TABLE OF CONTENTS

		Page
	ABSTRACT	vi
	ACKNOWLEDGEMENTS	vii
	LIST OF TABLES	viii
	LIST OF FIGURES	ix
1.	INTRODUCTION	
	1.1 General	1
	1.2 Computer Graphics System	4
	1.3 Scope of the Thesis	9
2.	PROGRAM LADNET AND TRANF	
	2.1 Introduction	11
	2.2 Ladder Network Design	13
	2.3 Transfer and Driving-Point Functions	27
3.	PROGRAM ANALY	
	3.1 Introduction	38
	3.2 Bode and Nyquist Plots	38
4.	ANALYSIS OF 10TH ORDER ELLIPTIC BAND-PASS FILTER AND SYSTEM FUNCTION	
	4.1 Introduction	72
	4.2 LNA of 10th Order Elliptic Band-Pass Filter	72
	4.3 Sensitivity Study of 10th Order Elliptic Band-Pass Filter	113

4.4 Stability of a System Function using Analy 122

5. SUMMARY AND DISCUSSIONS 134

REFERENCES 137

APPENDIX I 138

APPENDIX II 144

APPENDIX III 173

APPENDIX IV 186

APPENDIX V 200

COMPUTER-AIDED ANALYSIS OF LADDER NETWORKS AND SYSTEM FUNCTIONS USING INTERACTIVE GRAPHICS

by

Jerome Martynko

ABSTRACT

This thesis is concerned with the development of a Computer-Aided Design package to obtain the frequency response of Transfer Functions of ladder networks. This package uses interactive graphics whereby a ladder network is constructed on a Cathode-Ray Tube and its Transfer and Driving-Point functions are obtained. Further, the frequency response of system functions can also be obtained. Discussion and examples are given upon the development and use of the package. A 10th Order Elliptic Band-Pass filter is used as an example of how the package operates. In addition, a system function is studied for stability employing an option of the package.

ACKNOWLEDGEMENTS

The author expresses his deep gratitude to Dr. M.N.S. Swamy and Dr. S. Gracovetsky for their suggestion of the topic and for their guidance in the research done in this thesis.

He thanks Dr. V. Ramachandran for his suggestions in the writing of this thesis.

He also thanks Dr. A. Antoniou for his assistance in obtaining information for this thesis.

He appreciates the many helpful discussions with Mr. N. Yemenidjian.

Gratitude and appreciation goes to Ms. June Anderson for her patience in typing this thesis and to Ms. Lina D'Iorio for her assistance in typing the preliminary draft work.

This work was supported by the National Research Council of Canada under grant number A-7739, awarded to Dr. M.N.S. Swamy.

LIST OF TABLES

Table 2.1 Chain Matrix of Components in Fig. 2.2

LIST OF FIGURES

CHAPTER 1

Page

Fig. 1.1 Interactive Graphics Terminal with Teletype, Light Pen and CRT 2

Fig. 1.2 Historical Development of Computer Graphics 5

Fig. 1.3 PDP 11/45 GT-44 Graphics System, Concordia University, Electrical Engineering Department 6

Fig. 1.4 GT-44 Graphics System Internal System Operation 7

CHAPTER 2

Fig. 2.1 Filter Design-Analysis Process 12

Fig. 2.2 Initial Display of LADNET in Select A Command Mode 14

Fig. 2.3 LADNET Display in Location Strike Mode 17

Fig. 2.4 LADNET Display in Component Insert Mode 18

Fig. 2.5 LADNET Display with LC Component in Position 19

Fig. 2.6 LADNET Display with a Typical Ladder Network 20

Fig. 2.7 LADNET Display in Confirm A Command Mode 22

Fig. 2.8 Two-Part LC Network 31

CHAPTER 3

Fig. 3.1 Bode Plot between .1 and 2. rad/sec of Equation 3.5 45

Fig. 3.2 Bode Plot between .1 and 2. rad/sec of Equation 3.5 with Cursor at .9978 rad/sec 47

Fig. 3.3 Nyquist Plot between .1 and 2. rad/sec of Equation 3.5 49

Fig. 3.4 Nyquist Plot between .1 and 2. rad/sec of Equation 3.5 with Cross Marker at .523 rad/sec 51

Fig. 3.5 Bode Plot between .1 and 2.5 rad/sec of Equation 3.6 60

Fig. 3.6 Bode Plot between .1 and 2.5 rad/sec of Equation 3.6 with Cursor at .904 rad/sec 62

Fig. 3.7 Bode Plot between .1 and 2.5 rad/sec of Equation 3.6 with Cursor at 1.462 rad/sec 63

Fig. 3.8 Nyquist Plot between .1 and 2.5 rad/sec of Equation 3.6 64

Fig. 3.9 Nyquist Plot between .1 and 2.5 rad/sec of Equation 3.6 with Cross Marker at 1.02 rad/sec 66

CHAPTER 4

Fig. 4.1 10th Order Elliptic Band-Pass Filter 73

Fig. 4.2 Initial Display of LADNET in Select A Command Mode 75

Fig. 4.3 LADNET Display in Location Strike Mode 76

Fig. 4.4 LADNET Display in Component Insert Mode 77

Fig. 4.5 LADNET Display with R_1 in Position 1 of 10th Order Elliptic Band-Pass Filter 78

Fig. 4.6 LADNET Display with L_2C_2 in Positive 2 of 10th Order Elliptic Band-Pass Filter 80

Fig. 4.7 LADNET Display with $L_3^+C_3^+$ in Position 3 of 10th Order Elliptic Band-Pass Filter 81

Fig. 4.8 LADNET Display with Open-Circuit in Position 4 of 10th Order Elliptic Band-Pass Filter 82

Fig. 4.9 LADNET Display with $L_3^-C_3^-$ in Position 5 of 10th Order Elliptic Band-Pass Filter 83

Fig. 4.10 LADNET Display with L_4C_4 in Position 6 of 10th Order Elliptic Band-Pass Filter 84

