;
  Wf,Wo,Wi,DeltaW,Gain                : Real;
  PlotArray1,PlotArray2,
  MagPhaseArray,FreqArray             : PlotArray;
  ZMagn,ZPhase,PMagn,PPhase,Phase     : real;
  TempX,TempY                         : real;
  temp                                : char;
  OpenLoop, PicBig                    : boolean;
  j,jj,kk1,m,l,sizezeros,CNpoles      : integer;
  Dencoeff,Numcoeff,cdencoeff         : ary4;
  realpartpole,imagpartpole,realpartzero,
  crealpartpole,imagpartzero,cimagpartpole: ary3s;
  PSI                                 : ary1s;
  plotfile                            :file;

function Log(X:real):real;
            {computes the base-10 logarithm of X}
Begin
   If X=0 then Log:=0 else
   Log := Ln(X)/Ln(10);
End;

function Expon(Y,X:real):real;
               {computes Y raised to X power}
Begin
   Expon := exp( X * (ln(Y)));
end;

begin
   Boxuser; one:=1;
   Characteristic equation(A1A,size,Dencoeff);
   for i:=1 to size do
     PSI[i,size]:=B[i,1];
   for jj:=2 to size do
   begin
     for i:=1 to size do
     begin
       j:=size-jj+1;
       kk1:=j+1;
       PSI[i,j]:=Dencoeff[kk1] * B[i,1];
```

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```
          for l:=1 to size do
          begin
              PSI[i,j]:=PSI[i,j] +A1A[i,l] * PSI[l,kk1];
          end;
       end;
    end;
    for i:=1 to size do
    begin
       Numcoeff[i]:=0.0;
       for j:=1 to size do
       begin
          Numcoeff[i]:= Numcoeff[i] + PSI[j,i] * C[1,j];
       end;
    end;
    for i:=1 to size do
    begin
       m:=size+1-i;
       if Numcoeff[m] <> 0.0 then goto 1;
    end;
    1:sizezeros:=m-1;
    Clrscr;
    TextColor(lightblue);
    writeln('         *** Nyquist  Plotting Parameters
              ***');TextColor(yellow);

writeln('=========================================');
    PicBig:= false;

    Msg('Open (O) or (C) Closed Loop Plot ?',5,5);

    repeat
        Input('A',' ',45,5,2,true,F1,F10);
        temp:=copy(answer,1,1);
        if not(temp in ['O','C']) then Beep(950,350);
    until temp in ['O','C'];
    if temp = 'O' then OpenLoop := true
                  else OpenLoop := false;

    Msg('Graph window  (B) Big or (S) Select your own
                          size?',5,7);
    repeat
        input('A','',60,7,2,true,F1,F10);
{sets flag OpenLoop if user selects the open loop}
        temp := copy(answer,1,1);
        if not(temp in ['B','S']) then beep(350,150);
    until temp in ['B','S'];
    if (temp = 'B' )   then PicBig := true
                  else PicBig := false;

    if not (picbig) then
    begin
       Msg('Input your  first frequency to be
                     plotted?',5,9);
       Msg('(example:  .01, 1, 100, etc.)',10,10);
       Input('N','',50,9,8,true,F1,F10);
       Val(answer,Wo,code);{Wo is the first plotted freq}

       Msg('Input number of decades do you want
                       plotted?',5,12);

       Input('N','',50,12,2,true,F1,F10);
       Val(answer,NumberDecades,code);
    end
    else
    begin
       wo:=0.001;
       NumberDecades:=8;
    end;
```

```
   root_finder(sizezeros,Numcoeff,realpartzero,
              imagpartzero,one);
   root_finder(size,Dencoeff,realpartpole,
           imagpartpole,one);

   gain:=Numcoeff[sizezeros+1];
   for i:=1 to sizezeros+1 do
   begin
       Numcoeff[i]:= Numcoeff[i]/gain;
   end;
   clrscr;Boxuser;

   for i:=1 to maxorder do CDenCoeff[i] := 0.0;
         {initialize}
   for i:=1 to SizeZeros + 1 do
     CDenCoeff[i] := Numcoeff[i] * gain;
       {C.L. denominator equals the sum of open loop
        denominator and O.L numerator}

   for i:=1 to Size + 1 do
         CDenCoeff[i] := CDenCoeff[i] +Dencoeff[i];

   if Size > SizeZeros then Cnpoles:=Size

                      else CNPOLES:=SizeZeros;

                      {compute new denominator roots}
   root_finder(Cnpoles,CDenCoeff,CRealPartPole,
           CImagPartPole,one);

   StartDecade := trunc(Log(Wo));
                    {compute linear scale to plot }
   EndDecade := StartDecade + NumberDecades;
                    {log numbers. Also figure step}
   Wf := Wo * Expon(10.0,NumberDecades);
   DeltaW := Expon((Wf/Wo),0.0125);
   Wi := Wo;

   for Count := 1 to 81 do
                   {do 81 iterations...arbitrary #}
   Begin
     if OpenLoop then
   {compute bode numbers if openloop and later if
    closed loop }

     begin
       ZMagn:=1.0; ZPhase:=0.0;
       PMagn:=1.0; PPhase:=0.0;  {initialize}
       for i := 1 to SizeZeros do
     {compute magn and phase of zeros for freq step}
       begin
         ZMagn:=ZMagn * Sqrt(Sqr(RealPartZero[I])+
                      Sqr(Wi-ImagPartZero[I]));
         if RealPartZero[I] = 0.0 then
                    ZPhase:=ZPhase+pi/2.0 else
         begin
            if realpartzero[i] > 0.0 then
              ZPhase:= ZPhase - pi + ArcTan((Wi-
                  ImagPartZero[i])/(-RealPartZero[i]))

            else
               ZPhase:=ZPhase+ ArcTan((Wi-
                  ImagPartZero[i])/(-RealPartZero[i]));
         end;
       end;

       for i := 1 to Size do
         {compute magn and phase of poles for freq step}
```

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```
    begin
      PMagn:=PMagn * Sqrt(Sqr(RealPartPole[I])+
                          Sqr(Wi-ImagPartPole[I]));
      if RealPartPole[i] = 0.0 then
        PPhase:= PPhase+pi/2.0 else
      begin
        if RealPartPole[i] > 0.0 then
          PPhase:=PPhase - pi + ArcTan((Wi-
            ImagPartPole[i])/(-RealPartPole[I]))
        else
          PPhase:= PPhase+ArcTan((Wi-
            ImagPartPole[i])/(-RealPartPole[i]));
      end;
    end;

    Phase := Frac((ZPhase - PPhase)/(2*pi)) * (2*pi);

                                {Phase "modulo" 2Pi}
    TempX := abs((Gain*ZMagn/PMagn)*cos(Phase));
    TempY := abs((Gain*ZMagn/PMagn)*sin(Phase));
    if (PicBig) and (TempX > 100) then TempX := 100;
    if (PicBig) and (TempY > 100) then TempY := 100;

    If Phase<0 then Phase:= Phase+(2*pi);
    If ((Phase>(pi/2)) and (Phase<(3*pi/2))) then
                           TempX:= -TempX;
    If ((Phase>pi) and (Phase<(2*pi))) then
                           TempY := -TempY;
    MagPhaseArray[count,2] := Phase;
    MagPhaseArray[count,1]   := Gain*ZMagn/Pmagn;
    PlotArray1[Count,1] := TempX;
    PlotArray2[count,1] := TempX;

    PlotArray1[Count,2] := TempY;
    PlotArray2[count,2] := -TempY;

    FreqArray[Count,1] := wi;

    Wi := Wi * DeltaW;              {increment freq step}
  end

    else
{perform same steps as above if closed loop requested}

    begin
      ZMagn:=1.0;ZPhase:=0.0;PMagn:=1.0;PPhase:=0.0;
      for i := 1 to SizeZeros do
      begin
        ZMagn:=ZMagn * Sqrt(Sqr(RealPartZero[I])+
                          Sqr(Wi-ImagPartZero[I]));
        if RealPartZero[I] = 0.0 then
          ZPhase:=ZPhase+pi/2.0 else
        begin
          if RealPartZero[I] > 0.0 then
            ZPhase:=ZPhase - pi + ArcTan((Wi-
              ImagPartZero[i])/(-RealPartZero[i]))
          else
            ZPhase:=ZPhase+ArcTan((Wi-
              ImagPartZero[i])/(-RealPartZero[i]));
        end;
      end;

      for i := 1 to CNpoles do
      begin
        PMagn:=PMagn * Sqrt(Sqr(CRealPartPole[I])+
                          Sqr(Wi-CImagPartPole[I]));
        if CRealPartPole[I] = 0.0 then
            PPhase:=PPhase+pi/2.0   else
```

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```pascal
      begin
        if CRealPartPole[I] > 0.0 then
            PPhase:=PPhase -  pi + ArcTan((Wi-
    CImagPartPole[i]))/(-CRealPartPole[i]))
          else
            PPhase:=PPhase+ArcTan((Wi-
              CImagPartPole[i]))/(-CRealPartPole[i]));

      end;
    end;

    Phase := Frac((ZPhase - PPhase)/(2*pi)) * (2*pi);

                          {Phase "modulo" 2Pi}
    TempX := abs((Gain*ZMagn/PMagn)*cos(Phase));
    TempY := abs((Gain*ZMagn/PMagn)*sin(Phase));
    if (PicBig) and (TempX > 100) then TempX := 100;
    if (PicBig) and (TempY > 100) then TempY := 100;

    If Phase<0 then Phase:= Phase+(2*pi);
    If ((Phase>(pi/2)) and (Phase<(3*pi/2))) then
                            TempX:= -TempY;
    If ((Phase>pi) and (Phase<2*pi)) then
                            TempY := -TempY;

    PlotArray1[Count,1] := TempX;
    Plotarray2[count,1] := TempX;

    PlotArray1[Count,2] := TempY;
    PlotArray2[count,2] := -1.0 * TempY;

    Wi := Wi * DeltaW;
  end;
  Plot_Nyquist(StartDecade,EndDecade,
          NumberDecades,FreqArray,PlotArray1,
      Plotarray2,MagPhaseArray,PicBig,OpenLoop) ;

  Assign(Plotfile,'Plot.COM');
  Execute(plotfile);
end. {Nyquist}
```

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```
Program Root_Locus;
{ This program plots the root locus of the plant }
label 1;{label declerations for the goto statement}

{$I Typedef.sys}    {graphics routines}
{$I Graphix.sys}
{$I Kernel.sys}
{$I Windows.sys}
{$I Polygon.hgh}
{$I Axis.hgh}

{$I Ut-mod01.inc }   {I/O routines}
{$I Ut-mod02.inc}
{$I Ut-mod03.inc }

{$I GrapMenu.inc}    {graph options menu}

type
    ary4   = array [1..11] of real;
    ary6   = array [1..21] of integer;
Var
     I,J,code,LineCount                      : integer;
     PlotPole,PlotZero                       : PlotArray;

     PlotRealPole,PlotImagPole               : ary3s;
     DeltaGain,StartGain,EndGain,
     Variable_Gain,Xmin,Xmax,Ymin,Ymax,gain: Real;
     Neg_Feedback,dumpgraph,quit             : Boolean;

     list                                    : text;
     jj,kk1,m,l,sizezeros,one                : integer;
     holdpoly,dencoeff,numcoeff              : ary4;
     realpartpole,imagpartpole,realpartzero,
     imagpartzero                            : ary3s;
     PSI                                     : ary1s;
     plotfile                                : file;

{$I Polynom.inc}
{$I Rootfind.inc}


Procedure PrintGraphData;
         {dumps root locus data to printer}
Begin
  LeaveGraphic; Clrscr;
  repeat
    Textcolor(white);
    gotoxy(20,10);
    writeln('   *** PROGRAM OUTPUT OPTIONS ***   ');
    gotoxy(20,13);
    writeln('<P> Printer output                 ');
    Textcolor(yellow); gotoxy(20,14);
    writeln('       Check Your Printer!         ');
    Textcolor(white); gotoxy(20,15);
    writeln('<F> List to File name              ');
    gotoxy(20,16);
    writeln('        on the current drive       ');
    gotoxy(20,17);
    writeln('<Q> Quit                           ');
    gotoxy(42,15);textcolor(yellow);
    write('"RLOCI.RES"'); gotoxy(28,17);
    read(kbd,ch);
      If (ch = 'F') or (ch = 'f') or (ch = 'P') or
                                    (ch = 'p') then
      begin
        if (ch = 'F') or (ch = 'f') then
        begin
```

```
      gotoxy(24,15);textcolor(red);
      write('PRINTING.....                          ');
      assign(list,'Rloci.RES');
      rewrite(list);
   end
   else
   begin
      gotoxy(24,13);textcolor(red);
      write('PRINTING...;.......                     ');
      assign(list,'LST:');
      rewrite(list);
   end;

   LineCount := 0;
   writeln(list);
   writeln(list,'   ZEROS ');
   writeln(list);
   write(list,'                          ');
   writeln(list,'        REAL
            IMAGINARY');
   writeln(list);    LineCount := LineCount + 6;

   for i := 1 to sizeZeros do
   begin
      writeln(list,'                ',RealPartZero[i]:10:3,
                   '        ',ImagPartZero[i]:10:3);

   LineCount := LineCount + 1;
   end;
   writeln(list); writeln(list);
   writeln(list,'   POLES');
   writeln(list);
   write(list,'     GAIN                  ');
   writeln(list,'        REAL
            IMAGINARY');
   writeln(list); LineCount := LineCount + 7;
   Variable_Gain := StartGain;

   {compute root locations for varying values of
      gain and print them}

   DeltaGain := (EndGain-StartGain)/50;
   For J:= 1 to 50 do
   Begin
      HoldPoly := dencoeff;

      If Neg_Feedback then
      For I:= 1 to sizeZeros+1 do
         HoldPoly[I] := HoldPoly[I] +
            (gain*Variable_Gain * numcoeff[I])
      else
      For I:= 1 to sizeZeros +1 do
         HoldPoly[I] := HoldPoly[I] +( gain *
                   Variable_Gain * numcoeff[I]);

    Root_Finder(size,HoldPoly,PlotRealPole,
                PlotImagPole,one);
      writeln(list,Variable_Gain:10:4);
      LineCount := LineCount + 1;
      for i := 1 to size do
      begin
         writeln(list,'                ',i:2,'        ',
                   PlotRealPole[i]:10:3,
         '            ',PlotImagPole[i]:10:3);
      LineCount := LineCount + 1;
      end;
      writeln(list);LineCount := LineCount + 1;
      if LineCount > 50 then
```

```
        begin
           writeln(list, chr(12));
           LineCount := 0;
        end;
        variable_gain:=variable_gain+deltaGain;
     end;
   end;
  until ch in ['Q','q'];
  EnterGraphic;
  swapscreen;
  close(list);
end;


Begin
  one:=1;{Root Locus Input handler driver}
  P[1] := '5506N01001-010101';
  P[2] := '5508N01002-010103';
  P[3] := '1512N00503-010101';
  P[4] := '1513N00504-010103';
  P[5] := '1514N00505-010101';
  P[6] := '1515N00506-010103';
  P[7] := '4517A00207T010101';

  Clrscr; TextColor(lightblue);
  writeln(' *** ROOT LOCUS PLOTTING PARAMETERS ***');
  TextColor(Yellow);
  writeln('=========================================');
  writeln;writeln;writeln;
  TextColor(green);
  writeln('Input STARTING value for the variable
           gain:');
  writeln;
  writeln('Input ENDING value for the variable
           gain:');
  TextColor(yellow);
  writeln; writeln;

  writeln; TextColor(green);
  writeln('X-Minimum: ');
  writeln('X-Maximum: ');
  writeln('Y-Minimum: ');
  writeln('Y-Maximum: '); writeln;
  writeln('Positive or Negative Feedback? (P or N):');

  Input_Handler('N0107',Escape);
                          {prompts for NEW inputs}
  writeln;writeln;
  writeln('Any changes to these parameters?
                          (Y or N):');
  Input('A','',45,19,2,true,F1,F10);
  If answer='Y' then  Input_Handler('C0107',Escape);
                  {prompts for changes}

  Val(filvar[1],StartGain,code);
        {converts input strings into numeric values}
  Val(filvar[2],EndGain,code);
  Val(filvar[3],Xmin,code);
  Val(filvar[4],Xmax,code);
  Val(filvar[5],Ymin,code);
  Val(filvar[6],Ymax,code);

  If copy(filvar[7],1,1) <> 'N' then
                    Neg_feedback := false
                else Neg_feedback := true;

  INITGRAPHIC;{define values for graphics routine}
  NICEAXES(xmin,xmax,ymin,ymax,'');
```

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```pascal
    Characteristic_equation(A1A,size,dencoeff);
    {calculate dencoeff from the plant matrices}
    for i:=1 to size do
    {calculate numcoeff from the given plant matrices}
    begin
      PSI[i,size]:=B[i,1];
    end;
    for jj:=2 to size do
    begin
      for i:=1 to size do
      begin
        j:=size-jj+1;
        kk1:=j+1;
        PSI[i,j]:=dencoeff[kk1] * B[i,1];
        for l:=1 to size do
        begin
          PSI[i,j]:=PSI[i,j] +A1A[i,l] * PSI[l,kk1];
        end;
      end;
    end;
    for i:=1 to size do
    begin
      numcoeff[i]:=0.0;
      for j:=1 to size do
      begin
        numcoeff[i]:=numcoeff[i] + PSI[j,i] * C[1,j];
      end;
    end;
    for i:=1 to size do
    begin
      m:=size+1-i;
      if numcoeff[m] <> 0.0 then goto 1;
    end;
    1:sizezeros:=m-1;
            {calculate the zeros of the system}
    root_finder(sizezeros,numcoeff,realpartzero,
                imagpartzero,one);

    gain:=numcoeff[sizezeros+1];
    {convert highest degree numerator coefficient into 1.}

    for i:=1 to sizezeros+1 do
        numcoeff[i]:=numcoeff[i]/gain;

    For I:=1 to sizeZeros do
    Begin
      PlotZero[I,1] := RealPartZero[I];
      PlotZero[I,2] := ImagPartZero[I];
    end; {for}
    Case sizeZeros of
            0 : ;
            1 : begin
                  PlotZero[2,1]:=PlotZero[1,1];
                  PlotZero[2,2]:=PlotZero[1,2];
                  PlotZero[3,1]:=PlotZero[1,1];
                  PlotZero[3,2]:=PlotZero[1,2];
                  NICEAXES(xmin,xmax,ymin,ymax,'');
                  DrawPolygon(PlotZero,1,-3,-3,3,0);
                end;
            2: begin
                  PlotZero[3,1]:=PlotZero[1,1];
                  PlotZero[3,2]:=PlotZero[1,2];
                  NICEAXES(xmin,xmax,ymin,ymax,'');
                  DrawPolygon(PlotZero,1,-3,-3,3,0);
                end;
            else
              NICEAXES(xmin,xmax,ymin,ymax,'');
              DrawPolygon(PlotZero,1,sizeZeros,-3,3,0);
```