Fig. 4.11 LADNET Display with $L_5^+C_5^+$ in Position 7 of 10th Order Elliptic Band-Pass Filter 85

Fig. 4.12 LADNET Display with Open-Circuit in Position 8 of 10th Order Elliptic Band-Pass Filter 86

Fig. 4.13	LADNET Display with L_5C_5 in Position 9 of 10th Order Elliptic Band-Pass Filter	87
Fig. 4.14	LADNET Display with L_6C_6 in Position 10 of 10th Order Elliptic Band-Pass Filter	88
Fig. 4.15	LADNET Display in Component Insert Mode for Insertion of Short-Circuit in Position 11 of 10th Order Elliptic Band-Pass Filter	89
Fig. 4.16	LADNET Display with Short-Circuit in Position 11 of 10th Order Elliptic Band-Pass Filter	90
Fig. 4.17	LADNET Display with Complete 10th Order Elliptic Band-Pass Filter	91
Fig. 4.18	LADNET Display of 10th Order Elliptic Band-Pass Filter in Confirm Mode of Numeric Input Command	92
Fig. 4.19	LADNET Display of 10th Order Elliptic Band-Pass Filter in Confirm Mode of Transfer Function Command	95
Fig. 4.20	Bode Plot between .1 and 1.9 rad/sec of 10th Order Elliptic Band-Pass Filter	101
Fig. 4.21	Bode Plot between .5417 and 1.9 rad/sec of 10th Order Elliptic Band-Pass Filter	103
Fig. 4.22	Bode Plot between .5417 and 1.9 rad/sec of 10th Order Elliptic Band-Pass Filter with Cursor at .7794 rad/sec	104

Fig. 4.23 Bode Plot between .5417 and 1.9 rad/sec of 10th Order Elliptic Band-Pass Filter with Cursor at 1. rad/sec 105

Fig. 4.24 Bode Plot between .5417 and 1.9 rad/sec of 10th Order Elliptic Band-Pass Filter with Cursor at 1.279 rad/sec 106

Fig. 4.25 Bode Plot between .7 and .793 rad/sec of 10th Order Elliptic Band-Pass Filter 107

Fig. 4.26 Bode Plot between .7 and .793 rad/sec of 10th Order Elliptic Band-Pass Filter with Cursor at .753 rad/sec 108

Fig. 4.27 Bode Plot between .79 and 1.275 rad/sec of 10th Order Elliptic Band-Pass Filter 109

Fig. 4.28 Bode Plot between .79 and 1.275 rad/sec of 10th Order Elliptic Band-Pass Filter with Cursor at 1.001 rad/sec 110

Fig. 4.29 Bode Plot between 1.2 and 1.4 rad/sec of 10th Order Elliptic Band-Pass Filter 111

Fig. 4.30 Bode Plot between 1.2 and 1.4 rad/sec of 10th Order Elliptic Band-Pass Filter with Cursor at 1.327 rad/sec 112

Fig. 4.31 Nyquist Plot between .5417 and 1.9 rad/sec of 10th Order Elliptic Band-Pass Filter with Cross Marker at .779 rad/sec 114

Fig. 4.32	Bode Plot between .5417 and 1.9 rad/sec of 10th Order Elliptic Band-Pass Filter with 5% Variation in Inductor Values and -5% Variation in Capacitor Values Cursor at 1.007 rad/sec	119
Fig. 4.33	Bode Plot between .7 and .793 rad/sec of 10th Order Elliptic Band-Pass Filter with 5% Variation in Inductor Values and -5% Variation in Capacitor Values Cursor at .753 rad/sec	120
Fig. 4.34	Bode Plot between .79 and 1.275 rad/sec of 10th Order Elliptic Band-Pass Filter with 5% Variation in Inductor Values and -5% Variation in Capacitor Values Cursor at 1.001 rad/sec	121
Fig. 4.35	Bode Plot between 1.2 and 1.5 rad/sec of 10th Order Elliptic Band-Pass Filter with 5% Variation in Inductor Values and -5% Variation in Capacitor Values Cursor at 1.327 rad/sec	123
Fig. 4.36	Nyquist Plot between .1 and 10. rad/sec of Equation 4.1	127
Fig. 4.37	Nyquist Plot between .1 and 10. rad/sec of Equation 4.1 with Cross Marker at 1.31 rad/sec	128
Fig. 4.38	Nyquist Plot between 1.3 and 10. rad/sec of Equation 4.1	130
Fig. 4.39	Nyquist Plot between 1.3 and 10. rad/sec of Equation 4.1 with Cross Marker at 1.39 rad/sec	131

Fig. 4.40 Nyquist Plot between 1.3 and 10. rad/sec of Equation 4.1 with Cross Marker at 3.12 rad/sec 132

APPENDIX

II A	Program LADNET General Organization	144
II B	Insert Command Sequence	145
II C	Numeric Input Command Sequence	146
II D	Transfer Function Command Sequence	147
II E	Modify Value Command Sequence	148
II F	Reset Command Sequence	149
II G	Sensitivity Command Sequence	150
III A	Program TRANF Operation Sequence	173
IV A	Program ANALY Operation Sequence	186

CHAPTER 1

INTRODUCTION

1.1 GENERAL

Design engineering techniques in the past ten to fifteen years have been greatly enhanced by the advancement of computer technology. This advancement has added a new dimension to engineering design technique in the way of Computer-Aided Design (CAD) using interactive graphics.

CAD using interactive graphics is a specialized segment of computer technology, whereby an active and continuous expression of design ideas is achieved by using devices which are compatible to both the user and the computer. The most popular of these devices are illustrated in Fig. 1.1. Here we have a typical graphics terminal whereby the designer converses with the computer using a light pen, a teletype consol, and a Cathode-Ray Tube (CRT) display. By utilizing these devices, the designer can change or analyze the display shown. The flexibility and the advantages of employing such a system can be considered as follows:

a) Design work can be carried out in the terminology of the particular field.

b) Training and learning of specific computer languages and technology can be kept to an absolute minimum.

c) More creative and innovative design work can take place efficiently because of the almost instant turn around time given to the designer to check and analyze the design.

Fig. 1.1 Interactive Graphics Terminal with Teletype, Light Pen and CRT

d) Bothersome updating and modifications of drawings is kept to a minimum. The reason is that when the designer has completed a design, either a picture or drawing can be obtained from the CRT display.

The history and conception of CAD using interactive graphics dates back to the early 1960's, when Ivan Sutherland of M.I.T. developed his Sketchpad program[3]. Using a TX-2 computer located at Lincoln Laboratory M.I.T., Sutherland's research involved the ability to draw and manipulate figures and alphanumerics using the devices mentioned previously. Sutherland's work was quite extensive, in that some of the basic hardware and software structures developed still forms the basis for present day graphic systems.

Parallel to Sutherland's research, General Motors developed their own specific graphic system DAC-1 (Design Augmented by Computer). This system developed by General Motors surpassed the capabilities that were achieved by Sutherland. The DAC-1 system was able to do what Sutherland had achieved, but in addition, DAC-1 provided the features of scale expansion, rotation, zoom, and partial views of the display illustrated on the CRT. With the development of DAC-1, it was shown that a computer graphics system was feasible in an industrial environment.

Along side the Sketchpad and DAC-1 projects, Itek Laboratories established their own graphics system, Digigraphics, which was used in the development of optical lens. The achievements of these projects enabled the growth and expansion of many more graphic systems as shown in Fig. 1.2.

1.2 COMPUTER GRAPHICS SYSTEM

The computer graphics system illustrated in Fig. 1.3, shows the external hardware of a PDP 11/45 GT-44 Graphics System located at Concordia University, in the Electrical Engineering Department. This system was developed and supplied by Digital Equipment Corporation (DEC). Fig. 1.4 illustrates the internal operating structure of the GT-44 Graphics System. The internal structure and operation of the system is quite involved and detailed. Therefore, further information pertaining to the structure and operation is given in Appendix I.

The external hardware of the GT-44 system is as follows:

a) PDP 11/45 Computer with two RK05 disk drives capable of storing 2.4 million 16-bit words of data, along with 32K core of memory.

b) VT 11 Graphics Display Processor whose function is to link the PDP 11/45 to the CRT display. This unit generates and drives the CRT display.

c) VR 17 CRT display monitor which provides a viewing area of 9.25 inches by 9.25 inches.

d) 375 Light Pen is a light sensitive device which allows for the interactive capabilities.