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```
  end; {case}
  Variable_Gain := StartGain;
  DeltaGain := (EndGain-StartGain)/50;
      {divide gain to plot 50 points}

  For J:= 1 to 50 do
      {calculate and plot 50 points per graph}
  Begin
    HoldPoly := dencoeff;

    If Neg_Feedback then
    For I:= 1 to SizeZeros+1 do
      HoldPoly[I] := HoldPoly[I] +
            (gain*Variable_Gain * numcoeff[I])

    else
    For I:= 1 to SizeZeros +1 do
      HoldPoly[I] := HoldPoly[I] +
            (Gain *Variable_Gain * numcoeff[I]);

    Root_Finder(size,HoldPoly,PlotRealPole,
            PlotImagPole,one);

    For I:=1 to size do
          {fill plotting matrix with poles}
    Begin
      PlotPole[I,1] := PlotRealPole[I];
      PlotPole[I,2] := PlotImagPole[I];
    end;
    AxisGlb := true;
    Case size of
        {artificially fill plotting array if fewer
         than 3 points}
      0 : ;
      1 : begin
            PlotPole[2,1]:=PlotPole[1,1];
            PlotPole[2,2]:=PlotPole[1,2];
            PlotPole[3,1]:=PlotPole[1,1];
            PlotPole[3,2]:=PlotPole[1,2];
            NICEAXES(xmin,xmax,ymin,ymax,'');
            DrawPolygon(PlotPole,1,-3,-1,3,0);
          end;
      2:  begin
            PlotPole[3,1]:=PlotPole[1,1];
            PlotPole[3,2]:=PlotPole[1,2];
            NICEAXES(xmin,xmax,ymin,ymax,'');
            DrawPolygon(PlotPole,1,-3,-1,3,0);
          end;
          else
          NICEAXES(xmin,xmax,ymin,ymax,'');
          DrawPolygon(PlotPole,1,size,-1,3,0);
    end; {case}
    variable_gain:=variable_gain + Deltagain;
  end;

  Repeat until KeyPressed;
   quit := false;
  repeat
    Graph_Menu('Root Locus',DumpGraph,quit);
              {calls print/title menu}
    If DumpGraph then  PrintGraphData;
  until quit;
  LeaveGraphic;
  Assign(plotfile,'plot.com'); {re-execute plot.com}
  Execute(plotfile);
end. {root_locus}
```

```
Program Roots;
label 1; {label decleration for goto statement}
{$I Typedef.sys}

TYPE
    ary4 = array [1..11] of real;
    ary6 = array [1..21] of integer;
var
  posCounter,i,j,jj,kk1,m,l,
  cnpoles,sizezeros,one: integer;
  dencoeff,numcoeff,cdencoeff: ary4;
  realpartzero,imagpartzero,
  crealpartpole,cimagpartpole : ary3s;
  PSI                         : ary1s;
  plotfile   :file;
  gain       :real;

{$I Polynom.inc}
{$I Rootfind.inc}

BEGIN
  ClrScr; one:=1;
  Characteristic_equation(A1A,size,Dencoeff);
  for i:=1 to size do
    PSI[i,size]:=B[i,1];

  for jj:=2 to size do
  begin
    for i:=1 to size do
    begin
      j:=size-jj+1;
      kk1:=j+1;
      PSI[i,j]:=Dencoeff[kk1] * B[i,1];
      for l:=1 to size do
      begin
        PSI[i,j]:=PSI[i,j] +A1A[i,l] * PSI[l,kk1];
      end;
    end;
  end;
  for i:=1 to size do
  begin
    Numcoeff[i]:=0.0;
    for j:=1 to size do
    begin
      Numcoeff[i]:=Numcoeff[i] + PSI[j,i] * C[1,j];
    end;
  end;
  for i:=1 to size do
  begin
    m:=size+1-i;
    if numcoeff[m] <> 0.0 then goto 1;
  end;
1:sizezeros:=m-1;

  root_finder(sizezeros,Numcoeff,realpartzero,
              imagpartzero,one);

  gain:= Numcoeff[sizezeros+1];
  for i:=1 to sizezeros+1 do
  begin
    Numcoeff[i]:= Numcoeff[i]/gain;
  end;

  for i:=1 to maxorder do
      CDenCoeff[i] := 0.0;    {initialize}
  for i:=1 to SizeZeros + 1 do
      CDenCoeff[i] := Numcoeff[i] * gain;
```

```
  for i:=1 to Size + 1 do
     CDenCoeff[i] := CDenCoeff[i] + Dencoeff[i];

  if Size > SizeZeros then CNPOLES:=Size
  {NPoles should always be greater}
                  else CNPOLES:=SizeZeros;

                  {compute new denominator roots}
  root_finder(Cnpoles,CDenCoeff,CRealPartPole,
          CImagPartPole,one);

  ClrScr; textcolor(lightblue);{on-screen titles}
  writeln('      *** Plant Characteristic Equation
         Roots ***');
  writeln; writeln;highvideo;
  writeln('ROOTS OF THE NUMERATOR: ');

  For I:=1 to SizeZeros do {position for output}
  begin
     PosCounter := (I mod 2) ;
     If PosCounter = 1 then writeln;

     LowVideo;   {write zeros }
     write('s[',I,'] = ',RealPartZero[I]:10:3,
          ' +j ',ImagPartZero[I]:10:3);
     write('            ');
  end;

  writeln; writeln; HighVideo;
  writeln('ROOTS OF THE DENOMINATOR: ');


  For I:=1 to CNPoles do
  begin          {compute on-screen position}
     PosCounter := (I mod 2) ;
     If PosCounter = 1 then writeln;

     LowVideo;
                            {output roots}
     write('s[',I,'] = ',CRealPARTPOLE[I]:10:3,
          ' +j ',CImagPARTPOLE[I]:10:3);
     write('            ');
  end;{for}

  HighVideo;gotoxy(1,24);
  write('Press any key to continue or [Shift] [PrtSc]
        for hardcopy.');

  {check keyboard buffer for value change.
   If number changes by 1 or 2 indicates that shift key
   depressed.  If so, then remove "Press any key.."
   prompt from screen so it won't print to printer}

  keyold := mem[0000:1047]; not_erased := true;
  Repeat
     key := mem[0000:1047];
     if ((key=keyold + 1) or (key=keyold + 2)) and
        (not_erased) then
        begin
          GotoXY(1,24); write(' ':80);
          not_erased := false;
        end;
  Until KeyPressed;

  Assign(plotfile,'Plot.com');
  Execute(plotfile);

end. {Program Roots}
```

```pascal
Program Matrix_Manipulation(input,output);

{$I Typedef.SYS}
{$I Box.INC}
{$I Ut-mod01.INC}

var
    help3file,inversefile,determinfile,
    Polynomfile,eigenfile                    :file;

Procedure Matrix_mathematics_menu;

var
    i,Tab           : Integer;
    Okchoice        : Set Of Char ;
    Finished        : Boolean;

Procedure MenuItem(Pick:Char;Description :Str80;
                   Color:Integer);

Begin
  TextColor(color);
  Write (' ':tab,'('); TextColor(white); Write(pick);
  TextColor(color); Writeln(')',Description);
End;

Begin
  ClrScr; TextColor(white); Finished := False;
  GoToXY(19,4);
  Write('*** MATRIX MATHEMATICS MENU ***');
  for i := 1 to 4 do writeln(' ');
  Tab := 16;
  MenuItem('D','Determinant of A Matrix',yellow);
  MenuItem('C','Characteristic polynomial of A
                Matrix',yellow);
  MenuItem('I','Inverse of A Matrix',yellow);
  MenuItem('E','Eigenvalues of A Matrix',yellow);
  Writeln;
  Writeln;
  MenuItem('H','Help',lightmagenta);
  MenuItem('Q','Quit to SVS Main menu ',lightmagenta);
  TextColor(green);
  Box; Writeln;
  TextColor(white); GoToXY (40,22);
  Repeat
    Option;
  until ch in ['D','C','I','E','H','Q'];
  case ch of
    'D': begin
             Assign(determinfile,'determin.chn');
             Chain(determinfile);
         end;
    'I': begin
             Assign(inversefile,'inverse.chn');
             Chain(inversefile);
         end;
    'C': begin
             Assign(Polynomfile,'Polynom.chn');
             Chain(Polynomfile);
         end;
    'E': begin
             Assign(eigenfile,'eigen.chn');
             Chain(eigenfile);
         end;
    'H': begin
             Assign(help3File,'help3.CHN');
             Chain(help3File);
         end;
```

```pascal
      'Q': begin
             Assign(SvsFile,'svs.COM');
             Execute(SvsFile);
           end;
   End; {case}
End;

Begin {main program}
   Clrscr;
   Repeat
     begin
       Matrix_Mathematics_Menu;
     end;
   Until Finished = True;
End.{main program}
```

```pascal
Program Matrix_Determinant(input,output);
label 10;label 20;label 30;label 40;label 50;label 60;
label 70;label 80;

{$I Typedef.SYS}
{$I Ut-mod01.INC}
{$I Boxuser.INC}

var
    matrixfile :file;
    list        :text;
    counter,i,j,ii,k,m,n,even              :integer;
    temp_value,value,det,det_correction,
    determinant_old,determinant            :real;
    A1                                     :ary1s;
Begin
  counter := 0;
  Boxuser;
  for i:=1 to size do
  Begin
    for j:=1 to size do
    Begin
      A1[i,j]:= A1A[i,j];
    End;
  End;
  for i:= 1 to size do
  Begin
    k:=i;
    30:if A1[k,i] <> 0.0 then goto 10;
    k:=k+1;
    if (k-size) <= 0.0 then goto 30;
    goto 40;
    10:if (i-k) > 0.0 then goto 40;
    if (i-k) = 0.0 then goto 70;
    for m:=1 to size do
    Begin
      temp_value:=A1[i,m];
      A1[i,m]:=A1[k,m];
      A1[k,m]:=temp_value;
    End;
    counter:= counter+1;
    70:ii:=i+1;
    if ii > size  then goto 20;
    for m:=ii to size do
    Begin
      if A1[m,i] = 0.0 then goto 80;
      value:=A1[m,i] / A1[i,i];
      for n:= i to size do
      Begin
        A1[m,n]:= A1[m,n] - A1[i,n] * value;
      End;
    80:End;
  20:End;
  det:=1.0;
  for i:=1 to size do
  Begin
    det:=det * A1[i,i];
  End;
  det_correction:= exp( counter * LN(1));
  determinant_old:=det_correction * det;
  even:= counter mod 2;
  if even <> 0 then goto 60;
  determinant := determinant_old;
  goto 50;
  60:determinant:=-determinant_old;
  goto 50;
  40:determinant:=0.0;
  50:clrscr;writeln;TextColor(yellow);
```

```pascal
  Writeln('The given matrix is : '); writeln;

  for i:= 1 to size do
  Begin
    for j:= 1 to size do
    Begin
      Write('   ',A1A[i,j]:11);
    End;Writeln;
  End;Writeln;Writeln;
  Write('The determinant value is :');
  TextColor(white);writeln(determinant);

  keyread(key,keyold,not_erased);

  Repeat
    box_printer;gotoxy(58,15);textcolor(yellow);
    writeln('"DETERMIN.RES"');
    gotoxy(1,25);write('                              ');
    gotoxy(49,17);
    read(kbd,ch);
    if (ch='F') or (ch='f') or (ch='P') or (ch='p')
      then begin
      if (ch='F') or (ch='f') then
      begin
            gotoxy(45,15);textcolor(red);
        write('PRINTING.........          ');
        Assign(list,'Determin.RES');
        Rewrite(list);
      end;
      if (ch='P') or (ch='p') then
      begin
            gotoxy(45,13);textcolor(red);
        write('PRINTING.........          ');
        Assign(list,'LST:');
        Rewrite(list);
      end;
      writeln(list,'                            DETERMINANT
              RESULT   ');
      writeln(list);
      writeln(list,'The given matrix is:');
      writeln(list);
      for i:=1 to size do
      begin
        for j:=1 to size do
        begin
          write(list,'   ',A1A[i,j]:11);
        end;writeln(list);
      end;writeln(list);writeln(list);
      Write(list,'The determinant value is : ');
      writeln(list,determinant);
      writeln(list);writeln(list);
      close(list);
    end;
  Until ch in ['Q','q'];

  Assign(matrixfile,'matrix.com');
  Execute(matrixfile);

End.
```

```
Program Matrix inverse(input,output);
{$I Typedef.SYS}
{$I Ut-mod01.INC}
{$I Boxuser.inc}
type
     ary4    = array [1..11] of real;
     ary6    = array [1..21] of integer;
var
    matrixfile :file;
    list       :text;
    polynom_coeff      :ary4;
    Ainverse           :ary1s;
    singular,step,stepper :integer;

{$I Polynom.inc}
{$I Inverse.inc}

begin
    clrscr; Boxuser; singular:=0;
    characteristic_equation(A1A,size,Polynom_coeff);

inverse_find_matrix(A1A,polynom_coeff,size,Ainverse,
                    polynom_coeff,singular);
    clrscr;textcolor(yellow);
    writeln('The given matrix is: '); writeln;
    for step:=1 to size do
    begin
      for stepper:=1 to size do
      begin
        write('   ',A1A[step,stepper]:11);
      end;writeln;
    end;writeln;
    if singular=1 then
      writeln('The matrix is singular.')

    else

    begin
      writeln('The inverted matrix is:');writeln;
      for step:=1 to size do
      begin
        for stepper:=1 to size do
        begin
          write('   ',Ainverse[step,stepper]:10,'   ');
        end;writeln;
      end;
    end;

    keyread(key,keyold,not_erased);

    Repeat
      box_printer;gotoxy(58,15);textcolor(yellow);
      writeln('"INVERSE.RES"'); gotoxy(1,25);
      write('                                    ');
      gotoxy(49,17);
      read(kbd,ch);
      if (ch='F') or (ch='f') or (ch='P') or (ch='p')
        then begin
        if (ch='F') or (ch='f') then
        begin
          gotoxy(45,15);textcolor(red);
          write('PRINTING..........            ');
          Assign(list,'Inverse.RES');
          Rewrite(list);
        end;

        if (ch='P') or (ch='p') then
        begin
```

```
        gotoxy(45,13);textcolor(red);
        write('PRINTING...;...          ');
        Assign(list,'LST:');
        Rewrite(list);
      end;
      writeln(list,'                      MATRIX INVERSE
              RESULT    ');
      writeln(list);
      writeln(list,'The given matrix is:');
      writeln(list);
      for step:=1 to size do
      begin
        for stepper:=1 to size do
        begin
          write(list,'  ',A1A[step,stepper]:11);
        end;writeln(list);
      end;writeln(list);writeln(list);
      begin
        writeln(list,'The inverted matrix is:');
        writeln(list);
        for step:=1 to size do
        begin
          for stepper:=1 to size do
          begin
            write(list,' ',
                  Ainverse[step,stepper]:10,'  ');
          end;writeln(list);
        end;
      end;
      writeln(list);writeln(list);
      close(list);
    end;
  Until ch in ['Q','q'];

  Assign(matrixfile,'matrix.com');
  Execute(matrixfile);

end.
```

```
Program Matrix Manipulation(input,output);
{$I Typedef.SYS}
{$I Ut-mod01.INC}{$I Boxuser.inc}
type
      ary4    = array [1..11] of real;
      ary5    = array [1..21] of real;
      ary6    = array [1..21] of integer;

var
    matrixfile :file;
    list        :text;
    c2,C1       :ary4;
    RealPart,ImaginaryPart:ary3s;
    i,j,one        :integer;

{$I Polynom.inc}
{$I Rootfind.inc}

begin
  clrscr;Boxuser;one:=1;
  characteristic_equation(A1A,size,C1);

  root_Finder(size,C1,RealPart,ImaginaryPart,one);
  clrscr;Textcolor(yellow);
  writeln('The given matrix is:');writeln;
  for i:=1 to size do
  begin
    for j:=1 to size do
    begin
      write('  ',A1A[i,j]:11);
    end;writeln;
  end;writeln;writeln;
  writeln('The eigenvalues of the matrix are: ');
  writeln('                              REAL PART
                        IMAGINARY PART');
  for i:=1 to size do
  begin
    write('                                    ');
    write(RealPart[i]:3);
    write('         + j        ');
    write(ImaginaryPart[i]:3);writeln;
  end;

  keyread(key,keyold,not_erased);

  Repeat
    box_printer;gotoxy(58,15);textcolor(yellow);
    writeln('"EIGEN.RES"'); gotoxy(1,25);
    write('                              ');
    gotoxy(49,17);
    read(kbd,ch);
    if (ch='F') or (ch='f') or (ch='P') or (ch='p')
      then begin
      if (ch='F') or (ch='f') then
      begin
        gotoxy(45,15);textcolor(red);
        write('PRINTING.........      ');
        Assign(list,'Eigen.RES');
        Rewrite(list);
      end;
      if (ch='P') or (ch='p') then
      begin
        gotoxy(45,13);textcolor(red);
        write('PRINTING..;;....       ');
        Assign(list,'LST:');
        Rewrite(list);
      end;
```