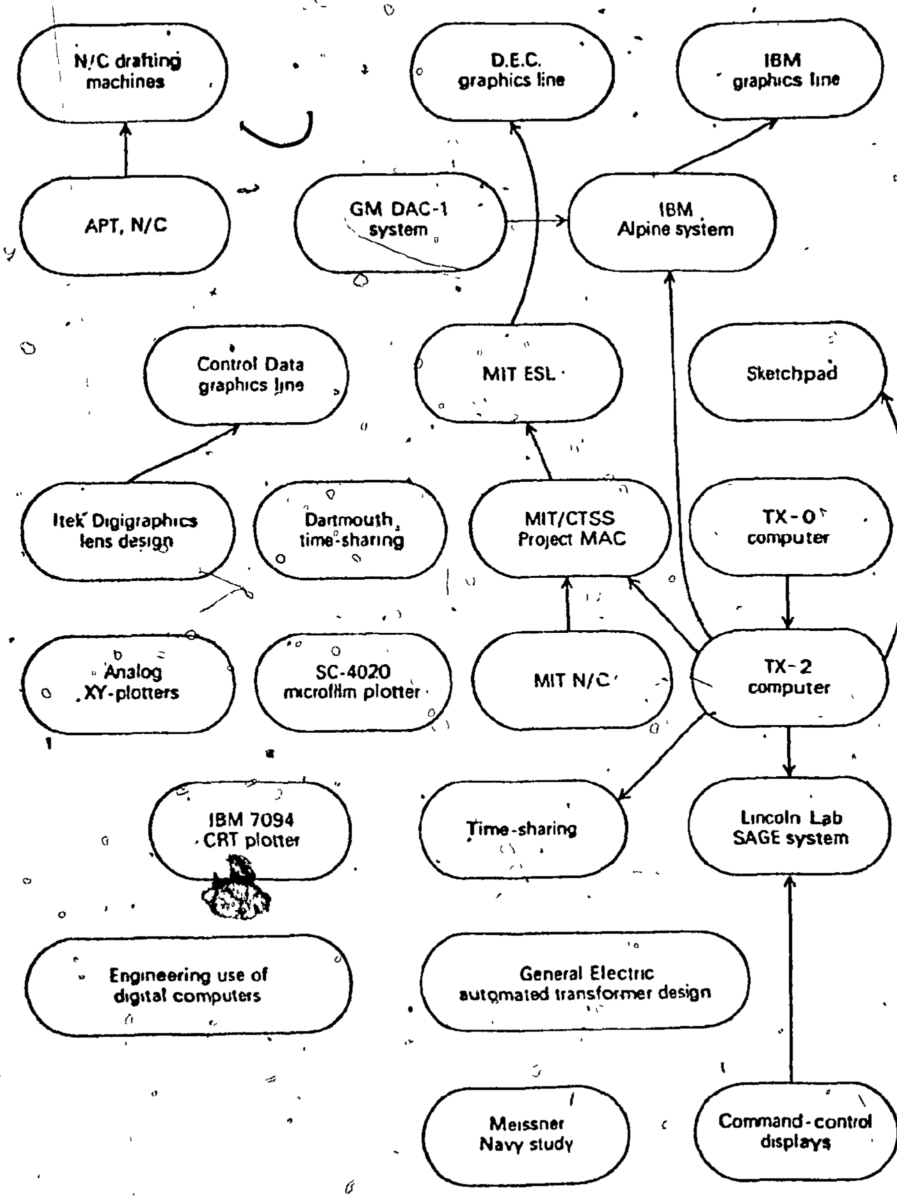

Fig. 1.2 Historical Development of Computer Graphics*

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*Reprinted from (4) page 6

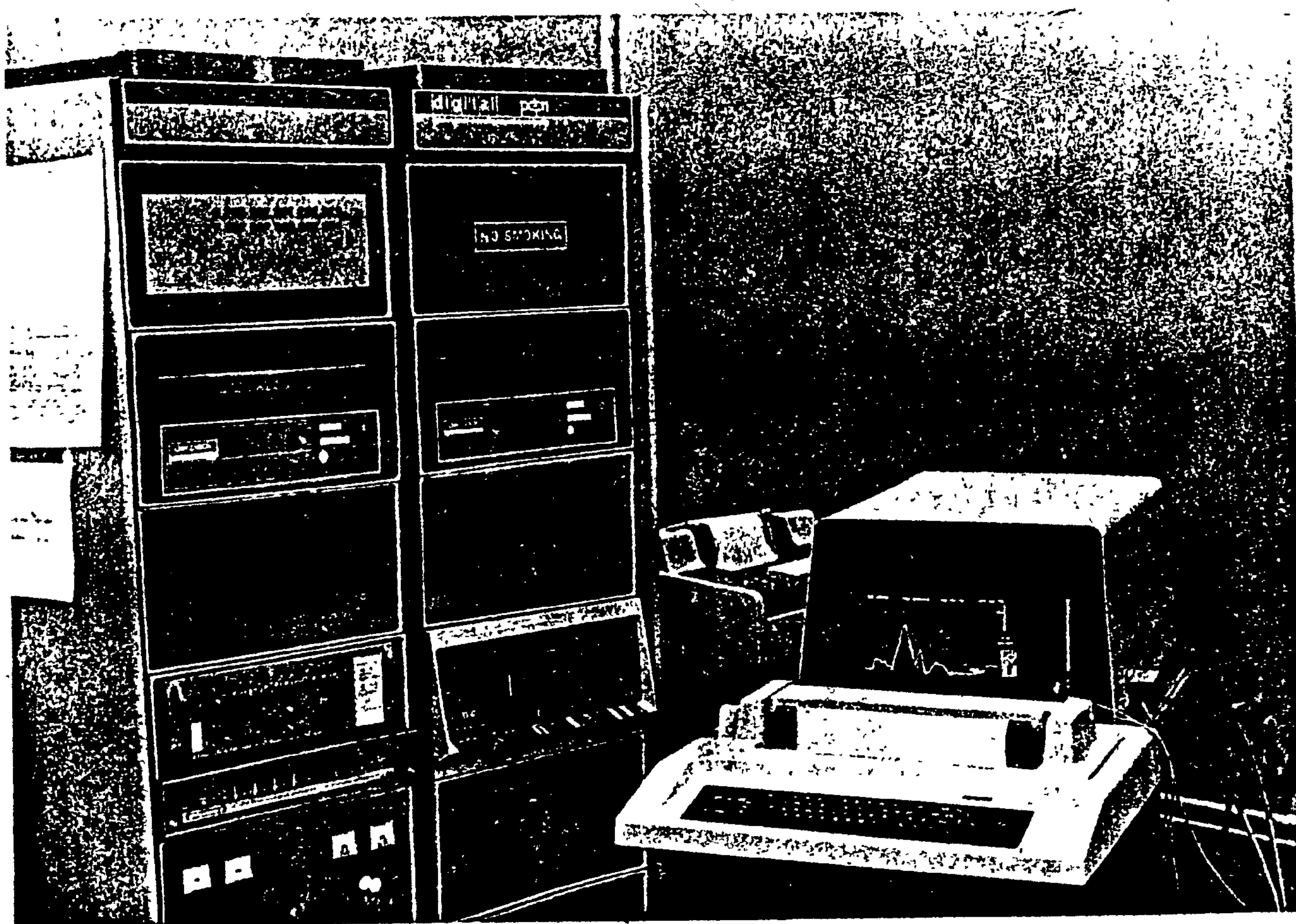


Fig. 1.3 PDP 11/45 GT-44 Graphics System, Concordia University Electrical Engineering Department

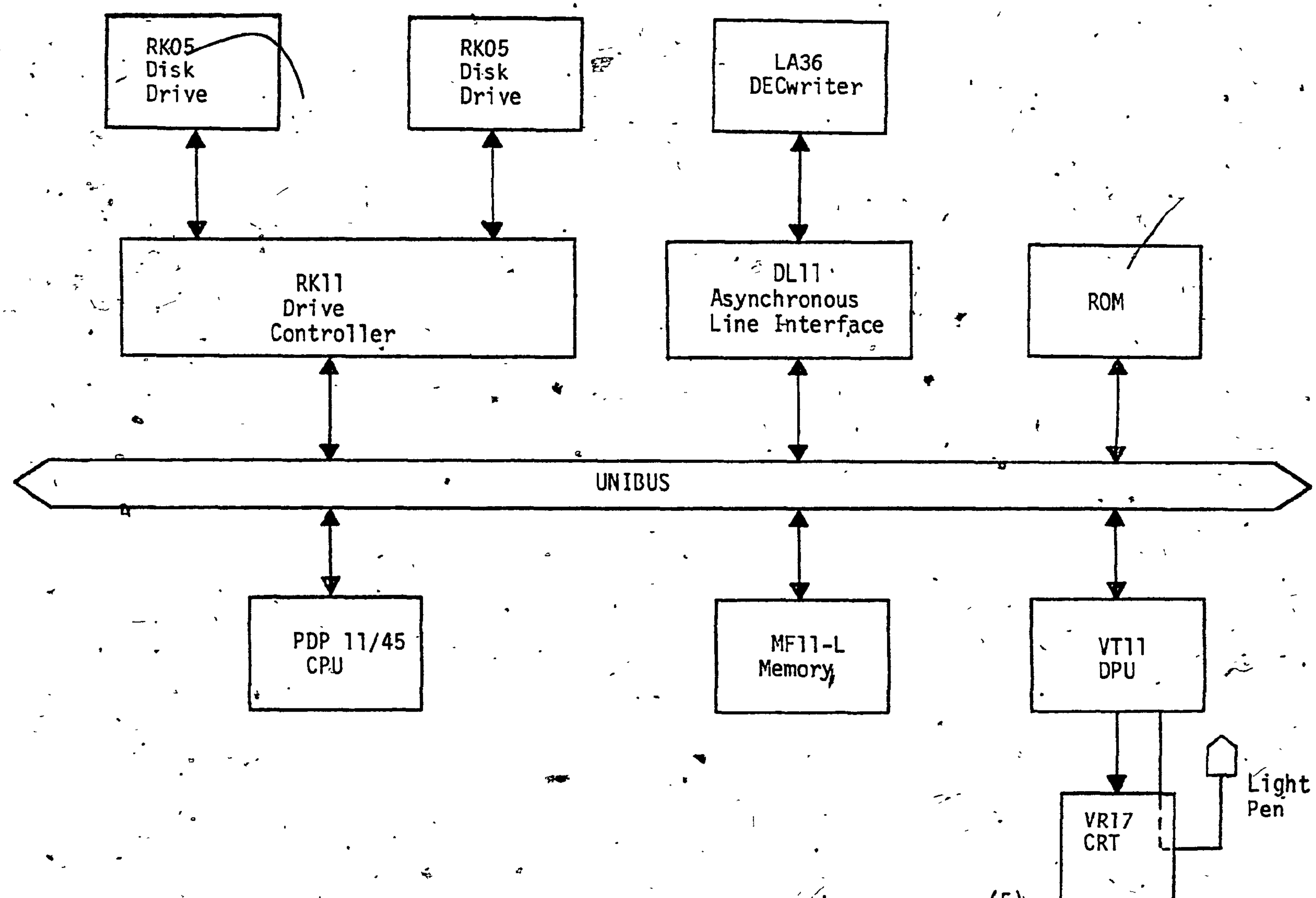


Fig. 1.4 GT-44 Graphics System Internal Operation (5)

e) LA 35/36 Dec Writer II is a teletype consol used as the main input/output device for generating graphics, editing and creating programs, and as a source of hard copy print out.

With the above system having two disk drives and 32K core of memory, the user is not restricted in utilizing the graphics or computational abilities alone, but a combination of both can be achieved quite comfortably.

The system above is utilized in the development of an analysis package for ladder networks and system functions. This system enabled the package to be developed as follows:

1) The graphics capability of the system is utilized to enable the construction of ladder networks of up to sixteen branches. Also, the graphics is used in the analysis of ladder networks and system functions by displaying the frequency response through the Bode and Nyquist plots.

2) The computational capability of the system is employed in the calculation of the Transfer and Driving-Point functions of a ladder network, as well as in the computation of the Bode and Nyquist plots.

1.3 SCOPE OF THE THESIS

In this thesis, the discussion will concentrate upon the development of a CAD package useful for the analysis of ladder networks and system functions.

Chapter 2 will discuss how a CAD package can be effectively used in a systematic design process. Stemming from the design process two aspects of the CAD package will be covered. The first aspect will deal with the graphics capability of the package. This discussion on the graphics will dwell upon the generation of the graphics and the interactive capabilities of the graphics. From this discussion, we will then proceed to explain how to use the graphic capabilities in building a ladder network on the CRT.

The second aspect that will be discussed is the computational capability which allows one to obtain the Transfer and Driving-Point functions of a ladder network.

Chapter 3 will discuss a third aspect of the CAD package which is the analysis of a ladder network. This aspect allows the designer to study a ladder network behaviour by the Bode plot and the Nyquist plot. Also provisions have been made whereby system functions can be entered into the computer and their behaviour obtained by the two plots previously mentioned.

Chapter 4 contains the analysis of a ladder network and a system function using the various aspects of the CAD package discussed in Chapters 2 and 3.

Chapter 5 contains the summary and discussions plus further research utilizing CAD systems with interactive graphics.

CHAPTER 2

PROGRAM LADNET AND TRANF

2.1 INTRODUCTION

When developing a CAD package various considerations must be taken into account. These considerations are as follows:

a) Computer system being utilized to develop the package.

b) The capability and requirements of the package to the particular application.

c) Organization of the package in a manner whereby its operation will be an asset to the designer.

The following sections in Chapter 2 as well as in Chapter 3 will touch upon these considerations.

2.2 FILTER DESIGN PROCESS

In the development of any design, the designer usually follows a sequential set of design-analysis steps to achieve the specified goal. Fig. 2.1 illustrates a sequential filter design-analysis process which is used in the development of the Ladder Network Analysis package (LNA). By establishing such a system procedure, the design-analysis cycle becomes orderly, efficient and rapid. In Fig. 2.1, the dashed area encloses the fundamental steps of the design-analysis cycle. These steps utilize the computer and thus form the heart of the process. In the following sections of this chapter we will discuss the operation of the first two design-analysis steps.