```
      writeln(list,'                              EIGENVALUES
                    RESULT     ');
      writeln(list);
      writeln(list,'The given matrix is:');
      writeln(list);
      for i:=1 to size do
      begin
        for j:=1 to size do
        begin
          write(list,'   ',A1A[i,j]:11);
        end;writeln(list);
      end;writeln(list);writeln(list);
      writeln(list,'
                The eigenvalues of the matrix are: ');
      writeln(list,'                        REAL PART
                    IMAGINARY PART');
      for i:=1 to size do
      begin
        write(list,'                          ');
        write(list,RealPart[i]:10);
        write(list,'        + i        );
        write(list,ImaginaryPart[i]:10);
        writeln(list);
      end;
      writeln(list);writeln(list);
      close(list);
    end;
  Until ch in ['F','f','P','p','Q','q'];

  Assign(matrixfile,'matrix.com');
  Execute(matrixfile);

end.
```

```pascal
Program Matrix Characteristic_Equation(input,output);
{$I Typedef.SYS}
{$I Ut-mod01.INC}
{$I Boxuser.inc}
type
      ary4    = array [1..11] of real;
      ary6    = array [1..21] of integer;

var
    matrixfile :file;
    list        :text;
  C1                                          :ary4;
  i,j,vertpos,horizpos,poscounter   :integer;
  exponent                            :string[2];

{$I Polynom.inc}

begin
  clrscr;Boxuser;
  characteristic_equation(A1A,size,C1);clrscr;
  Textcolor(yellow);    writeln;
  writeln('The given matrix is : ');writeln;
  for i:=1 to size do
  begin
    for j:=1 to size do
    begin
      write('   ',A1A[i,j]:11);
    end;writeln;
  end;writeln;writeln;
  writeln('The characteristic polynomial of given
          matrix is: ');
  vertpos:=size+7;
  for i:=size+1 downto 1 do
  begin
    j:=size+1-i;
    poscounter:=(j mod 4) +1;horizpos:=poscounter * 14;

    if poscounter = 1 then vertpos:=vertpos+2;
    if i <> 1   then
    begin
      gotoXY(horizpos-10,vertpos);write(C1[i]:7:4);
      msg(' S +',horizpos,vertpos);
      str(i-1:2,exponent);
      msg(exponent,horizpos+1,vertpos-1);
    end
    else
    begin
      gotoXY(horizpos-10,vertpos);write(C1[i]:7:4);
    end;
  end;

  keyread(key,keyold,not_erased);

  Repeat
    box printer;gotoxy(58,15);textcolor(yellow);
    writeln('"POLYNOM.RES"');
    gotoxy(1,25);write('                                    ');
    gotoxy(49,17);
    read(kbd,ch);
    if (ch='F') or (ch='f') or (ch='P') or (ch='p')
        then  begin
      if (ch='F') or (ch='f') then
      begin
        gotoxy(45,15);textcolor(red);
        write('PRINTING.........          ');
        Assign(list,'Polynom.RES');
        Rewrite(list);
      end;
```

```
      if (ch='P') or (ch='p') then
      begin
        gotoxy(45,13);textcolor(red);
        write('PRINTING..;...            ');
        Assign(list,'LST:');
        Rewrite(list);
      end;
      writeln(list,'                        POLYNOMIAL
                   RESULT    ');
      writeln(list);
      writeln(list,'The given matrix is:');
      writeln(list);
      for i:=1 to size do
      begin
        for j:=1 to size do
        begin
          write(list,'   ',A1A[i,j]:11);
        end;writeln(list);
      end;writeln(list);writeln(list);
      write(list,'The characteristic polynomial of
                  given matrix is:');
      writeln(list,' ( Descending power of S ) ');
      writeln(list);
      for i:=size+1 downto 1 do
      begin
        write(list,C1[i]:7:4,'   ');
        str(i-1:2,exponent);
      end;
      writeln(list);writeln(list);
      close(list);
    end;
  Until ch in ['Q','q'];

  Assign(matrixfile,'matrix.com');
  Execute(matrixfile);

end.
```

```
Program Control(input,output);
{$I Typedef.SYS}
     {Program type and variable definitions}
{$I Ut-mod01.INC} {input utility programs}

type
     Ary1     = Array[1..11,1..11] of real;
var
     Stepping,Steps,step,steppings,
     Temp1,Temp2,value1,value2,m,mplus,
     last_rank,k,value1plus,kplus          :integer;
     new_matrix1,new_matrix2               :ary1s;
     big_matrix                            :ary1;
     list                                  :text;

{$I control.inc}  {finds controllability result}
{$I Boxuser.inc}
Begin
   value1 := 1; value1plus:= value1;
   ClrScr;Textcolor(yellow);
   Writeln('The A matrix is : ');writeln;
   For steps := 1 to size do
   Begin
     For stepping := 1 to size do
     Begin
        Write('   ',A1A[steps,stepping]:11);
     End; Writeln;
   End;writeln;writeln;
   Writeln('The B Matrix is : ');writeln;
   For steps := 1 to SIZE do
   Begin
     for stepping:=1 to ni do
     begin
        Write('   ',B[steps,stepping]:11);
     end;writeln;
   End;writeln;writeln;
   For steps:=1 to size do
   Begin
     For stepping :=1 to ni do
     Begin
       new_matrix2[steps,stepping] := B[steps,stepping];

       new_matrix1[steps,stepping] := B[steps,stepping];

     End;
   End; mplus:= size-1; value2:=value1;
   For steps := 1 to mplus do
   Begin
        matrix_multiplication(A1A,new_matrix1,
              new_matrix1,size,size,value2);
     step := value1 +1; value1 := value1 + value2;
     For k := 1 to size do
     Begin
       For stepping := step to value1 do
       Begin
         steppings := stepping-step+1;
         new_matrix2[k,stepping]:=
                       new_matrix1[k,steppings];
       End;
     End;
   End;
   For steps :=1 to size do
   Begin
     For stepping:=1 to value1 do
     Begin
        big_matrix[steps,stepping]   :=
new_matrix2[steps,stepping];
     End;
```

```
    End; mplus:=1;
    For steps :=1 to size do
    Begin
        Matrix_reduction(big matrix,mplus,size,last_rank);
        mplus := last_rank +1;
    End;
    If last rank = size then
    Writeln('The system is controllable. ');Writeln;
    If last_rank < size then
    Writeln('The system is uncontrollable.  ');Writeln;
    value1:=value1plus;
    KEYREAD(KEY,KEYOLD,NOT_ERASED);
    repeat
      box printer;gotoxy(58,15);textcolor(yellow);
      writeln('"CONTROL.RES"');
      gotoxy(1,25);write('                        ');
      gotoxy(49,17);
      Read(kbd,ch);
      If (ch='F') or (ch='f')  or (ch='p') or (ch='P')
      then  Begin
          If (ch='F') or (ch='f') then
          Begin
            gotoxy(45,15);Textcolor(red);
            writeln('PRINTING........            ');
            Assign(list,'control.RES');
            Rewrite(list);
          End;
          If (ch='P') or (ch='p') then
          Begin
            gotoxy(45,13);Textcolor(red);
            writeln('PRINTING.......                ');
            Assign(list,'LST:');
            Rewrite(list);
          End;
          Writeln(list, '              CONTROLLABILITY
                      RESULT       ');
          Writeln(list);
          Writeln(list,'The Plant matrix A is : ');
          writeln(list);
          For steps := 1 to size do
          Begin
            For stepping := 1 to size do
            Begin
              Write(list,'   ',A1A[steps,stepping]:11);
            End;Writeln(list);
          End;Writeln(list);Writeln(list);
          Writeln(list,'The input Matrix B is : ');
          writeln(list);
          For steps := 1 to SIZE do
          Begin
            For stepping := 1 to ni do
            Begin
              Write(list,'   ',B[steps,stepping]:11);
            End;writeln(list);
          End;Writeln(list);Writeln(list);
          If last rank = size then
          Writeln(list,'The system is controllable. ');
          Writeln;
          If last_rank < size then
          Writeln(list,'The system is uncontrollable. ');
          Writeln;
          writeln(list);writeln(list);
          Close(list);
      End;
    Until Ch in ['Q','q'];
    Assign(SvsFile,'svs.COM');
    Execute(SvsFile);
End.
```

```pascal
Program Observability(input,output);
label 1;label 2;label 3;label 4;

{$I Typedef.SYS}  {program type and definitions}

type
     Ary1    = Array[1..11,1..11] of real;

var
     stepping,steps,step,temp1,temp2,
     add_no,value2,last_rank               : integer;
     matrix                                : ary1s;
     matrix_matrix                         : ary1;
     list                                  : text;
{$I Boxuser.inc}
{$I Control.inc}
{$I Ut-mod01.inc}   {utility input routins}

Begin
  ClrScr; Textcolor(yellow);
  Writeln('The Plant matrix A is: ');writeln;
  For steps := 1 to size do
  Begin
    For stepping := 1 to size do
    Begin
      Write('   ',A1A[steps,stepping]:11);
    End;Writeln;
  End;Writeln;writeln;
  Writeln('The output Matrix C is : ');writeln;
  For stepping := 1 to no do
  begin
    for steps:=1 to size do
    begin
        Write('   ',C[stepping,steps]:11);
    end;writeln;
  end;
  writeln;writeln;
  add_no:=no; value2 :=1;
  For steps:= 1 to no do
  Begin
    For stepping:=1 to size do
    Begin
      matrix_matrix[steps,stepping] :=
                         C[steps,stepping];
      matrix[steps,stepping]:= C[steps,stepping];
    End;
  End;
  4:matrix_reduction(matrix_matrix,add_no,
                  size,last_rank);
          {calculate the rank of the matrix}
  If last_rank < size then GoTo 2;
  Writeln('The system is observable with index ',
                         value2,' .' );Writeln;
  KEYREAD(KEY,KEYOLD,NOT_ERASED);
  GoTo 1;
  2:If value2 < size then GoTo 3;
  Writeln ('The system is unobservable. ');
  KEYREAD(KEY,KEYOLD,NOT_ERASED);
  Writeln;GoTo 1;
  3:value2 := value2+1;
  matrix_multiplication(matrix,A1A,matrix,no,
                         size,size);
          {multiply the A and C matrices }
  For steps := 1 to no do
  Begin
    step:= last_rank + steps;
    for stepping:=1 to size do
    Begin
```

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```
      matrix_matrix[step,stepping] :=
                 matrix[steps,stepping];
     End;
  End;
  add_no := last_rank + no;
  GoTo 4;
  1:repeat
   Box_printer;gotoxy(58,15);Textcolor(yellow);
   writeln('"OBSER.RES"'); gotoxy(1,25);
   write('                                       ');
   gotoxy(49,17);
   Read(Kbd,ch);
   If (ch='P') or (ch='p') or (ch='F') or (ch='f')
   then Begin
     If (ch='F') or (ch='f') then
     Begin
       GotoXY(45,15);textcolor(red);
       writeln('PRINTING........;..              ');
       Assign(list,'obser.RES');
                 {print observability output }
       Rewrite(list);{to file on the current drive}
     End;
     If (ch='P') or (ch='p') then
     Begin
       gotoxy(45,13);textcolor(red);
       writeln('PRINTING.........              ');
       Assign(list,'LST:');
     {print observability result to the printer}
       Rewrite(list);
     End;
     Writeln(list,'              OBSERVABILITY RESULT   ');

     Writeln(list);Writeln(list);
     Writeln(list,'The Plant matrix A is :');
     writeln(list);
     For steps := 1 to size do
     Begin
       For stepping := 1 to size do
       Begin
         Write(List,'   ',A1A[steps,stepping]:11);
       End;Writeln(list);
     End;Writeln(list);Writeln(list);
     Writeln(list,'The Output Matrix C is : ');
     writeln(list);
     For steps:= 1 to no do
     begin
       for stepping:=1 to size do
       begin
         Write(list,'   ',C[steps,stepping]:11);
       end;writeln(list);
     end;Writeln(List);Writeln(list);
     If last_rank = size then
     Writeln(list,'The system is observable with
                 index ',value2,' .');
     If (value2 >= size ) and (last_rank < size) then
     Writeln (list,'The system is unobservable. ');
     writeln(list);writeln(list);
     Close(list);
   End;
  Until Ch in ['Q','q' ];

 Assign(SvsFile,'svs.COM');
              {re-execute SVS main program}
   Execute(SvsFile);
End.
```

```
Program Luenberg_observer(input,output);
{$I Typedef.SYS}

{$i Ut-mod01.INC}
{$I Ut-mod02.inc}

label 940;label 960;label 22;label 28;  label 950;

Type
    ary1     = array [1..10] of real;
    ary2     = array [1..30,1..30] of real;
    ary3     = array [1..30] of real;
    ary4     = array [1..11] of real;
    ary6     = array [1..11] of integer;
Var
    rrl ,rim,ooo,oooo                      :real;
    i,NR1,l ,mm,nrm,nrp,ixx,jxx,s, one,
    nrn,nr,r,rp,k ,t,o,umran,ii,jj,
    code,vertpos,horizpos,poscounter    :integer;
    h,aj,e                                 :ary1;
    coeff,coef,desired_feedback            :ary4;
    f                                      :ary1s;
    beta,x                                 :ary3;
    phi,u                                  :ary2;
    list                                   :text;
    strg,exponent                          :string[2];
    change                                 :boolean;
    specification                          :string[5];
    Realpartvalue,imaginarypartvalue       :ary3s;
    temp,inputtype                         :char;


{$I Ut-mod03.inc}

{$I Luenberg.inc}

{$I Pole.inc}
{$I Rootfind.inc}
{$I Boxuser.inc}

Begin
    ClrScr; luen:=true;one:=1;
    for i:=1 to size do
      for l:=1 to 1 do
        E[i]:=B(i,l);
    gotoxy(1,22);
    invvideo('Press <ESC> to change it!,              ');
    gotoxy(1,23);
    invvideo('Then type your input with <ENTER> key  ');
    gotoxy(1,1); Textcolor(lightblue);
    writeln('        *** Luenberger Observer Design
          Parameters ***');
    TextColor(yellow);
    writeln('=====================================');
    TextColor(yellow);
    msg('Input degree of observer  ( 10 max)' ,1,5);
    Repeat
      input('N',' ',40,5,3,true,F1,F10);
      val(answer,r,code);
      if (r > 10) and ( r < 1 ) then beep(900,350);
    until (r <= 10) and (r > 0);
    rp:=r+1;
    msg('Input the Desired Feedback Coefficients in
        Factored <F> Form ',1,7);
    msg('              or Coefficient <C> Form ',1,8);
    repeat
      Input('A','C',64,7,2,true,F1,F10);
      temp:=copy(answer,1,1);
```

```
    if not (temp in ['F','C']) then beep(900,350);
  until temp in ['F','C'];
  inputtype:=temp;

  Case inputtype of
    'F':begin
          if change then
          for i:=1 to size do
          begin
            str(realpartvalue[i]:8:2,Filvar[2*i+9]);
            str(imaginarypartvalue[i]:8:2,
                            Filvar[2*i+10]);
          end;
          input_Factored('POLES',size,RealPartvalue,
                            ImaginaryPartvalue);
        end;
    'C':begin
          if change then
          for i:= 1 to size-1  do
          begin
            str(Desired_feedback[size-1-i]:8:2,
                            Filvar[size+22-i]);
          end;
          input_coef('POLES',size-1,Desired_feedback);
        end;
  end;ClrScr;Writeln;gotoxy(1,22);
  invvideo('Press <ESC> to change it!,               ');
  gotoxy(1,23);
  invvideo('Then type your input with <ENTER> key  ');
  gotoxy(1,1); TextColor(lightblue);
  Writeln('          *** Luenberger Observer Design
          Input Parameters ***');
  textcolor(yellow);
  writeln('=========================================');

  textcolor(green);
  msg('Input observer characteristic polynomial
                        Factored (F) Form ',1,5);
  msg('                 or Coefficient (C) Form ',1,6);
  repeat
    input('A','C',65,5,2,true,F1,F10);
    temp:= copy(answer,1,1);
    if not (temp in ['F','C']) then beep(900,350);
  until temp in ['F','C'];
  if temp = 'C' then  goto 950;

  if change then
  for i:=1 to r do
  begin
    str(realpartvalue[i]:8:2,Filvar[2*i+9]);
    str(imaginarypartvalue[i]:8:2,Filvar[2*i+10]);
  end;
  input_Factored('POLES',r,RealPartvalue,
                  ImaginaryPartvalue);

  Polynomial_of_roots(r,Realpartvalue,
                  Imaginarypartvalue,coef); GoTo 960;

  950:if change then
  for i:= 1 to r   do
  begin
    str(coef[r-i]:8:2,Filvar[r+22-i]);
  end;

  input_coeff('POLES',r,coef);

  root_finder(r,coef,realpartvalue,
                  imaginarypartvalue,one);
```

```
ClrScr;Writeln;Writeln;
Writeln('The observer eigenvalues are : ');
Writeln('    REAL PART            IMAGINARY PART');
for i:= 1 to r do
Begin
    Write('    ',realpartvalue[i]:10,'      +         ',
    imaginarypartvalue[i]:10,' j ');  Writeln;
End;
Writeln;Writeln;
Writeln('The Observer characteristic polynomial
        coefficints in ascending powers of S');
Writeln;
for i:=1 to rp do
Begin
    Write(coef[i]:10,'  ');
End; Writeln;Writeln;
960:KEYREAD(KEY,KEYOLD,NOT_ERASED);ClrScr;
for i:= 1 to 30 do
Begin
    for l:= 1 to 30 do
    Begin
        PHI[i,l] :=0.0;
    End;
End;
for i:= 1 to r do
Begin
    H[i]:= 0.0;
End;
H[1]:=1.0;
for i := 1 to r do
Begin
    for l:= 1 to r do
    Begin
        F[i,l]:= 0.0;
    End;
    F[i,1] := -COEF[rp-i];
    if i = r then goto 28;
    F[i,i+1] := 1.0;
28:End;
for i:=1 to 20 do
begin
    X[i]:=0.0;
    BETA[i]:=0.0;
End;
nr := size * r;
for i:= 1 to nr do
Begin
    BETA[i] := 0.0;
End;
nrp := nr+1;
nrn := nr +size;
for i := 1 to size do
Begin
    BETA[nr+i] := desired_feedback[i];
End;
for i := 1 to r do
Begin
    ii:= size*(i-1);
    for l:= 1 to r do
    Begin
        jj:= size * (l-1);
        for k:= 1 to size do
        Begin
            PHI[ii+k,jj+k] := -F[i,l];
        End;
    End;
End;
for ii:= 1 to r do
```

```
    Begin
    i:=(ii-1) * size;
    for l:= 1 to size do
    Begin
      for k:= 1 to size do
      Begin
        PHI[i+l,i+k] := PHI[i+l,i+k]+ A1A[k,l];
      End;
    End;
End;
for  ii:= 1 to r do
Begin
    i := size * (ii-1);
    for l:= 1 to size do
    Begin
      PHI[nr+l,i+l] := H[ii];
    End;
End;
for i:= 1 to size do
Begin
    for l:= 1 to no do
    Begin
      PHI[nr+i,nr+l] := C[l,i];
    End;
End;
nrm := nr +no;
for ii:= 1 to r do
Begin
    i:= size * (ii-1);
    t:= nrm + no  *(ii-1);
    for k:= 1 to no do
    Begin
      for s:= 1 to size do
      Begin
        PHI[i+s,t+k] := -C[k,s];
      End;
    End;
End;
mm:= r* (size+no) + no;

Boxuser;
TextColor(white);

linear_equation(PHI,NRN,MM,BETA,X,K,U);

for ii:= 1 to r do
Begin
    i:= size * (ii-1);
    AJ[ii] := 0.0;
    for o := 1 to size do
    Begin
      AJ[ii]:=AJ[ii] +E[o] *X[i+o];
    End;
End;
nr1 := nr+1;
ClrScr;Writeln;Writeln;textcolor(yellow);
Writeln('The F Matrix is : ');Writeln;
for i:= 1 to r do
Begin
    for o:=1 to r do
    Begin
      Write('   ',F[i,o]:11);
    End;Writeln;
End;
KEYREAD(KEY,KEYOLD,NOT_ERASED); ClrScr;Writeln;
textcolor(yellow);Writeln('The G1 Matrix is : ');
Writeln;
for  ii:= 1 to r do
```

```
Begin
   i:= no *(ii-1) + nrm;
   for o:= 1 to no do
   Begin
      Write('   ',X[o+i]:11);
   End;Writeln;
End;writeln;writeln;
Writeln ('The G2 Matrix is : ');Writeln;
for i := 1 to r do
Begin
   Writeln('   ',AJ[i]:11);
End;
KEYREAD(KEY,KEYOLD,NOT_ERASED);
ClrScr;textcolor(yellow);Writeln;
Writeln ('The output feedback coefficients are
           ( Ascending powers of S ) :');Writeln;
for o:= nr1 to nrm do
Begin
   Write('   ',X[o]:11);
End;Writeln;writeln;
Writeln('The compensator feedback coefficients are
           (ascending powers of S ) :');
writeln;for i:= 1 to r do
Begin
   Write('   ',H[i]:11);
End;
KEYREAD(KEY,KEYOLD,NOT_ERASED);

Repeat
   Box printer;textcolor(yellow);gotoxy(58,15);
   write('"LUENBERG.RES"   ');
   gotoxy(1,25);write('                         ');
   gotoxy(49,17);
   Read(kbd,ch);
   if (ch='P') or (ch='p') or (ch='F') or (ch='f') then
   Begin
      if (ch='F') or (ch='f') then
      Begin
         gotoxy(45,15);Textcolor(red);
         write('PRINTING.........         ');
         Assign(list,'luenberg.RES');
         Rewrite(list);
      End;
      if (ch='P') or (ch='p') then
      Begin
         gotoxy(45,13);textcolor(red);
         write('PRINTING.........         ');
         Assign(list,'LST:');
         Rewrite(list);
      End;
      Writeln(list,'LUENBERGER OBSERVER RESULT ');
      For i:=1 to 2 do writeln(list);
      Writeln(list,'The plant matrix A is : ');
      Writeln(list);
      for i:=1 to size do
      Begin
         for l:=1 to size do
         Begin
            Write(list,'   ',A1A[i,l]:11);
         End;Writeln(list);
      End;Writeln(list);
      Writeln(list,'The input matrix B is :') ;
      Writeln(list);
      for i:=1 to size do
      Begin
         for l:=1 to 1 do
         Begin
            Write(list,'   ',B[i,l]:11);
```

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```
          End;Writeln(list);
     End;Writeln(list);
     Writeln(list,'The  output Matrix C is:');
     Writeln(list);
     for i:= 1 to no do
     Begin
          for l:=1 to size do
          Begin
             Write(list,'  ',C[i,l]:11);
          End;writeln(list);
     End;Writeln(list);
     Writeln(list,'The desired feedback coefficients
                     are : ');Writeln(list);
     for i:=1 to size do
     Begin
          for l:=1 to 1 do
          Begin
             Write(list,'  ',desired_feedback[i]:11);
          End;Writeln(list);
     End;Writeln(list);
     Writeln(list,'The observer eigenvalues are : ');
     Writeln(list,'REAL PART            IMAGINARY PART');
     for i:= 1 to r do
     Begin
          Write(list,'',realpartvalue[i]:10,'  +       '
          imaginarypartvalue[i]:10,' J ');  Writeln(list);
     End;Writeln(list);
     Writeln(list,'The Observer characteristic
      polynomial coefficints in ascending powers of S');

     Writeln(list);
     for i:=1 to rp do
     Begin
          Write(list,'  ',coef[i]:11);
     End;Writeln(list); writeln(list);
     Writeln(list,'The F Matrix is : ');Writeln(list);
     for i:= 1 to r do
     Begin
          for o:=1 to r do
          Begin
             Write(list,'  ',F[i,o]:11);
          End;Writeln(list);
     End;Writeln(list);
     Writeln(list,'The G1 Matrix is : ');Writeln(list);
     for ii:= 1 to r do
     Begin
          i:= no *(ii-1) + nrm;
          for o:= 1 to no do
          Begin
             Write(list,'  ',X[o+i]:11);
          End;Writeln(list);
     End;Writeln(list);
     Writeln (list,'The G2 Matrix is : ');Writeln(list);

     for i := 1 to r do
     Begin
        Writeln(list,'   ',AJ[i]:11);
     End;Writeln(list);
     Writeln (list,'The output feedback coefficients
                     are :');Writeln(list);
     for o:= nr1 to nrm do
     Begin
          Write(list,'  ',X[o]:11);
     End;Writeln(list);writeln(list);
     Writeln(list,'The compensator feedback
             coefficients are :');Writeln(list);
     for i:= 1 to r do
     Begin
```

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```
          Write(list,'   ',H[i]:11);
      End;
      for i:=1 to 3 do writeln(list);
      Close(list);
    End;
    Until ch in ['Q','q'];
    Assign(SvsFile,'svs.COM');
    Execute(SvsFile);
End.
```

```
program optimal control(input,output);
{$I Typedef.sys}
{$I Graphix.sys}
{$I Kernel.sys}
{$I Windows.sys}
{$I Polygon.hgh}
{$I Axis.hgh}

{$I Ut-mod01.INC}        { I/O procedures}
{$I Ut-mod02.INC}
{$I Ut-mod03.inc}

{$I Grapmenu.inc}
{$I Boxuser.inc}
label 2;label 3;
const
    xarray : string[14] ='TIME INTERVALS';
var
    GTNY   : array [1..80] of real;
    GTN    : array [1..10,1..80] of real;
    PSI,P1,D3,D4,FI,Q,gamma       :ary1s;
    D2,D1,GT                      :ary3s;
    ti,i,j,l,nterm,kk,code        :integer;
    y,ymax,ymin,r,denominator,negatif,si,result :real;
    grapharray,grapharray1        :plotarray;
    dumpgraph,quit                :boolean;
    list                          :text;
    ans                           :char;

{$I Optimal.inc}

Procedure PrintGraphData;
  {this procedure dumps optimal result data to printer}

Begin
    LeaveGraphic;Clrscr; Textcolor(yellow);
    Center('*** PROGAM OUTPUT OPTIONS ***',1,10,80);
    TextColor(green);
    msg('Press <P> Print results to the printer ',1,12);
    msg('      <F> List results to file name
         "OPTIMAL.RES" on the current drive',1,13);
    msg('      <Q> Quit ',1,14);
    repeat
      Read(kbd,ch);
      If (ch = 'F') or (ch = 'f') or (ch = 'p')
                      or (ch = 'P') then
      begin
        if (ch = 'F') or (ch = 'f') then
        begin
          Assign(list,'Optimal.RES');
          Rewrite(list);
        end
        else
        begin
          assign(list,'LST:');
          rewrite(list);
        end;
        Writeln(list);
        write(list);
        writeln(list,'OPTIMAL CONTROL RESULT ');
        writeln(list);
        write(list,'The order of the system is:');
        writeln(list,size:2);
        write(list,'The number of time intervals is:');
        writeln(list,si:2);
        write(list,'The scaler R is:');
        writeln(list,r:7:4);
```

```pascal
      write(list,'The sample interval is:');
      writeln(list,ti:4);
      writeln(list);
      writeln(list,'The A matrix is:');writeln(list);
      for l:= 1 to size do
      begin
        for j:= 1 to size do
        begin
           write(list,'   ',A1A[l,j]:11);
        end;writeln(list);
      end; writeln(list);
      writeln(list,'The B matrix is:');writeln(list);
      for l:= 1 to size do
      begin
        for j:= 1 to ni do
        begin
           write(list,'   ',B[l,j]:11);
        end;writeln(list);
      end; writeln(list);
      writeln(list,'The Q matrix is:');writeln(list);
      for l := 1 to size do
      begin
        for j:= 1 to size do
        begin
           write(list,'   ',Q[l,j]:11);
        end;writeln(list);
      end; writeln(list);
      writeln(list,'The FI matrix is:');writeln(list);
      for l:= 1 to size do
      begin
        for j:= 1 to size do
        begin
           write(list,'   ',FI[l,j]:11);
        end;writeln(list);
      end; writeln(list);
      writeln(list,'The GAMMA matrixis:');
      writeln(list);
      for l:= 1 to size do
      begin
        for j:= 1 to ni do
        begin
           write(list,'   ',GAMMA[l,j]:11);
        end;writeln(list);
      end; writeln(list);

      writeln(list,'MINIMIZATION OVER ALL STAGES ');
      writeln(list);
      write(list,'N (stages)');
      for l:=1 to i do
         write(list,'    GAIN:',i,'   ');

      writeln(list);
      write(list,'---------- ');
      for l:=1 to i do
         write(list,' -----------');
      writeln(list);
      for j:= 1 to ti do
      begin
        write(list,'  ',j:2,'      ');
        for l:=1 to i do
        begin
          write(list,'   ', graphArray1[j,l]:10);
        end;writeln(list);
      end;
    end;
  until ch in ['F','f','Q','q','P','p'];
  EnterGraphic;
  swapscreen;
```

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```
   close(list);
end;

begin
   clrscr;TextColor(lightblue);
   writeln('      *** Design of Optimal Control
             procedure ***');
   Textcolor(yellow);
   writeln('==========================================');
   gotoXY(1,25);InvVideo('Press <ESC> to change it!,
   Then Type your input with <ENTER> key');
   TextColor(green);
   Msg('Input number of time intervals for SUM
        procedure? ( MAX 99 ) ',1,4);
   input('N','50',65,4,6,true,F1,F10);
   val(answer,ti,code);
   Msg('What is your sample interval? ',1,6);
   input('N','0.1',35,6,6,true,F1,F10);
   val(answer,si,code);
   Msg('What is the value of scalar R ? ',1,8);
   Input('N','0.0',35,8,6,true,F1,F10);
   val(answer,r,code);
   Msg('For the following options Which cost
        function do you want ? ',1,10);
   TextColor(lightmagenta);
   Msg('COST=terminal+fuel+trajectory or
        COST=terminal+trajectory  <0>',1,11);
   Msg('COST=terminal+fuel            or
        COST=terminal              <1>',1,12);
   msg(' ',1,13);textcolor(yellow);
   msg('Where  ',1,14); textcolor(lightmagenta);
   msg('                            T              ',1,15);
   msg('        Terminal = 1/2 X (N) Q X(N)    ',1,16);
   msg('                                       ',1,17);
   msg('                       N-1 T           ',1,18);
   msg('     Trajectory = 1/2 SUM  X (k) Q X(k)',1,19);
   msg('                       k=0             ',1,20);
   msg('                                       ',1,21);
   msg('                                       ',1,22);
   msg('                       N-1 T           ',1,23);
   msg('        Fuel = 1/2 SUM  U (k) R U (k)  ',1,23);
   msg('                       k=0             ',1,24);

   Input('N','0',65,10,2,true,F1,F10);
   val(answer,nterm,code);clrscr;
   writeln('enter the element of Q matrix: ');
   for i:=1 to size do
   begin
      for j:=1 to size do
      begin
         Q[i,j]:=0.0;
         write('Q(');write(i);write(',');write(j);
         write(')= ');readln(Q[i,j]);
      end;writeln;
   end;
   Repeat
      ClrScr; Writeln;
      Writeln('The Q Matrix is : '); writeln;
      for i :=1 to size do
      Begin
         for j := 1 to size do
         Begin
            Write('  ', Q[i,j]:11);
         End; Writeln;
      End; writeln;
      Write('Do you want to change any element of
             the Matrix ? ( Y / N ) ');
      Read(Kbd,Ans); writeln;
             {allows user to change entered data }
```

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```pascal
    if ( Ans  ='Y') or ( Ans ='y') then
    Begin
      write('Input the row to change : '); readln(i);
      write('Input the column to change : ');
      readln(j);writeln;
      write('Q(',i,',',j,')= ');readln(result);
      Q[i,j]:=result;
    End;
  Until Ans in ['N','n'];
  textcolor(white);
  Boxuser;
  FI_and_GAMMA(SI,FI,GAMMA);
    { call procedure to calculate fi and
                                gamma matrices }
  TextColor(yellow); clrscr;
  writeln('The FI matrix is : ');
  for i:=1 to size do
  begin
    for j:=1 to size do
    begin
      write('   ',FI[i,j]:11);
    end;writeln;
  end;writeln;writeln;
  writeln('The gamma matrix is: ');
  for i:=1 to size do
  begin
    for j:=1 to ni do
    begin
      write('   ',GAMMA[i,j]:11);
    end;writeln;
  end;writeln;writeln;
  keyread(key,keyold,not_erased);
  Boxuser;
  for i:=1 to size do
  begin
    D1[i]:=0.0;
    D2[i]:=0.0;
    for j:=1 to size do
    begin
      D3[i,j]:=0.0;
      D4[i,j]:=0.0;
      P1[i,j]:=Q[i,j];
    end;
  end;
  y:=0.0;ymax:=0.0;ymin:=0.0;
  for kk:=1 to TI do
  begin
    denominator:=0.0;
    for i:=1 to size do
    begin
      for j:=1 to size do
      begin
        D1[i]:=D1[i] + GAMMA[j,1] * P1[j,i];
      end;
    end;
    for i:=1 to size do
    begin
      for j:=1 to size do
      begin
        D2[i]:=D2[i] + D1[j] * FI[j,i];
      end;
      denominator:=denominator + D1[i] * GAMMA[i,1];
    end;
    denominator:=denominator+ R;
    negatif:=-1.0;
    for i:=1 to size do
    begin
      GT[i]:= negatif * D2[i] / denominator;
```

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```
        GTN[I,KK]:=GT[I];
        D1[i]:=0.0;
        D2[i]:=0.0;
      end;
      for i:=1 to size do
      begin
        for j:=1 to size do
        begin
          PSI[i,j]:=FI[i,j] + GAMMA[i,1] * GT[j];
        end;
      end;
      for i:=1 to size do
      begin
        for j:=1 to size do
        begin
          for l:=1 to size do
          begin
            D3[i,j]:=D3[i,j] + PSI[l,i] * P1[l,j];
          end;
        end;
      end;
      for i:=1 to size do
      begin
        for j:=1 to size do
        begin
          for l:=1 to size do
          begin
            D4[i,j]:=D4[i,j] +D3[i,l] * PSI[l,j];
          end;
          if nterm <= 0 then goto 2;
          P1[i,j]:=D4[i,j] + R * GT[i] * GT[j]; goto 3;
          2:P1[i,j]:=D4[i,j] + Q[i,j] + R * GT[i] *
                     GT[j];
          3:D4[i,j]:=0.0;
        end;
      end;
      for i:=1 to size do
      begin
        for j:=1 to size do
        begin
          D3[i,j]:=0.0;
        end;
      end;
    end;
    for i:=1 to size do
    begin
      for j:=1 to  ti do
      begin
        GTNY[J]:=GTN[I,J];
        if abs(y) < 1.0e07 then y:=GTNY[j]
                        else y:= 1.0e07 ;
        if y > Ymax then Ymax:=y;
        if Y < Ymin then Ymin:=Y;
        Grapharray[j,1] := j;
        grapharray[j,2] := y;
        grapharray1[j,i]:= y;
      end;
      Ymax:= 1.2 * Ymax;

      initgraphic;
      selectwindow(1);

      gotoxy(4,4);write('G');
      gotoxy(4,5);write('A');
      gotoxy(4,6);write('I');
      gotoxy(4,7);write('N');
      gotoxy(3,9);write(i:2);
```