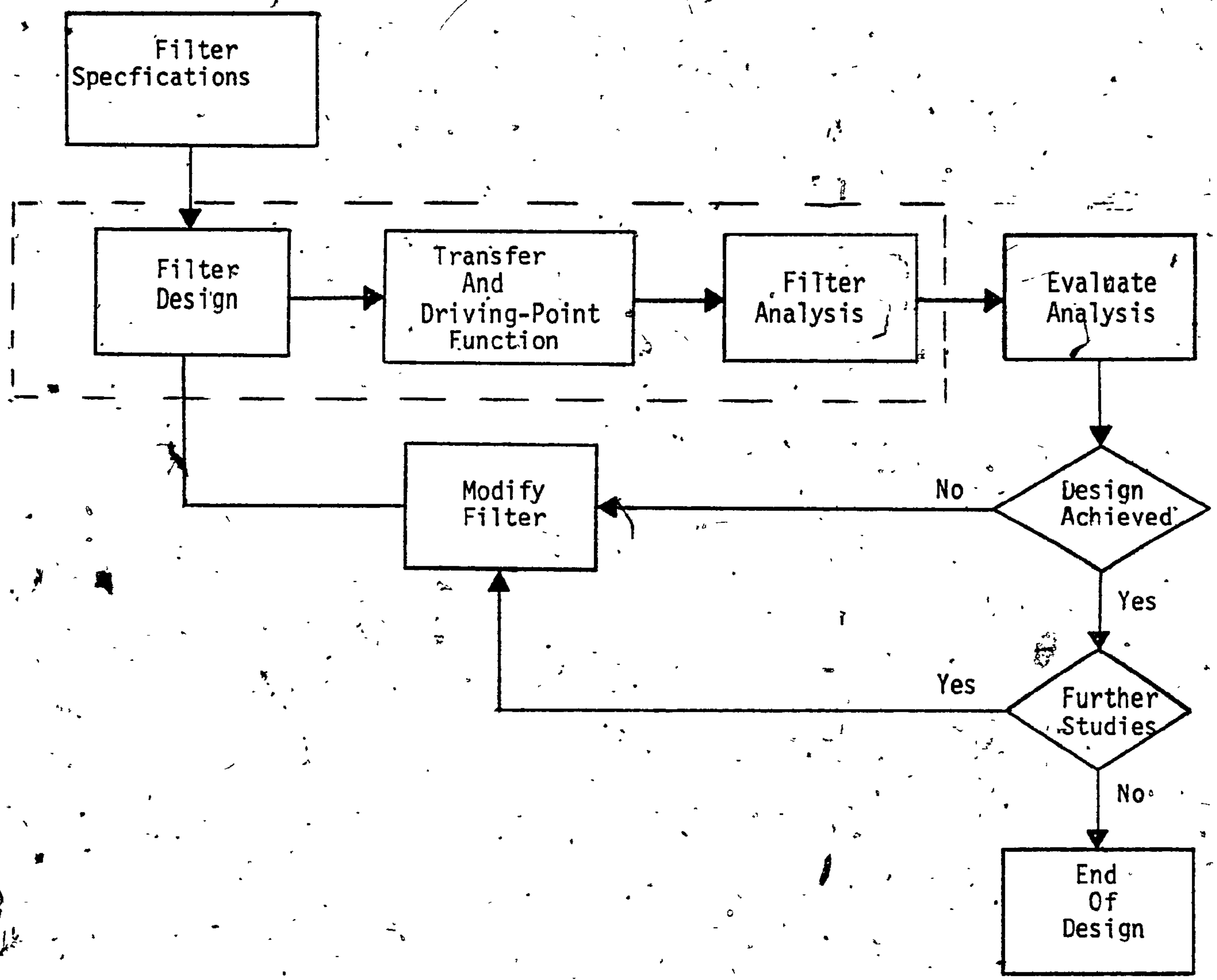


Fig. 2.1 Filter Design-Analysis Process

2.3 LADDER NETWORK DESIGN

When the filter design specifications have been established or a specific filter is to be studied, we then enter the Ladder Design block. This step of the process is activated by running the program LADNET. When running LADNET, the program generates a display on the CRT which is illustrated in Fig. 2.2. The display in Fig. 2.2 is generated by using the Fortran Graphics Software package which is part of the GT-44 Graphics system. The display consists of three main portions and which are as follows:

1. Generation of the ladder circuit.
2. Generation of the command string or menu.
3. Generation of the components.

The generation of both the ladder circuit and the command menu are contained directly inside the main program. The components are previously established in a separate library file and are called into operation when LADNET is run. The detailed operations of LADNET as to the software development and flow charting is given in Appendix II. Before we proceed into the operation of LADNET, a brief explanation will be given as to how the display becomes interactive.

In order for the display to become interactive, an internal tag code is established. This tag code enables the light pen to interact with the display and transmit the necessary information to the computer. Each display shown in Fig. 2.2 except for the bottom

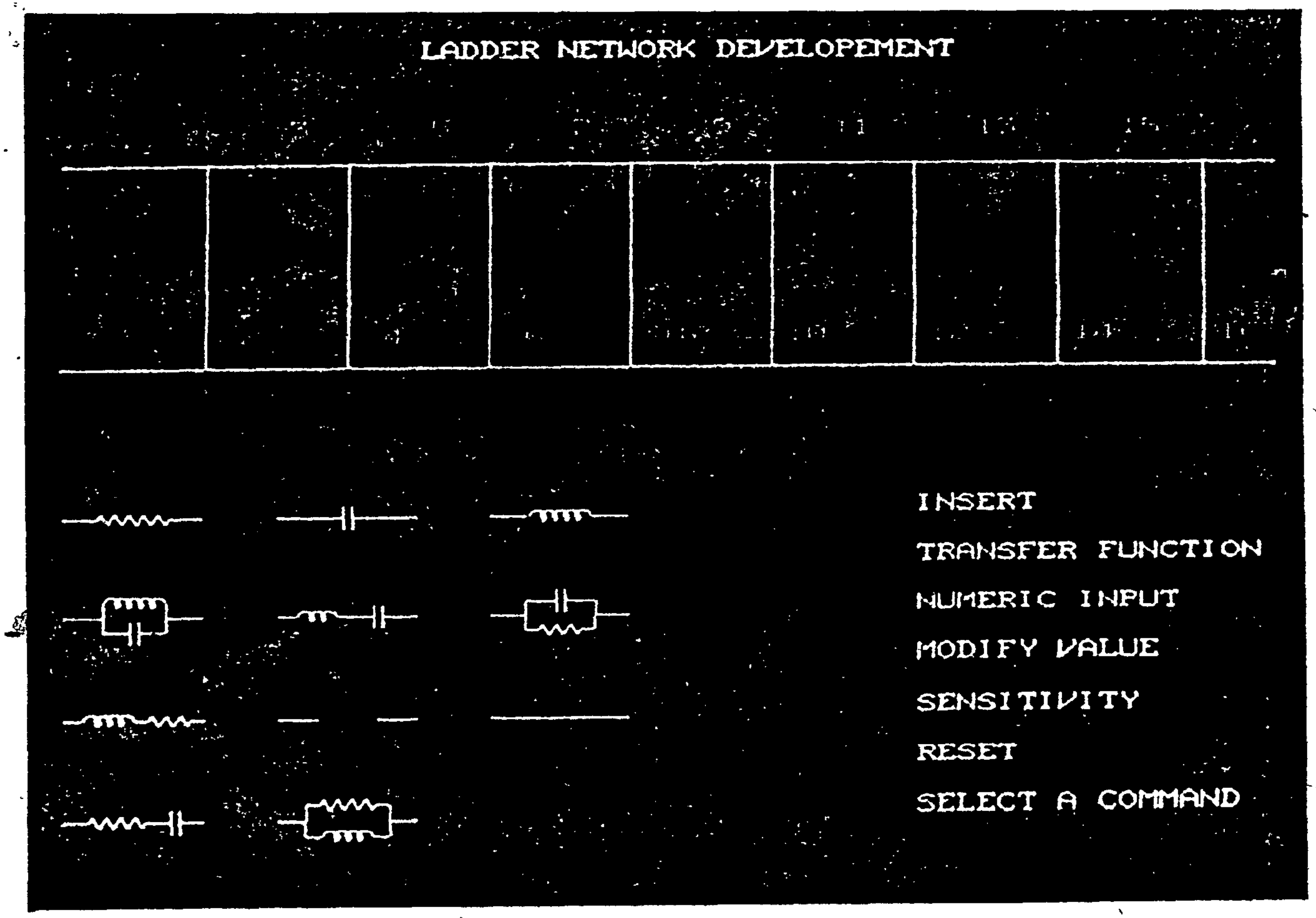


Fig. 2.2 Initial Display of LADNET in Select A Command Mode

line of the ladder circuit has its own individual tag. The tag code was established in the following manner:

1. Tag numbers between 1 and 6 are reserved for the command menu.
2. Tag numbers between 101 and 111 are reserved for the components.
3. Tag numbers between 201 and 216 are reserved for the ladder circuit.

By establishing such a tag system, the operation of the program is regulated in a sequential manner. When the user picks up the light pen, the program LADNET is waiting for a specific display strike. This specific strike is one of the commands contained in the menu. The flow of the design and interaction is sequenced by a series of if statements. For instance, if the designer tries to change the ladder display without striking a command, the display remains passive. The reason being is that upon receiving the light pen strike an if statement checks whether or not the tag associated with the display is within its specified range. Let us take an example, whereby the designer strikes location 8 in the ladder circuit (Fig. 2.2). The light pen transmits the information that display 201 was activated. The if statement checks whether the strike lies between 1 and 6 which is reserved for the command menu. Since the tag does not lie between 1 and 6 nothing will happen and the light pen is called upon for the next strike. This sequence of operation is always repeated for any light pen strike. Let us now proceed to study the operation of LADNET.

When the display appears on the screen (Fig. 2.2) the words *SELECT A COMMAND* are flashing. The designer is obligated to choose a command from the menu. Since at this particular time the ladder is empty, the logical procedure would be to develop the filter by placing components on the ladder. In order to place a component, the command *INSERT* must be activated by the light pen. By striking *INSERT*, the display enters it's Next Mode of Operation as shown in Fig. 2.3. Fig. 2.3 shows that *SELECT A COMMAND* is replaced by the word *LOCATION* which is now flashing. Also, *INSERT* goes into a flashing mode to tell the designer that this particular command is in effect. This flashing feature is established for all the command menu. The next procedure is to strike a location on the ladder circuit. Let us strike position 8. The line that was located at position 8 disappears, along with the word *LOCATION* which is replaced by *WHICH COMPONENT* (Fig. 2.4). The designer now proceeds to strike a component which will jump to location 8 and the display returns to it's original mode of operation ready for the next command (Fig. 2.5).

Using the above procedure, the ladder network can be built up accordingly. If a mistake is made in the placing of a component, the above procedure is also used to change that particular component. Once a ladder network has been developed, the designer then proceeds to enter values for each component.