```
      drawtext(250,195,1,xarray);
      Niceaxes(0,ti,ymin,ymax,'   ');
      Selectworld(worldndxglb);
      Selectwindow(windowndxglb);
      Drawpolygon(grapharray,1,-(ti-1),0,0,0);

      repeat until keypressed;
      quit:=false;
      repeat
        Graph_menu('OPTIMAL CONTROL GAIN
                    PLOT',dumpgraph,quit);

        if dumpgraph then printgraphdata;
      until quit;
      leavegraphic;
    end;

  Assign(SvsFile,'svs.COM');
  Execute(SvsFile);
end.
```

```pascal
program pole_placement(input,output);

{$I Typedef.sys}  {comman type & variable definitions}
{$I Ut-mod01.inc}
{$I Ut-mod02.inc}

label 100;label 110;label 120;label 130;label 140;
label 150; label 160;label 170;label 180;label 190;
label 200;label 210;

type
  ary6              = array [1..21] of integer;
  ary4              = array [1..11] of real;

var
  AA,PIN,P10                                :ary1s;
  CCC                                       :ary4;
  CC,H,DEN,E,HH                             :ary4;
  realpart,imaginarypart,real_part,
  imaginary_part,realroot,imaginaryroot,
  realpart1,imaginarypart1                  :ary3s;
  nn,umran,i,j,jj,k,l,n2,n1,m ,er           :integer;
  vertpos,horizpos,poscounter,code          :integer;
  gain1,test                                :real;
  input2                                    :char;
  exponent,strg                             :string[2];
  Change,factored                           :boolean;
  specification                             :string[5];
  inputfile                                 :file;
  reduceorder,msize,one                     :integer;
  list                                      :text;

{$I Ut-mod03.inc}
{$I Pole.inc}
{$I Polynom.inc}
{$I Inverse.inc}
{$I Rootfind.inc}
{$I Boxuser.inc}

begin   { open-loop calculations}
  nn:=size+1;  Boxuser;luen:=false;one:=1;
  CHARACTERISTIC_EQUATION(A1A,SIZE,DEN);
                      {call polynom.inc}
  clrscr;TextColor(yellow);
  writeln('Denominator  of Y(s)/U(s) :');
  vertpos:=2;
  for i:=nn downto 1 do
  begin
    j:=nn-i;
    poscounter:=(j mod 4) +1;
    horizpos:=poscounter*14;
    if poscounter = 1 then vertpos:= vertpos+2;
    if i <> 1 then
    begin
      gotoXY(horizpos-10,vertpos);
      write(DEN[i]:7:4);
      msg('S +',horizpos,vertpos); str(i-1:2,exponent);

      msg(exponent,horizpos+1,vertpos-1);
    end
    else
    begin
      gotoXY(horizpos-10,vertpos);write(DEN[i]:7:4);
    end;
  end;writeln;writeln;writeln;writeln;

  root_finder(size,den,realpart1,imaginarypart1,one);
```

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```
writeln('The poles of the Y(s)/U(s) are:');
write('                                    REAL PART');
writeln('          IMAGINARY PART ');
for i:=1 to size do
begin
   write('                              ');
   write(realpart1[i]:7:4); write('        +j         ');
   writeln(imaginarypart1[i]:7:4);
end;

keyread(key,keyold,not_erased);clrscr;

for i:= 1 to size do
   P10[i,size]:=B[i,1];

for jj:= 2 to size do
begin
   for i:=1 to size do
   begin
      j:=size -jj+1; k:=j+1;
      P10[i,j]:=DEN[k] * B[i,1];
      for l:=1 to size do
         P10[i,j]:= P10[i,j] +A1A[i,l] * P10[l,k];
   end;
end;
for i:=1 to size do
begin
   CC[i]:=0.0;
   for j:=1 to size do
      CC[i]:= P10[j,i] * C[1,j] + CC[i];
end;
for i:=1 to size do
begin
   m:=nn-i;
   if CC[m] <> 0.0 then goto 100;
end;
100:Textcolor(yellow);
writeln('Numerator of Y(s)/U(s) :');
vertpos:=2;
for i:= m downto 1 do
begin
   j:= m - i;
   poscounter:=(j mod 4) +1;horizpos:=poscounter*14;
   if poscounter = 1 then vertpos:= vertpos+2;
   if i <> 1 then
   begin
      gotoXY(horizpos-10,vertpos);write(CC[i]:7:4);
      msg('S +',horizpos,vertpos); str(i-1:2,exponent);

      msg(exponent,horizpos+1,vertpos-1);
   end
   else
   begin
      gotoXY(horizpos-10,vertpos);write(cc[i]:7:4);
   end;
end;writeln;writeln;writeln;writeln;
msize:=m-1;

root_finder(msize,CC,realroot,imaginaryroot,one);

writeln('The zeros of the Y(s)/U(s) are:');
write('                                    REAL PART');
writeln('          IMAGINARY PART ');
for i:=1 to msize do
begin
   write('                              ');
   write(realroot[i]:7:4); write('        +j         ');
   writeln(imaginaryroot[i]:7:4);
```

```
   end;

   keyread(key,keyold,not_erased);clrscr;

   m:=m-1;
   clrscr;textcolor(green);highvideo;
   msg('Input the desired closed-loop characteristic
        equation ',1,6);
   msg('Factored (F) form or Coefficient (C)
        form ?',1,7);

   repeat read(kbd,input2)
   until input2 in ['F','f','C','c'];
   if (input2 = 'F') or (input2='f') then
   begin
     if change then
     for j:=1 to size do
     begin
       str(real_part[j]:10:2,filvar[2*j+9]);
       str(imaginary_part[j]:10:2,filvar[2*j+10]);
     end;
     input_factored('POLES',size,real_part,
                     imaginary_part);
     goto 120;
   end;
   if (input2='C') or (input2='c') then
   clrscr;m:=size+1;
   if change then
   for j:=m downto 1 do
   begin
     str(E[j]:10:2,Filvar[size+22-j]);
   end;umran:=1;
   input_coeff('POLES',size,e);

   root_finder(size,E,real_part,imaginary_part,one);
   clrscr;
   write('The roots of desired closed-loop
          characteristic');
   writeln(' polynomial are: ');
   write('                      REAL PART');
   writeln('        IMAGINARY PART ');
   for i:=1 to size do
   begin
     write('                                  ');
     write(real_part[i]:7:4);write('      +j     ');
     writeln(imaginary_part[i]:7:4);
   end;
   keyread(key,keyold,not_erased);clrscr;
   goto 180;

   120:for i:=1 to size do
   begin
     for j:=1 to size do
     begin
       AA[i,j]:=0.0;
     end;
   end;
   i:=0;
   160:i:=i+1;
   if imaginary_part[i] <>0.0 then goto 150;
   AA[i,i]:=real_part[i]; goto 170;
   150:AA[i,i]:=real_part[i];   j:=i+1;
   AA[i,j]:=-imaginary_part[i];
   AA[j,i]:=imaginary_part[i];
   i:=j;     AA[i,i]:=real_part[i];
   170:if (i-size) < 0 then goto 160;

   CHARACTERISTIC_EQUATION(AA,SIZE,E);
```

```
180:for i:=1 to size do
begin
   H[i]:= E[i] - DEN[i];
end;
for i:=1 to size do
begin
   CCC[i]:=C[1,i];
end;

INVERSE_FIND_MATRIX(P10,CCC,SIZE,PIN,CCC,ER);

for i:=1 to size do
begin
   HH[i]:=0.0;
   for j:=1 to size do
   begin
      HH[i]:= HH[i] + PIN[j,i] * H[j];
   end;
end;
for i:=1 to size do
begin
   for j:=1 to size do
   begin
      AA[i,j]:= A1A[i,j] - B[i,1] * HH[j];
   end;
end;

CHARACTERISTIC_EQUATION(AA,SIZE,E);

if CC[1]=0.0 then
begin
   gain1 :=1.0; goto 210;
end
else
gain1:=  E[1] / CC[1] ;
210:if gain1 =0.0 then gain1 :=1.0;
textcolor(yellow);
for i:=1 to size do
begin
   HH[i]:= HH[i] /gain1;
end;
140:for i:=1 to size do
begin
   H[i]:=H[i]/gain1;
end;if H[size]:=0.0 then reduceorder:=reduceorder-1;
clrscr;Writeln('Numerator of the Heq(s) is :');
vertpos:=2;
for i:= size downto 1 do
begin
   j:= size -i;
   poscounter:=(j mod 4) +1;horizpos:=poscounter*14;
   if poscounter = 1 then vertpos:= vertpos+2;
   if i <> 1 then
   begin
      gotoXY(horizpos-10,vertpos);write(H[i]:7:4);
      msg('S +',horizpos,vertpos); str(i-1:2,exponent);

      msg(exponent,horizpos+1,vertpos-1);
   end
   else
   begin
      gotoXY(horizpos-10,vertpos);write(H[i]:7:4);
   end;
end;writeln;writeln;writeln;
reduceorder:=size-1;
root_finder(reduceorder,H,realpart,
            imaginarypart,one);
writeln('The roots of the Heq(s) are :');
```

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```pascal
  write('                                          REAL PART');
  writeln('            IMAGINARY PART ');
  for i:=1 to reduceorder do
  begin
    write('                                ');
    write(realpart[i]:7:4); write('        +j        ');
    writeln(imaginarypart[i]:7:4);
  end;
  keyread(key,keyold,not_erased); clrscr;
  n2:=NN-1;
  190:if H[n2] <> 0.0 then goto 200;
  n2:=n2-1;  goto 190;
  200:n1:=n2-1;
  TextColor(yellow);  gotoXY(1,2);
  writeln('The feedback coefficients [ k ] are : ');
  writeln; for i:=1 to size do
  begin
    write('   ');write(HH[i]:7:4);
  end;writeln;writeln;
  write('The gain [ K ] is :');
  writeln(gain1:7:4);writeln;

  keyread(key,keyold,not_erased);
  Repeat
    box printer;textcolor(yellow);gotoxy(58,15);
    write('"POLE.RES" ');
    gotoxy(1,25);write('                                   ');
    gotoxy(49,17);
    Read(Kbd,ch);
    If (ch='P') or (ch='p') or (ch='F') or (ch='f')
    then    Begin
      If (ch='F') or (ch='f') then
      Begin
        gotoxy(45,15);textcolor(red);
        write('PRINTING......              ');
        Assign(list,'pole.res');
               {print pole placement output }
        Rewrite(list);{to file on the current drive}
      End;
      If (ch='P') or (ch='p') then
      Begin
        gotoxy(45,13);textcolor(red);
        write('PRINTING........            ');
        Assign(list,'LST:');
               {print pole placement result to the printer}

        Rewrite(list);
    End;
    Writeln(list,'     POLE PLACEMENT RESULT  ');
    Writeln(list);Writeln(list);
    Writeln(list,'The Plant matrix A is : ');
    writeln(list);
    For i := 1 to size do
    Begin
      For j := 1 to size do
      Begin
        Write(List,'   ',A1A[i,j]:11);
      End;Writeln(list);
    End;Writeln(list);Writeln(list);
    Writeln(list,'The Input matrix B is :');
    writeln(list);
    For i := 1 to size do
    Begin
      For j := 1 to ni do
      Begin
        Write(List,'   ',B[i,j]:11);
      End;Writeln(list);
    End;Writeln(list);Writeln(list);
```

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```
      Writeln(list,'The Output Matrix C is :');
      writeln(list);
      For i := 1 to no do
      begin
        for j:=1 to size do
        begin
          Write(list,'    ',C[i,j]:11);
        end;writeln(list);
      end;Writeln(List);Writeln(list);

      write(list,'Denominator  of Y(s)/U(s) -');
      writeln(list,' Descending powers of S:');
      writeln(list);
      for i:=nn downto 1 do
      begin
        write(list,'    ',DEN[i]:7:4);
      end;writeln(list);writeln(list);
      writeln(list,'The poles of the Y(s)/U(s) are:');
      write(list,'     REAL PART');
      writeln(list,'          IMAGINARY PART ');
      for i:=1 to size do
      begin
        write(list,'                              ');
        write(list,realpart1[i]:7:4);
        write(list,'     +j      ');
        writeln(list,imaginarypart1[i]:7:4);
      end;writeln(list);writeln(list);

      write(list,'Numerator of Y(s)/U(s) -');
      writeln(list,' Descending powers of S:');
      writeln(list);
      for i:= m+1 downto 1 do
      begin
        write(list,'    ',CC[i]:7:4);
      end;writeln(list);writeln(list);
      writeln(list,'The zeros  of the Y(s)/U(s) are:');

      write(list,'                    REAL PART');
      writeln(list,'          IMAGINARY PART ');
      for i:=1 to msize do
      begin
        write(list,'                              ');
        write(list,realroot[i]:7:4);
        write(list,'     +j      ');
        writeln(list,imaginaryroot[i]:7:4);
      end;writeln(list);writeln(list);
      write(list,'Desired closed-loop Characteristic
                 polynomial ');
      writeln(list,'- Descending powers of S :');
      writeln(list);
      for i:= size+1 downto 1 do
      begin
        write(list,'    ',E[i]:7:4);
      end;writeln(list);writeln(list);

      write(list,'The roots of desired closed-loop
                 characteristic');
      writeln(list,' polynomial are: ');
      write(list,'                  REAL PART');
      writeln(list,'          IMAGINARY PART ');
      for i:=1 to size do
      begin
        write(list,'                              ');
        write(list,real_part[i]:7:4);
        write(list,'     +j      ');
        writeln(list,imaginary_part[i]:7:4);
      end;writeln(list);writeln(list);
```

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```
      Write(list,'Numerator of the Heq(s) is -');
      writeln(list,' Descending powers of S :');
      writeln(list);
      for i:= size downto 1 do
      begin
        write(list,'    ',H[i]:7:4);
      end;writeln(list);writeln(list);
      writeln(list,'The roots of the Heq(s) are :');
      write(list,'                REAL PART');
      writeln(list,'          IMAGINARY PART ');
      for i:=1 to reduceorder do
      begin
        write(list,'                                ');
        write(list,realpart[i]:7:4);
        write(list,'      +j        ');
        writeln(list,imaginarypart[i]:7:4);
      end;writeln(list);writeln(list);
      writeln(list,'The feedback coefficients [ k ]
              are : ');
      writeln(list);  for i:=1 to size do
      begin
        write(list,'   ');write(list,HH[i]:7:4);
      end;writeln(list);writeln(list);
      write(list,'The gain [ K ] is : ');
      writeln(list,gain1:7:4);
      writeln(list);writeln(list);

      Close(list);
    End;
  Until Ch in ['Q','q' ];

  Assign(SysFile,'svs.COM');
        {re-execute SVS main program}
  Execute(SysFile);
End.
```

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```
( ********************************************************* )
( *                 TURBO GRAPHIX version 1.00A          * )
( *                 Type definition module               * )
( *                 Copyright (C) 1985 by                * )
( *                 BORLAND International                * )
( ********************************************************* )

const MaxWorldsGlb=4;
      Maxorder=9;
      MaxWindowsGlb=16;
      MaxPiesGlb=10;
      MaxPlotGlb=200;
      MaxBlocks =10;
      StringSizeGlb=80;
      HeaderSizeGlb=10;
      RamScreenGlb:boolean=true;
      CharFile:string[StringSizeGlb]='4x6.fon';
      MaxProcsGlb=27;
      MaxErrsGlb=7;
      Extension:String[4]='.svs';

type  wrkstring=string[StringSizeGlb];
      WorldType=record
                     x1,y1,x2,y2:real;
                  end;
      WindowType=record
                     x1,y1,x2,y2:integer;
                     header:wrkstring;
                     drawn,top:boolean;
                     size:integer;
                  end;
      worlds=array [1..MaxWorldsGlb] of WorldType;
      windows=array [1..MaxWindowsGlb] of WindowType;
      PlotArray=array [1..MaxPlotGlb,1..2] of real;
      character=array [1..3] of byte;
      CharArray=array [32..126] of character;
      PieType=record
                  area:real;
                  text:wrkstring;
               end;
      PieArray=array [1..MaxPiesGlb] of PieType;
      BackgroundArray=array [0..7] of byte;
      LineStyleArray=array [0..7] of boolean;
      Ary1s=Array [1..10,1..10] of real;
      Ary2s=Array [1..10,1..10] of integer;
      Ary3s=Array [1..10] of real;
      Str2=String[2];
      Str4=String[4];
      Str5=String[5];
      Str20=String[20];
      Str25=string[25];
      Str40=String[40];
      Str80=String[80];
      Str255=String[255];

var   X1WldGlb,X2WldGlb,Y1WldGlb,Y2WldGlb,
      AxGlb,AyGlb,BxGlb,ByGlb:real;
      X1RefGlb,X2RefGlb,Y1RefGlb,Y2RefGlb:integer;
      LinestyleGlb,MaxWorldGlb,MaxWindowGlb,
      WindowNdxGlb:integer;
      X1Glb,X2Glb,Y1Glb,Y2Glb:integer;
      XTextGlb,YTextGlb,VStepGlb:integer;
      PieGlb,DirectModeGlb,ClippingGlb,
      AxisGlb,HatchGlb:boolean;
      MessageGlb,BrkGlb,HeaderGlb,TopGlb,
      GrafModeGlb:boolean;
      CntGlb,ColorGlb:byte;
      ErrCodeGlb:byte;
```

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```
      LineStyleArrayGlb:LineStyleArray;
      ErrorProc:array [0..MaxProcsGlb] of ^WrkString;
      ErrorCode:array [0..MaxErrsGlb] of ^WrkString;
      PcGlb:string[40];
      AspectGlb:real;
      GrafBase:integer;
      world:worlds;
      window1:windows;
      CharSet:CharArray;
      D:Ary2s;
      A1A,B,C:Ary1s;
      Len,Space,Drive:Str2;
      Size,ni,no,Block1,Key,Keyold:Integer;
      Not_erased,Finished,Exit,Inserton,F1,F10:Boolean;

      Ch:Char;
      TemPlate,Answer,Previous_Answer:Str80;
      SvsFile:File;
      P,Filvar:Array[1..35] of str40; {menu prompts}
      worldndxglb :integer;
      escape,retriev,luen : boolean;
```

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```pascal
procedure Bodeplot;
label 1; {label decleration for goto statement}
var
   Code,I,Count,NumberDecades,StartDecade,
   EndDecade : integer;
   Wf,Wo,Wi,DeltaW,Gain                      : Real;
   PlotArray1,PlotArray2,MagPhaseArray,
   FreqArray      : PlotArray;
   ZMagn,ZPhase,PMagn,PPhase,Phase           : real;
   TempX,TempY                               : real;
   temp                                      : char;
   OpenLoop                                  : boolean;
   j,jj,kk1,m,l,cnpoles,sizezeros,one        : integer;
   dencoeff,numcoeff,cdencoeff               : ary4;
   realpartpole,imagpartpole,realpartzero,
   imagpartzero,crealpartpole,cimagpartpole: ary3s;
   PSI                                       : ary1s;

function Log(X:real):real;
           {computes the base-10 logarithm of X}
Begin
   If X=0 then Log:=0 else
   Log := Ln(X)/Ln(10);
End;

function Expon(Y,X:real):real;
             {computes Y raised to X power}
Begin
   Expon := exp( X * (ln(Y)));
end;

begin
   ClrScr; boxuser; one:=1;
   Characteristic_equation(A1A,size,Dencoeff);
   for i:=1 to size do
   begin
      PSI[i,size]:=B[i,1];
   end;
   for jj:=2 to size do
   begin
      for i:=1 to size do
      begin
         j:=size-jj+1;
         kk1:=j+1;
         PSI[i,j]:=Dencoeff[kk1] * B[i,1];
         for l:=1 to size do
         begin
            PSI[i,j]:=PSI[i,j] +A1A[i,l] * PSI[l,kk1];
         end;
      end;
   end;
   for i:=1 to size do
   begin
      Numcoeff[i]:=0.0;
      for j:=1 to size do
      begin
         Numcoeff[i]:=Numcoeff[i] + PSI[j,i] * C[1,j];
      end;
   end;
   for i:=1 to size do
   begin
      m:=size+1-i;
      if numcoeff[m] <> 0.0 then goto 1;
   end;
   1:sizezeros:=m-1;
   Clrscr;TextColor(lightblue);
   writeln(' *** Bode  Plotting Parameters ***');
   TextColor(yellow);
```

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```
  writeln('=====================================');
  Msg('Open (O) or Closed (C) Loop Plot?',5,5);
  repeat
    input('A','',45,5,2,true,F1,F10);
    {sets flag OpenLoop if}
    temp := copy(answer,1,1);
                    {user selects the open}
    if not(temp in ['O','C']) then beep(350,150);
                    {loop option for plot }
  until temp in ['O','C'];
  if (temp = 'O' ) then OpenLoop := true
                    else OpenLoop := false;
  Msg('What is the first frequency to be
        plotted?',5,7);
  Msg('(example: .01, 1, 100, etc.)',10,8);
  Input('N','',50,7,8,true,F1,F10);
  Val(answer,Wo,code);   {Wo is the first plotted freq}

  Msg('Input number of decades do you want
        plotted?',5,10);
  Input('N','',51,10,2,true,F1,F10);
  Val(answer,NumberDecades,code);

  root_finder(sizezeros,Numcoeff,realpartzero,
              imagpartzero,one);
  root_finder(size,Dencoeff,realpartpole,
              imagpartpole,one);


  gain:= Numcoeff[sizezeros+1];
  for i:=1 to sizezeros+1 do
  begin
    Numcoeff[i]:= Numcoeff[i]/gain;
  end;
  boxuser;

  for i:=1 to maxorder do CDenCoeff[i] := 0.0;
  for i:=1 to SizeZeros + 1 do
      CDenCoeff[i] := Numcoeff[i] * gain;

  for i:=1 to Size + 1 do
      CDenCoeff[i] := CDenCoeff[i] + Dencoeff[i];

  if Size > SizeZeros then CNPOLES:=Size
      {NPoles should always be}
    else CNPOLES:=SizeZeros;
  {greater,but to be safecompute new denominator roots}

  root_finder(Cnpoles,CDenCoeff,CRealPartPole,
            CImagPartPole,one);

  StartDecade := trunc(Log(Wo));
                  {compute linear scale to plot }
  EndDecade := StartDecade + NumberDecades;
                  {log numbers. Also figure step}
  Wf := Wo * Expon(10.0,NumberDecades);
  DeltaW := Expon((Wf/Wo),0.0125);
  Wi := Wo;

  for Count := 1 to 81 do{do 81 iterations...arbitrary}

  Begin

    if OpenLoop then{compute bode numbers if openloop}
                    {and later  if closed loop}
    begin
```

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```pascal
      ZMagn:=1.0; ZPhase:=0.0; PMagn:=1.0; PPhase:=0.0;

      for i := 1 to SizeZeros do
        {compute magn and phase of zeros for freq step}
      begin
        ZMagn:=ZMagn * Sqrt(Sqr(RealPartZero[I])+
               Sqr(Wi-ImagPartZero[I]));
        if RealPartZero[i] = 0.0 then
           ZPhase:=ZPhase+pi/2.0 else;
        begin
          if realpartzero[i] > 0.0 then
             ZPhase:=ZPhase - pi +arctan((wi-
                   imagpartzero[i])/(-realpartzero[i]))

          else
             ZPhase:=ZPhase + arctan((wi-
                   imagpartzero[i])/(-realpartzero[i]));
        end;
      end;

      for i := 1 to Size do
        {compute magn and phase of poles for freq step}
      begin
        PMagn:=PMagn * Sqrt(Sqr(RealPartPole[I]) +
               Sqr(Wi-ImagPartPole[I]));
        if RealPartPole[I] = 0.0 then
           PPhase:= PPhase+pi/2.0 else
        begin
          if realpartpole[i] > 0.0 then
             PPhase:=PPhase - pi +arctan((wi-
                   imagpartpole[i])/(-realpartpole[i]))
          else
             PPhase:=PPhase + arctan((wi-
                   imagpartpole[i])/(-realpartpole[i]));
        end;
      end;

      PlotArray1[Count,1] := Log(Wi);
      {fill plotting matrix with magnitude values}
      PlotArray1[Count,2] := 20*Log(Gain*
                             (ZMagn/PMagn));

      PlotArray2[Count,1]:=Log(Wi);{fill phase matrix}
      PlotArray2[Count,2] := (180/pi)*(ZPhase-PPhase);

      {next stmt covers freq wrap-around}
      if PlotArray2[Count,2] > 0 then
         PlotArray2[count,2]:=PlotArray2[count,2]-360;

      Wi := Wi * DeltaW;                {increment freq step}

    end

    else
  {perform same steps as above if closed loop requested}

    begin
      ZMagn:=1.0;ZPhase:=0.0;PMagn:=1.0;PPhase:=0.0;
      for i := 1 to SizeZeros do
      begin
        ZMagn:=ZMagn * Sqrt(Sqr(RealPartZero[I])+
               Sqr(Wi-ImagPartZero[I]));
        if RealPartZero[I] = 0.0 then
           ZPhase:=ZPhase+pi/2.0 else
        begin
          if Realpartzero[i] > 0.0 then
```

```
            ZPhase:=ZPhase - pi +arctan((wi-
                 imagpartzero[i])/(-realpartzero[i]))
         else
            ZPhase:=ZPhase + arctan((wi-
                 imagpartzero[i])/(-realpartzero[i]));
      end;
   end;
   for i := 1 to CNpoles do
   begin
      PMagn:=PMagn * Sqrt(Sqr(CRealPartPole[I])+
            Sqr(Wi-CImagPartPole[I]));
      if CRealPartPole[I] = 0.0 then
         PPhase:=PPhase+pi/2.0  else
      begin
         if crealpartpole[i] > 0.0 then
            PPhase:=PPhase - pi + arctan((wi-
                 cimagpartpole[i])/(-crealpartpole[i]))
         else
            PPhase:=PPhase +arctan((wi-
                 cimagpartpole[i])/(-crealpartpole[i]));

      end;
   end;

   PlotArray1[Count,1] := Log(Wi);
 (fill plotting matrix with magnitude values)
   PlotArray1[Count,2] := 20*Log(Gain *
                      (ZMagn/PMagn));
   PlotArray2[Count,1]:=Log(Wi);(fill phase matrix)

   PlotArray2[Count,2] := (180/pi)*(ZPhase-PPhase);

            (next stmt covers freq wrap-around)
   if PlotArray2[Count,2] > 0 then
      PlotArray2[count,2]:=PlotArray2[count,2]-360;

   Wi := Wi * DeltaW;
   end;
 end;
 PlotBode(StartDecade,EndDecade,NumberDecades,
         PlotArray1,PlotArray2,OpenLoop);
end; {bodeplot}
```

```pascal
procedure PlotBode(StartDecade,EndDecade,
                   NumberDecades:Integer;
                   PlotArray1,PlotArray2:PlotArray;
                   OpenLoop: Boolean);
const
  MagnArray: array[1..12] of
             char = ('M',' ','A',' ','G',' ','N','I','T','U','D',
                     'E',' ','d',' ','B');
  PhasArray: array[1..12] of
             char = ('P',' ','H',' ','A',' ','S',' ','E',' ',' ','d','e',
                     'g',' ');
    FreqArray: string[19] = 'FREQUENCY (rad/sec)';

var i,j,n            :integer;
    ch               :char;
    x1,x2            :integer;
    Delta            :real;
    MagLabel         : string[3];
    PhsLabel         : string[4];
    DecLabel         : string[3];
    Title1,
    Title2           : string[80];
    DumpGraph        : Boolean;
    w                : real;
    quit             : Boolean;
    list             : text;

function Log(X:real):real;
Begin
   If X=0 then Log:=0 else
   Log := Ln(X)/Ln(10);
End;

function Expon(Y,X:real):real;
            {computes Y raised to X power}
Begin
   Expon := exp( X * (ln(Y)));
end;

Procedure PrintGraphData;
            {prints numbers to a file or printer}
Begin
   LeaveGraphic;Clrscr;
   repeat
   Textcolor(white);    gotoxy(20,10);
   writeln('   *** PROGRAM OUTPUT OPTIONS ***   ');
   gotoxy(20,13);
   writeln('<P> Printer output                  ');
   Textcolor(yellow);    gotoxy(20,14);
   writeln('     Check Your Printer!            ');
   Textcolor(white);    gotoxy(20,15);
   writeln('<F> List to File name               ');
   gotoxy(20,16);
   writeln('     on the current drive           ');
   gotoxy(20,17);
    writeln('<Q> Quit                           ');
   gotoxy(42,15);textcolor(yellow);write('"BODE.RES"');

   gotoxy(28,17);
   read(kbd,ch);
    If (ch = 'F') or (ch = 'f') or (ch = 'P') or
        (ch = 'p') then
     begin
        if (ch = 'F') or (ch = 'f') then
        begin
          gotoxy(24,15);textcolor(red);
          write('PRINTING.....                      ');
```

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```
            assign(list,'Bode.RES');
            rewrite(list);
         end
         else
         begin
            gotoxy(24,13);textcolor(red);
            write('PRINTING...........                        ');

            assign(list,'LST:');
            rewrite(list);
         end;

         Title1:=('      w (rad)                    Gain (db)
                   Phase (deg)');
         Title2:=('----------------------------');

         writeln(list,'                 BODE PLOT RESULT ');

         writeln(list);writeln(list);
         writeln(list,Title1);
         writeln(list,Title2);
         writeln(list); writeln(list);
         for i:= 1 to 81 do
         begin
            w := expon(10.0,PlotArray1[i,1]);
            writeln(list,'      ',w:11:3,'                        ',
                    PlotArray1[i,2]:8:3,'                        ',
                    PlotArray2[i,2]:7:3);
            if i= 47 then
            begin
               write(list,chr(12));
               writeln(list);
               writeln(list,Title1);
               writeln(list,Title2);
               writeln(list); writeln(list);
            end;
         end;
      end;
   until ch in ['Q','q'];
   EnterGraphic;
   (when finished printing, go back to graphics mode
and display graph)
   swapscreen;
   close(list);
end;

Begin
   initgraphic;    {set-up windows for display}
   DefineWindow(1,0,0,XMaxGlb,YMaxGlb);
   DefineWindow(2,5,15,XMaxGlb-5,YMaxGlb-15);
   DefineWindow(3,5,15,XmaxGlb-5,YMaxGlb-15);
   DefineWorld(1,0,0,100,100);
   DefineWorld(2,StartDecade,60,EndDecade,-60);
   DefineWorld(3,StartDecade,0,EndDecade,-360);
   SelectWorld(1);
   SelectWindow(1);
   SetBackground(0);
   SelectWorld(2);
   SelectWindow(2);
   DrawBorder;

   SetLineStyle(1);
   For I:=1 to 5 do {draw horizontal graph lines}
      DrawLine(StartDecade,-60+(20*I),
              EndDecade,-60+(20*I));
   For J:=0 to NumberDecades-1 do
            {draw vertical logarithmic graph lines}
   Begin
```

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```
    For I:= 1 to 10 do
    Begin
       Delta:=StartDecade + (Log(I) + J);
       Drawline(Delta,-60,Delta,60);
    end;
  end;
  SelectWindow(1);              {y-axis titles}
  For I:= 1 to 12 do
  Begin
     DrawText(5,55+6*I,1,MagnArray[I]);
     DrawText(630,60+6*I,1,PhasArray[I]);
  end;
  DrawText(250,195,1,FreqArray);{x-axis title}
  For I:= 0 to 6 do          {y-axis scale label}
  Begin
     Str(60-20*I:3,MagLabel);
     DrawText(12,13+28*I,1, MagLabel);
     Str(0-60*I:4,PhsLabel);
     DrawText(600,13+28*I,1,PhsLabel);
  end;
  For I:= 0 to NumberDecades do
        {label the logarithmic scale}
  Begin
     Str(Trunc(StartDecade)+I:3,DecLabel);
     DrawText(36+(570 div NumberDecades) *I,
           186,1,DecLabel);
     DrawText(30+(570 div NumberDecades) *I,
           190,1,'10');
  end;
  SetLineStyle(0);
  SelectWindow(2); SelectWorld(2);
  DrawPolygon(PlotArray1,1,-81,0,1,0);
              {plot the magnitude}
  SelectWorld(3);
  SelectWindow(3);
  SetLineStyle(3);
  DrawPolygon(PlotArray2,1,-81,0,1,0);
              {plot the phase}
  copyscreen;              {save screen to memory}
  repeat until keypressed;
  quit := false;
  repeat      {call for graph options menu}
     if OpenLoop then
        Graph_Menu('Open Loop Bode Plot',DumpGraph,quit)

     else
        Graph_Menu('Closed Loop Bode',DumpGraph,quit);
     If DumpGraph then PrintGraphData;
              {dump numbers if desired}
  until quit;
  LeaveGraphic;      {leave graphics mode}
end;
```

```
(* This program draw line for menu box. *)
procedure box;
var i   :integer;
begin
  Highvideo;TextColor(yellow);gotoxy(1,2);
  write(chr(218));            {draw upper left corner}
  for i := 1 to 77 do    {draw upper horizontal line}

  begin
    write(chr(196));
  end; write(chr(191));
  gotoxy(1,5);  write(chr(192)) ;
  for i:= 2 to 78 do
    write(chr(196));
  write(chr(217));
  for i:= 3 to 4 do
  begin
    gotoxy(1,i);write(chr(179));   {draw vertical lines}

    gotoxy(79,i);write(chr(179));
  end;
  gotoxy(1,23);
  for i := 1 to 78 do
    write(chr(196));
  writeln(' ');
  TextColor(white);gotoXY(20,22);
  writeln('Make your selection  ');
  gotoxy(40,22);Lowvideo; {make input promt}
end;
```

```
Procedure Fi_and_gamma(var T:real;
                       var fi:ary1s;
                       var gamma:ary1s );
label 1;
var
    A2,A3,A4,A5                    :ary1s;
    i,j,k                         :integer;
    test_value,step               :real;

begin
   test_value:=1.0e-08;
   step:=1.0;
   for i:=1 to size do
   begin
     for j:=1 to size do
     begin
       FI[i,j]:=0.0;
       FI[i,i]:=1.0;
       A4[i,j]:= A1A[i,j];
       A2[i,j]:= (T./2.0) * FI[i,j];
       A5[i,j]:= T * FI[i,j];
     end;
   end;
   1:for i:=1 to size do
   begin
     for j:=1 to size do
     begin
       A3[i,j]:=(T/step) * A4[i,j];
       FI[i,j]:=FI[i,j] + A3[i,j];
       A2[i,j]:=A2[i,j] + ( T / ((step+1.0) *
   (step+2.0))) * A3[i,j];
       A5[I,J]:=A5[I,J] + ( T / (step+1.0)) * A3[i,j];
     end;
   end;
   for i:=1 to size do
   begin
     for j:=1 to size do
     begin
       A4[i,j]:=0.0;
       for k:=1 to size do
         A4[i,j]:=A4[i,j] + A1A[i,k] * A3[k,j];
     end;
   end;
   step:=step+1.0;
   for i:=1 to size do
     for j:=1 to size do
       if abs(A3[i,j]) > (test_value * abs (FI[i,j]))
         then goto 1;

   for i:=1 to size do      {initialize}
     for j:=1 to  ni do
       GAMMA[i,j]:=0.0;

   for i:=1 to size do         {calculate GAMMA matrix }
     for j:=1 to ni do
       for k:=1 to size do
         GAMMA[i,j] :=GAMMA[i,j] + A5[i,k] * B[k,j];
end;
```

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```
Procedure Matrix_reduction(Var dumy_square:Ary1;
                           Var n,m,rank:Integer);

Label 142;Label 145;Label 235;Label 170;Label 180;
Label 162; Label 198;Label 200;Label 224;Label 226;
Label 228;Label 234;

VAR
    reduction_matrix                       : Ary1;
    Jjc,Nmin,i,j,jj,kj,k,j1,start,
    l,ll,imin,li,lli,jk,lf                 : Integer;
    compare_value,temp_value,sum           : Real;

Begin
   For i := 1 to n do
     For j:=1 to m do
       reduction_matrix[i,j] := dumy_square[i,j];

   compare_value := 1.00E-8;
   Jjc :=1;
   Nmin := n - 1;

   If nmin = 0 then goto 235;
   For i := 1 to nmin do
   Begin
     For j := jjc to m do
     Begin
       Jj :=j;
       For k := i to n do
       Begin
         Kj :=k;
         If abs( reduction_matrix[k,j]) >=compare_value
            then GoTo 142;
       End;
     End;
     GoTo 235;
     142:If kj = i then GoTo 145;
     For j1 := jj to m do
     Begin
       Temp_value := reduction_matrix[i,j1];
       reduction_matrix[i,j1]:=reduction_matrix[kj,j1];

       reduction_matrix[kJ,j1] :=temp_value;
     End;
     145:temp_value := reduction_matrix[i,jj];
     For jk := jj to m do
       reduction_matrix[i,jk] := reduction_matrix[i,jk]
                                  /temp_value;

     If i <>1 then GoTo 180;
     start :=2;
     162:for l := start to n do
     Begin
       Temp_value := reduction_matrix[l,jj];
       If abs( reduction_matrix[l,jj]) <= compare_value
          then GoTo 170;
       For ll :=jj to m do
         reduction_matrix[l,ll]:=reduction_matrix[l,ll]-
                 temp_value * reduction_matrix[i,ll];

     170:End;
     GoTo 200;
     180:imin :=i-1;
     For li :=1 to imin do
     Begin
       Temp_value := reduction_matrix[li,jj];
       If abs( reduction_matrix[li,jj]) <=compare_value
          then GoTo 198;
```

```
          For lli := jj to M do
          reduction_matrix[li,lli] :=
          reduction_matrix[li,lli]-reduction_matrix[i,lli]
                                       *temp_value;

    198 :End; start := i + 1;
    GoTo 162;
    200:If jj = m then goto 235;
    Jjc := jj +1;
  End;
  For jk := jj to m do
  Begin
     Temp_value := reduction_matrix[n,jk];
     Jjc := jk;
     If abs( reduction_matrix[n,jk]) <= compare_value
        then GoTo 226;
     For j1 := jk to m do
       reduction_matrix[n,j1] :=reduction_matrix[n,j1]/
                            temp_value;

     GoTo 228;
  226:End;
  GoTo 235;
  228:For lf:= 1 to nmin do
  Begin
     Temp_value := reduction_matrix[lf,jjc];
     If abs( reduction_matrix[lf,jjc]) <= compare_value
          then GoTo 234;
     For j1 :=jjc to m do
       reduction_matrix[lf,j1] :=reduction_matrix[lf,j1]
                            -temp_value *
                            reduction_matrix[n,jjc];

  234:End;
  235:Rank :=0;
  For i := 1 to n do
  Begin
     Sum := 0.0;
     For j :=1 to m do
     Begin
        If abs(reduction_matrix[i,j]) <= compare_value
           then reduction_matrix[i,j] := 0.0;
        dumy_square[i,j] := reduction_matrix[i,j];
        Sum := sum + abs (reduction_matrix[i,j]);
     End;
     If sum >= compare_value then  rank :=  rank +1;
  End;
End;

Procedure matrix_multiplication(VAR matrix,matrix1,
                                matrix2:Ary1s;
                                VAR L,M,N :Integer );

var mult_matrix1,result_matrix,mult_matrix2 : Ary1s;
    k,j,i                                    : Integer;


Begin
   For j:=1 to m do
   begin
     For i :=1 to l do
     begin
       mult_matrix1[i,j] := matrix[i,j];
     end;
     For k:=1 to n do
        mult_matrix2[j,k] := matrix1[j,k];
   End;
   For i :=1 to l do
```

```
  Begin
    For j:=1 to n do
    Begin
      result_matrix[i,j] := 0.0;
      For k:= 1 to m do
        result_matrix[i,j] := result_matrix[i,j] +
          mult_matrix1[i,k] * mult_matrix2[k,j];
    End;
  End;
  For i:= 1 to l do
  Begin
    For j :=1 to n do
      matrix2[i,j] := result_matrix[i,j];
  End;
End;
```

```
procedure Inverse_find_matrix(VAR A:Ary1s;
                              var XDOT:ary4;
                              var ORDER:integer;
                              var AINV:ary1s;
                              var X:ary4;
                              var singular:integer);

label 5;label 6;label 12;label 16;label 20;label 51;

var
     B2                        :ary1s;
     comp,temporary_value :real;
     n,i,j,k,m                 :integer;

begin
  n:=1;
  for i:=1 to order do
  begin
     for j:=1 to order do
     begin
        AINV[i,j]:= 0.0;
        B2[i,j]:=A[i,j];
     end;
  end;
  for i:= 1 to order do
  begin
     AINV[i,i]:=1;
     X[i]:=XDOT[i];
  end;
  for i:=1 to order do
  begin
     comp:=0.0;
     k:=i;
6:if (abs (B2[k,i]) -abs(comp)) <= 0.0 then goto 5;

     comp:=B2[k,i];
     n:=k;
5:k:=k+1;
     if (k-order) <= 0 then goto 6;
     if B2[n,i] = 0.0 then goto 51;
     if (n-i) < 0 then goto 51;
     if (n-i) = 0 then goto 12;
     for m:=1 to order do
     begin
        temporary_value:= B2[i,m];
        B2[i,m] :=B2[n,m];
        B2[n,m] :=temporary_value;
        temporary_value:= AINV[i,m];
        AINV[i,m]:= AINV[n,m];
        AINV[n,m]:= temporary_value;
     end;
     temporary_value:=X[i];
     X[i]:=X[n];
     X[n]:=temporary_value;
12:X[i]:=X[i] /-B2[i,i];
     temporary_value:=B2[i,i];
     for m:=1 to order do
     begin
        AINV[i,m]:= AINV[i,m] / temporary_value;
        B2[i,m]:=B2[i,m] / temporary_value;
     end;
     for j:=1 to order do
     begin
        if (j-i) = 0 then goto 16;
        if B2[j,i] = 0.0 then goto 16;
        X[j]:=X[j] - B2[j,i] * X[i];
        temporary_value:=B2[j,i];
        for n:=1 to order do
```

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```
        begin
          AINV[j,n]:= AINV[j,n] - temporary_value *
                      AINV[i,n];
          B2[j,n]:=B2[j,n] - temporary_value * B2[i,n];
        end;
    16:end;
  end;
  goto 20;
  51:singular:=1;
20:end;
```

```
Procedure linear_equation(var AA:ary2;
                          var nw,m:integer;
                          var BB,x:ary3;
                          var K:integer;
                          var U:ary2);

label 1;label 2;label 3;label 4;label 5;label 71;
label 81;label 120;label 8;label 6 ;label 10;label 130;
label 7;

Var
    is,it,kk,n,k1,ii,mm,i,j              :integer;
    a1                                   :ary2;
    id                                   :ary3;
    b1,c1,ic,w                           :real;

Begin {linear equation}
  n:=nw;
  mm:=m+1;
  for i:=1 to n do
  Begin
    A1[i,mm] := BB[i];
    for j:= 1 to m do
      A1[i,j] := AA[i,j];

  End;
  k:=1;
  if (n-m) >= 0 then goto 1;
  it:= n+1;
  n:=m;
  for i:= it to m do
  Begin
    for j:=1 to mm do
      A1[i,j] := 0.0;

  End;
  1:for i:=1 to m do
    ID[i]:= i;

  2:kk:=k+1;
  is:=k;
  it:=k;
  B1:=abs(A1[k,k]);
  for i:=k to n do
  Begin
    for j:=k to m do
    Begin
      if( abs(A1[i,j])-B1) <= 0 then goto 3;
      is:=i;
      it := j;
      B1:=abs(A1[i,j]);
    3:End;
  End;
  if(is-k) <= 0 then goto 4;
  for j:= k to mm do
  Begin
    c1:= A1[is,j];
    A1[is,j] := A1[k,j];
  A1[k,j]:= c1;
  End;
  4:if(it-k) <=0 then goto 5;
  ic:=ID[k];
  ID[k] :=ID[it];
  ID[it] :=ic;
  for i:= 1 to n do
  Begin
    C1 :=A1[i,it];
    A1[i,it] := A1[i,k];
```

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```
      A1[i,k] :=c1;
  End;
  5:if  A1[k,k] <> 0 then goto 71;
  kk:=k;
  k:=k-1;
  for j:=kk to m do
    A1[j,j] := -1.0;

  goto 6;
  71:if (k-n) >0 then goto 120;
  if (k-n) < 0 then goto 81;
  A1[n,mm] :=A1[n,mm] / A1[n,n];
  goto 7;
  81:for j:=kk to mm do
  Begin
    A1[k,j] := A1[k,j] / A1[k,k];
    for i:= kk to n do
    Begin
      w:=A1[i,k] * A1[k,j];
      A1[i,j] :=A1[i,j] -w;
      if (abs(A1[i,j]) - 0.0001*abs(w)) >= 0
         then goto 8;
      A1[i,j] :=0.0;
    8:End;
  End;
  if (k-m) >0 then goto 120;
  if (k-m) = 0 then goto 6;
  k:=kk;
  goto 2;
  6:for i:=kk to n do
    if A1[i,mm] <> 0 then goto 120;

  7:k1:=k-1;
  for is:=1 to k1 do
  Begin
    i:=k-is;
    ii:=i +1;
    for it:=ii to k do
    Begin
      for j:=kk to mm do
        A1[i,j] :=A1[i,j] -A1[i,it] *A1[it,j];

    End;
  End;
  for i:=1 to m do
  Begin
    for j:=1 to m do
    Begin
      if (ID[j]-i) <> 0 then goto 10;
      X[i] :=A1[j,mm];
      if (k-m) = 0 then goto 10;
      for is:=kk to m do
        U[i,is-k] := A1[j,is];

    10:End;
  End;
  k:=m-k;
  goto 130;
  120:Writeln;
  Writeln('There are no equations');Delay(2000);
130:End; (linear equation)
```

```
Procedure Polynomial_of_roots(var n:integer;
                              var rr,ri:ary3s;
                              var cf:ary4);
(This program calculates the coefficients of a
 polynomial from its roots)

label 1;label 3;label 111;label 222;label 2;
label 5;label 21;label 50;

var
   ick,nn,mp,i,ii,l,m,mm,mmp                :integer;
   sumreal,prreal1,sumimag,prreal,primag    :real;
   j                                        :ary6;

Begin
   nn:=n+1;
   CF[nn]:=1.0;
   for m:=1 to n do
   Begin
     sumreal:=0.0;
     sumimag:=0.0;
     l:=1;
     J[1]:=1;
     goto 2;
     1:J[l]:=J[l]+1;
     2:if (l-m) >0 then goto 50;
     if (l-m) = 0 then goto 5;
     mm:=m-1;
     for i:=1 to mm do
        Begin
           ii:= i+1;
           J[ii]:=J[i]+1;
        End;
     5:prreal:=1.0;
     prreal1:=1.0;
     primag:= 0.0;
     for i:=1 to m do
     Begin
        prreal:=prreal1;
        ick:=J[i];
        prreal1:= prreal*RR[ick] - primag*RI[ick];
        primag:=  prreal*RI[ick]+primag*RR[ick];
     End;
     sumreal := sumreal+prreal1;
     sumimag:=  sumimag+primag;
     for i:=1 to m do
     Begin
        l:=m-i+1;
        if (J[l]-n+m-l) >0 then goto 50;
        if (J[l]-n+m-l) <0 then goto 1;
     End;
     mp:=n-m+1;
     mmp:=mp mod 2;
     if mmp <> 0 then goto 111;
     CF[mp]:= sumreal;goto 222;
     111: CF[mp]:=-sumreal;
   222:End;
   goto 21;
   50:Writeln;
   Writeln('There is an error in polynomial
             calculation from roots procedure');
   Delay(2000);
   21:mmp:= n mod 2;
   if mmp <> 0 then goto 3;
   for i:= n downto 1 do
      CF[i]:=-CF[i];

3:End;
```

```
{Plot Nyquist is a routine to draw the Nyquist plot
 from the data generated in the Nyquist procedure. }

Procedure Plot_Nyquist(StartDecade, EndDecade,
                       NumberDecades:Integer;
                       FreqArray,PlotArray1,
                       Plotarray2,
                       MagPhaseArray:PlotArray;
                       BigPic,OpenLoop:Boolean);

var
   Xint,Yint, i,j,n,code : integer;
   Ymin,Ymax,  Xmin,Xmax   : real;
   XLabel,YLabel           : String[3];
   Title1,Title2           : String[80];
   DumpGraph,quit          : Boolean;
   w,XminL,YminL           : Real;
   GraphWidthX,GraphWidthY: Real;
   Xexponent,Yexponent     : integer;
   XexpLabel,YexpLabel     : string[3];
   GraphArray              : PlotArray;
   List                    : text;


function Expon(Y,X:real):real;
              {computes Y raised to X power}
Begin
   Expon := exp( X * (ln(Y)));
end;

Procedure PrintGraphData;
          {dump data used to make graph to printer}
Begin
   LeaveGraphic;Clrscr;
   repeat
    Textcolor(white);     gotoxy(20,10);
    writeln('  *** PROGRAM OUTPUT OPTIONS ***  ');
    gotoxy(20,13);writeln('<P> Printer output      ');
    Textcolor(yellow);    gotoxy(20,14);
    writeln('     Check Your Printer!         ');
    Textcolor(white);    gotoxy(20,15);
    writeln('<F> List to File name            ');
    gotoxy(20,16);
    writeln('     on the current drive        ');
    gotoxy(20,17);
    writeln('<Q> Quit                         ');
    gotoxy(42,15);
    textcolor(yellow);write('"NYQUIST.RES"');
    gotoxy(28,17);
    read(kbd,ch);
     If (ch = 'F') or (ch = 'f') or (ch = 'P') or
        (ch = 'p') then
      begin
        if (ch = 'F') or (ch = 'f') then
        begin
          gotoxy(24,15);textcolor(red);
          write(' PRINTING.....                  ');
          assign(list,'Nyquist.RES');
          rewrite(list);
        end
        else
        begin
          gotoxy(24,13);textcolor(red);
          write(' PRINTING..........             ');

          assign(list,'LST:');
          rewrite(list);
```

```
        end;
        Title1:=('    w (rad)            Magnitude
               Phase (rad)               Xplot              YPlot');

      Title2:=('----------------------------------');
      writeln(list,'          NYQUIST PLOT RESULT   ');
        writeln(list);writeln(list);
        writeln(list,Title1); Writeln(list,Title2);
        writeln(list); writeln(list);
        for i:= 1 to 81 do
        begin
          w := FreqArray[i,1];
          writeln(list,w:9:3,'             ',
                   MagPhaseArray[i,1]:11:3,'          ',
                   MagPhaseArray[i,2]:11:3,'      ',
                   PlotArray1[i,1]:10:3,'     ',
                   PlotArray1[i,2]:10:3);
          if i= 47 then
          begin
            writeln(list);
            write(list,chr(12));
            writeln(list,Title1);
            writeln(list,Title2);
            writeln(list); writeln(list);
          end;
        end;
      end;
    until ch in ['Q','q'];
    EnterGraphic;
    swapscreen;
      close(list);
    end;


Begin {Plot Nyquist} {prompt for window parameters}
   if not(BigPic) then
   begin
      P[3]:= '1511N00503-010101';
      P[4]:= '1512N00504-010101';
      P[5]:= '1513N00505-010101';
      P[6]:= '1514N00506-010101';

   Clrscr; TextColor(LightBlue);
   writeln('   *** NYQUIST PLOTTING PARAMETERS ***');
   textcolor(yellow);
        writeln('================================');

   HighVideo;
   writeln;writeln;Textcolor(white);
   msg('Input Plotting Coordinates for the
        Nyquist Plot',1,6);
   TextColor(yellow);
   writeln;writeln;writeln;writeln; writeln;
   writeln('X-Minimum:  ');
   writeln('X-Maximum:  ');
   writeln('Y-Minimum:  ');
   writeln('Y-Maximum:  ');


   Input Handler('N0306',Escape);
   writeln;writeln;
   writeln('Any changes to these parameters?
             (Y / N):');
   Input('A','',45,16,2,true,F1,F10);
   If (answer='Y') or (F1) then
        Input Handler('C0306',Escape);
   Val(filvar[3],Xmin,code);
   Val(filvar[4],Xmax,code);
```

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```
      Val(filvar[5],Ymin,code);
      Val(filvar[6],Ymax,code);
    end
    else
    begin
     Xmax:= 100;
          {set default values for "big picture" plot}
     Xmin:= -100;
     Ymax:= 100;
     Ymin:= -100;
    end;

    INITGRAPHIC;
    niceaxes(xmin,xmax,ymin,ymax, '');
    n:=1;
    for i:=1 to 80 do
    if (abs(plotarray1[i,1]) > Xmax) or
     (abs(plotarray1[i,2]) > Ymax) then     n:= n+1;
    if n<>1 then n:= n-1;
             {use 1 extra point beyond graph border}

    DrawPolygon(PlotArray1,n,-80,0,1,0);
                        {draw graph on screen}
    n:=1;
    for i:=1 to 80 do
    if (abs(plotarray2[i,1]) > Xmax) or
                      (abs(plotarray1[i,2]) > Ymax) then

    n:= n+1;
    if n<>1 then n:= n-1;
    Setlinestyle (1);
    DrawPolygon(Plotarray2,n,-80,0,1,9);

    Repeat until Keypressed;
                    {Put option menu on screen}
    quit:= false;
    repeat
    if OpenLoop then
        Graph_Menu('Open Loop NyquistPlot',
                   DumpGraph,quit)
    else
    Graph_Menu('Closed Loop Nyquist Plot',
               DumpGraph,quit);
    if DumpGraph then PrintGraphData;
    until quit;
    LeaveGraphic;
end;
```

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```
{Graph_Menu provides a window on screen and offers the
user options to make a title, print the graph, print
the numbers from the graph, or quit and return to the
menu.   }

Procedure Graph_Menu(TitleWindowName:STR25;
                     var DumpGraphData,quit : boolean);

var
   Line1, Line2, Line3  : string[40];

Procedure TitlePrompt;
begin
   TextColor(White);
   Center('*** Graph Title ***',1,2,80);

   P[1]:= '1010A04001-010100';
   P[2]:= '1012A04002-010100';
   P[3]:= '1014A04003-010100';

   textcolor(yellow);
   msg('Line 1:',1,10);
   msg('Line 2:',1,12);
   msg('Line 3:',1,14);

   textcolor(green);
   msg('Type your title for your graph.',6,20);

   Input_handler('N0103',escape);

   Line1:= copy(filvar[1],1,40);
   Line2:= copy(filvar[2],1,40);
   Line3:= copy(filvar[3],1,40);

end;

Procedure ShowTitle;
     {makes title block and writes title to block}

begin
   copyscreen;
   SetLineStyle(0);
   DefineWindow(3,11,20,40,60);
   DefineWorld(3,0,0,40,16);
   SelectWorld(3); SelectWindow(3);
   DefineHeader(3,TitleWindowName); {puts header on box}

   SetBackground(0);
   SetHeaderOn;DrawBorder;
   DrawTextW(1,4,1,Line1);
   DrawTextW(1,8,1,Line2);
   DrawTextW(1,12,1,Line3);
   SetBreakOff; SetMessageOff;

   repeat
     read(kbd,ch);
     case ord(ch) of
      {allow user to move title box anywhere on screen}
        72 : MoveVer(-4,true); {up arrow}
        75 : MoveHor(-1,true); {left arrow}
        77 : MoveHor(1,true);  {right arrow}
        80 : MoveVer(4,true);  {down arrow}
     end;
   until ord(ch)= 13;
            {freeze box and continue with <return> key}
end;

begin
```

```
  DumpGraphData:= False;
  selectscreen(1);
  copyscreen; SetLineStyle(0);
        {save underlying screen and display menu box}
  DefineWindow(4,11,20,35,90);
  DefineWorld(4,0,0,20,20);
  SelectWorld(4); SelectWindow(4);
  DefineHeader(4, 'Graph Options Menu');
  SetHeaderOn; SetBackground(0);DrawBorder;
  DrawTextW(1,4,1,'<P>  Print Graph to the printer');
        {display menu options}
  DrawTextW(1,7,1,'<T>  Make Title to the Graph');
  DrawTextW(1,10,1,'<N> Print Table of Numbers');
  DrawTextW(1,13,1,'      used to Generate Graph');
  DrawTextW(1,17,1,'<Q> Continue to the Program');
  repeat
    Option;
    case ch of      {interpret user input}
      'P': begin
             swapscreen;
                {redisplays screen without menu box}
             hardcopy(false,1);  {print to printer}
             copyscreen;
             ch := 'P';
           end;
      'T': begin
             leavegraphic;     {leave graphics screen}
             TitlePrompt;      {prompt for title}
             entergraphic;     {return to graphics mode}
             swapscreen;       {bring back graph}
             ShowTitle;{display title box on screen}
             copyscreen;{save graph with title box}
             ch := 'T';
           end;
      'N': begin
             DumpGraphData := True;
                {sets boolean to cause numbers }
                {to be printed}
             ch := 'N';
           end;
      'Q': ;

    end;
  until ch in ['P','T','N','Q'];
  if ch = 'Q' then Quit := true
              else Quit := false;
end;
```

```
procedure input_Factored(Zeros_or poles:str5;
                            NFactors:integer;var real_part,
                            imaginary_part:ary3s);

{Begin processing Factored form Input-Internal routine}

var
   i,j    : integer;
   test   : real;

 begin

     P[11]     := '0905N01011-000101';
     P[12]     := '2505N01012-000101';
     P[13]     := '0907N01013-000101';
     P[14]     := '2507N01014-000101';
     P[15]     := '0909N01015-000101';
     P[16]     := '2509N01016-000101';
     P[17]     := '0911N01017-000101';
     P[18]     := '2511N01018-000101';
     P[19]     := '0913N01019-000101';
     P[20]     := '2513N01020-000101';
     P[21]     := '0915N01021-000101';
     P[22]     := '2515N01022-000101';
     P[23]     := '0917N01023-000101';
     P[24]     := '2517N01024-000101';
     P[25]     := '0919N01025-000101';
     P[26]     := '2519N01026-000101';
     P[27]     := '0921N01027-000101';
     P[28]     := '2521N01028-000101';
     P[29]     := '0923N01029-000101';
     P[30]     := '2523N01030-000101';


     ClrScr; TextColor(White);    {write screen titles}
     gotoXY(1,24);
     Invvideo('Press <ESC> to change an entry');
     Center('*** Desired characteristic Polynomial
                 Input***',1,1,80);
     HighVideo;
     writeln;TextColor(green);
     if Zeros_or Poles = 'ZEROS' then
         writeln('NUMERATOR Transfer Function
                 Input -- FACTORED Form')
     else
         writeln('Characteristic equation
                 Input -- FACTORED Form');

     HighVideo;writeln;writeln;
     for j:=1 to NFactors do    {type prompt strings}
         begin
          writeln('    s =                    +j');
          writeln;
         end;

     str((NFactors*2+10):2,strg);

     specification := concat('N11',strg);

     Input_handler(specification, escape);
                        {call the input handler}

     for j:= 1 to NFactors do
                    {compute the zero values from}
         begin       {input handler string Filvar}
          val(filvar[2*j+9 ],test,code);
          if code = 0 then Real_Part[j]:=test;
                 {val conversion successful if code}
```

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```
          val(filvar[2*j+10],test,code);
                              {=0, error otherwise}
          if code = 0 then Imaginary_Part[j]:=test;

        end;
  end; {procedure Input_factored}

{Begin processing Coefficient form Input-Internal
procedure }

Procedure Input_Coeff(Zeros_or_Poles:Str5;
                      NCoeff:integer;
                      var Coeff: ary4);

var
   i,j,                      {counters}
   NCoeff_old : integer;  {holds old poly order if
                            changing order}
   test: real;        {holds "val" results until validated}

begin

    P[21]   := '0406N01021-000101';
              {Input-Handler descriptors for coeff}
   P[22]   := '1806N01022-000101';   {form input}
   P[23]   := '3206N01023-000101';
   P[24]   := '4606N01024-000101';
   P[25]   := '0408N01025-000101';
   P[26]   := '1808N01026-000101';
   P[27]   := '3208N01027-000101';
   P[28]   := '4608N01028-000101';
   P[29]   := '0410N01029-000101';
   P[30]   := '1810N01030-000101';

  NCoeff_old:= NCoeff;

  ClrScr; TextColor(White); {print screen titles}
  gotoxy(1,24);
  invvideo('Press <ESC> to change an entry');
  gotoxy(1,1);
  writeln('                 *** Desired characteristic
          Polynomial input ***');
  TextColor(Green);
  if Zeros_or_Poles = 'POLES' then

        writeln('NUMERATOR Transfer Function
                Input -- COEFFICIENT Form')
     else
     begin
        write('COEFFICIENT Form ---');
        TextColor(lightmagenta);
        if not luen then
          writeln('Highest degree coefficient
                  MUST be 1.0');

    end;
    HighVideo;

    if NCoeff > NCoeff_old then
    begin
      for j:=1 to NCoeff_old - NCoeff do
          for i:=NCoeff_old + 1 downto 1 do
            Filvar[i+1] := Filvar[i];

    end;

  if NCoeff < NCoeff_old then
```

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```
    begin
     for j:= 1 to NCoeff_old - NCoeff do
         for i:= 1 to NCoeff_old + 1 do
             Filvar[i] := Filvar[i+1];
    end;


  VertPos:=4;
  for i:=NCoeff+1 downto 1 do
      begin
       j:=NCoeff+1 - i;
       PosCounter := (j mod 4) + 1;
       HorizPos := PosCounter * 14;
       If PosCounter = 1 then VertPos := VertPos + 2;

       if i<> 1 then{prompts for coeff input}
           begin
            msg('s +',HorizPos,VertPos);
            str(i-1:2,Exponent);
            msg(Exponent,HorizPos+1,VertPos-1);
           end;
      end;

      str((20+NCoeff+1):2,strg); {sets up and calls
                                  input handler}

      specification := concat('N21',strg);

      Input_handler(specification,escape);

      for j:= NCoeff+1 downto 1 do
          begin
           val(Filvar[NCoeff+22-j],test,code);
           if code = 0 then Coeff[j]:=test;
          end;
end;
```

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```
procedure characteristic_equation(var A3:ary1s;
                                  var N:integer;
                                  var C2:ary4);

(This procedures computes the characteristic equation
polynomials coefficients by using the principle-minor
method)

label 10;label 20;label 30;label 40;label 50;
label 60;label 15; label 70;label 80;label 90;
label 100;label 1;label 2;label 5;

var
    B3,A1                                      :ary1s;
    integer_vector                             :ary6;
    D10       : array [1..280] of real;
    mm,ii,l,m,i,kk,nr,nc,k1,i1i,
    counter,m1m,even,nn,k,j1,n1,m1             :integer;
    temp_value,det,det_correction,
    determinant_old,determinant,value_c2,value :real;

begin
  nn:=n+1;
  for i:=1 to nn do
  begin
    C2[i]:=0.0;
  end;
  C2[nn]:=1.0;
  for m:=1 to n do
  begin
    k:=0; l:=1;
    integer_vector[1]:=1;
    goto 2;
1:integer_vector[l]:=integer_vector[l]+1;
2:if (l-m) > 0 then goto 90;
  if (l-m) = 0 then goto 5;
  mm:=m-1;
  for i:= 1 to mm do
  begin
    ii:=i+1;
    integer_vector[ii]:=integer_vector[i]+1;
  end;
5:for i:=1 to m do
  begin
    for kk:=1 to m do
    begin
      nr:=integer_vector[i];
      nc:=integer_vector[kk];
      B3[i,kk]:=A3[nr,nc];
    end;
  end;
  k:=k+1;

  counter := 0;
  for i1i:=1 to M do
  begin
    for j1:=1 to M do
    begin
      A1[i1i,j1]:= B3[i1i,j1];
    end;
  end;
  for i1i:= 1 to M do
  Begin
    k1:=i1i;
30:if A1[k1,i1i] <> 0.0 then goto 10;
    k1:=k1+1;
    if (k1-M) <= 0 then goto 30;
    goto 40;
```

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```
      10:if (i1i-k1) > 0 then goto 40;
      if (i1i-k1) = 0 then goto 70;
      for m1m:=1 to M do
      Begin
         temp_value:=A1[i1i,m1m];
         A1[i1i,m1m]:=A1[k1,m1m];
         A1[k1,m1m]:=temp_value;
      End;
      counter:= counter+1;
      70:ii:=i1i+1;
      if ii > M  then goto 20;
      for m1m:=ii to M do
      Begin
         if A1[m1m,i1i] = 0.0 then goto 80;
         value:=A1[m1m,i1i] / A1[i1i,i1i];
         for n1:= i1i to M do
         begin
            A1[m1m,n1]:= A1[m1m,n1] - A1[i1i,n1] * value;

         end;
      80:End;
   20:End;
   det:=1.0;
   for i1i:=1 to M do
   begin
      det:=det * A1[i1i,i1i];
   end;
   det_correction:= exp( counter * ln(1.0));
   determinant_old:=det_correction * det;
   even:= counter mod 2;
   if even <> 0 then goto 60;
   determinant := determinant_old;
   goto 50;
   60:determinant:=-determinant_old;
   goto 50;
   40:determinant:=0.0;

   50:D10[k]:=determinant;
   for i:= 1 to m do
   begin
      l:=m-i+1;
      if (integer_vector[l]-(n-m+1)) > 0 then goto 90;

      if (integer_vector[l]-(n-m+1)) < 0 then goto 1;
   end;

   m1:=n-m+1;
   value_c2:=exp( m * ln(1.0));
   even:= m mod 2;
   for i:=1 to k do
   begin
         if even = 0 then
         begin
            value_c2:=value_c2;
            goto 15;
         end;
         if even <> 0 then
         begin
            value_c2:=-1.0 * value_c2;
         end;
      15:C2[m1]:=C2[m1] + D10[i] * value_c2;
      value_c2:=exp( m * ln(1.0));
   end;

   end;goto 100;
   90:writeln('Error in characteristic equation');
100:end;
```

```
{ This procedure uses modified BARSTOW method to
  calculate the roots of the polynomial }

PROCEDURE root_finder(var n:integer;
                      var A:ary4;
                      var u,v:ary3s;
                      var ir:integer );


{ label decleration for the GOTO statement}

label 3;label 4;label 7;label 9;label 10;label 13;
label 15;label 19;label 20; label 23;label 30;
label 32;label 33;label 34;label 36;label 49;
label 50;label 52;label 53; label 70;label 72;label 73;
label 75;label 76;label 81;label 82;label 100;

var
    irev,i,nc,m,nl,np,j,i1:integer;

    p,q,r,f,e,cbar,d,qp,pp:real;

    H,B,C: array [1..21] of real;


Begin
    irev:=ir; {take given values}
    nc:=n+1;
    for i:=1 to nc do
        H[i]:= A[i];

    p:=0.0;   {initialization}
    q:=0.0;
    r:=0.0;
    3:if H[1] <> 0 then goto 4;
    nc:=nc-1;
    U[nc]:=0.0;
    V[nc]:=0.0;
    for i:= 1 to nc do
        H[i]:= H[i+1];

    goto 3;
    4:if (nc-1) = 0 then goto 100;
    if (nc-2) <> 0 then goto 7;
    r:=-H[1]/H[2];
    goto 50;
    7:if (nc-3) <> 0 then goto 9;
    p:=H[2]/H[3];
    q:=H[1]/H[3];
    goto 70;
    9:if (abs(H[nc-1]/H[nc])-abs(H[2]/H[1])) >= 0.0
        then goto 19;
    irev:=-irev;
    m:=nc div 2;
    for i:=1 to m do
    begin
        nl:=nc+1-i;
        F:=H[nl];
        H[nl]:=H[i];
        H[i]:=F;
    end;
    if Q <> 0.0 then goto 13;
    p:=0.0;
    goto 15;
    13:p:=p/q;
    q:=1.0/q;
    15:if r = 0.0 then goto 19;
    r:=1.0/r;
```

```
19:e:=5.0e-10;
B[nc]:=H[nc];
C[nc]:=H[nc];
B[nc+1]:=0.0;
C[nc+1]:=0.0;
np:=nc-1;
20:for j:= 1 to 1000 do
begin
    for i1:= 1 to np do
    begin
        i:=nc-i1;
        B[i]:=H[i] + R * B[i+1];
        C[i]:=B[i] + R * C[i+1];
    end;
    if (abs(B[1]/H[1])-e) <= 0.0 then goto 50;
    if C[2] <> 0.0 then goto 23;
    r:=r+1.0;
    goto 30;
23:r:=r - B[1]/C[2];
30:for i1:= 1 to np do
    begin
        i:=nc-i1;
        B[i]:= H[i] - p * B[i+1] - q * B[i+2];
        C[i]:= B[i] - p * C[i+1] - q * C[i+2];
    end;
    if H[2] <> 0.0 then goto 32;
    if (abs(B[2]/H[1])-e) > 0.0 then goto 34;
    if (abs(B[2]/H[1])-e) <= 0.0 then goto 33;
32:if (abs(B[2]/H[2])-e) > 0.0 then goto 34;
33:if (abs(B[1]/H[1])-e) <= 0.0 then goto 70;
34:cbar:= C[2] - B[2];
    d:=C[3] * C[3] - cbar * C[4];
    if d <> 0.0 then goto 36;
    p:=p - 2.0;
    q:= q * (q + 1.0);
    goto 49;
36:p:= p + (B[2] * C[3] - B[1] * C[4])/d;
    q:= q + (-B[2] * cbar + B[1] * C[3])/d;
49:end;
e:=e * 10;
goto 20;
50:nc:= nc-1;
V[nc]:= 0.0;
if irev >= 0 then goto 52;

U[nc]:=1.0/r;
goto 53;
52:U[nc]:=r;
53:for i:=1 to nc do
    H[i]:= B[i+1];

goto 4;
70:nc:=nc-2;
if irev >= 0 then goto 72;
qp:=1.0/q;
pp:=p/(q * 2.0);
goto 73;
72:qp:= q;
pp:=p/2.0;

73:f:=pp * pp - qp;
if f >= 0.0 then goto 75;
U[nc+1]:= -pp;
U[nc]:=-pp;
V[nc+1]:= sqrt(-f);
V[nc]:=-V[nc+1];
goto 76;
75:if pp <> 0.0 then goto 81;
```

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```
    U[nc+1]:= -sqrt(f);
    goto 82;
81:U[nc+1]:=-(pp/abs(pp)) * ( abs(pp) + sqrt(f));
82:V[nc+1]:= 0.0;
    U[nc]:= qp/U[nc+1];
    V[nc]:=0.0;
76:for i:=1 to nc do
      H[i]:= B[i+2];

    goto 4;
100:end;
```

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