In Fig. 2.6 we have a ladder network whereby the components will

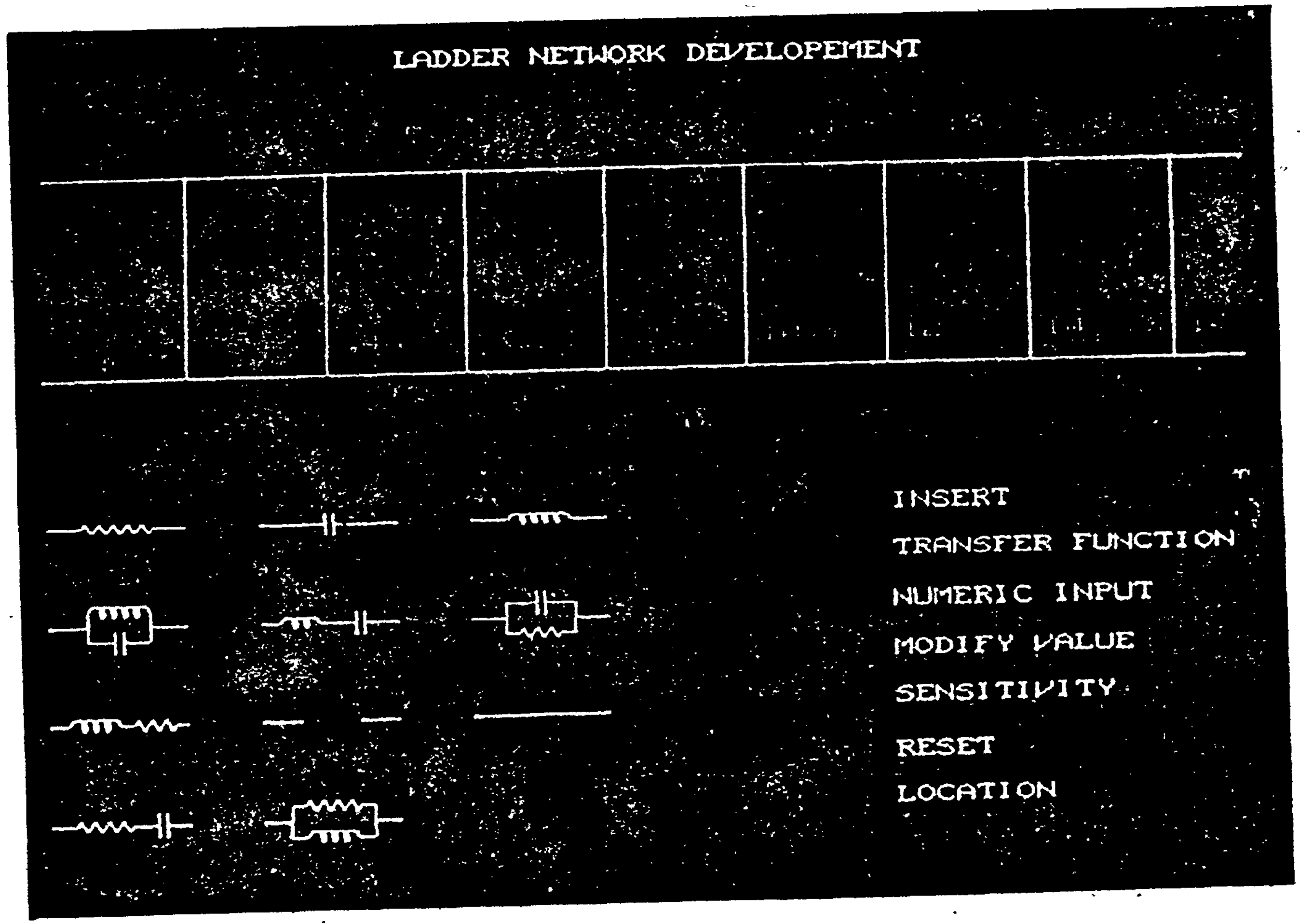


Fig. 2.3 LADNET Display in Location Strike Mode

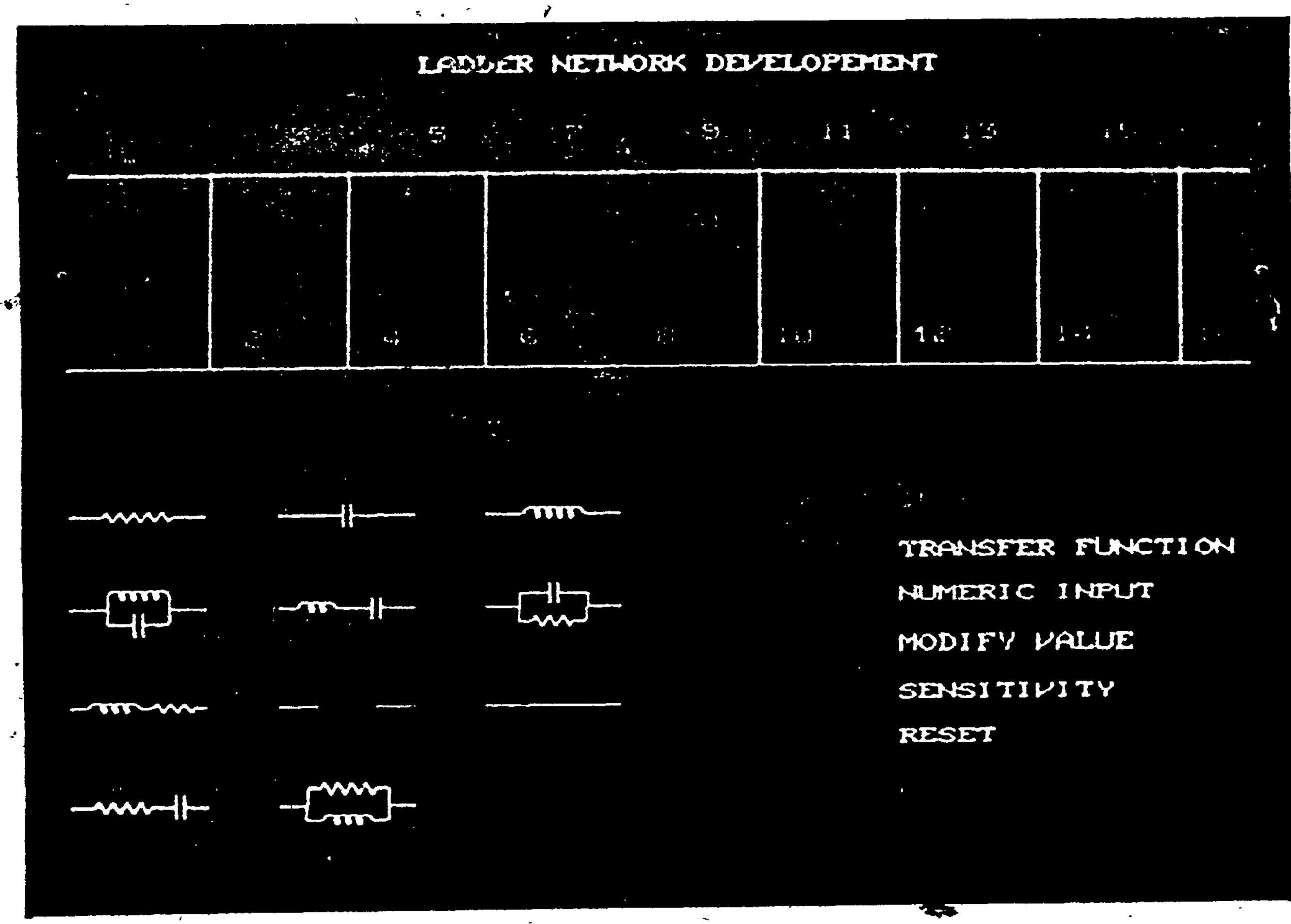


Fig. 2.4 LADNET Display in Component Insert Mode

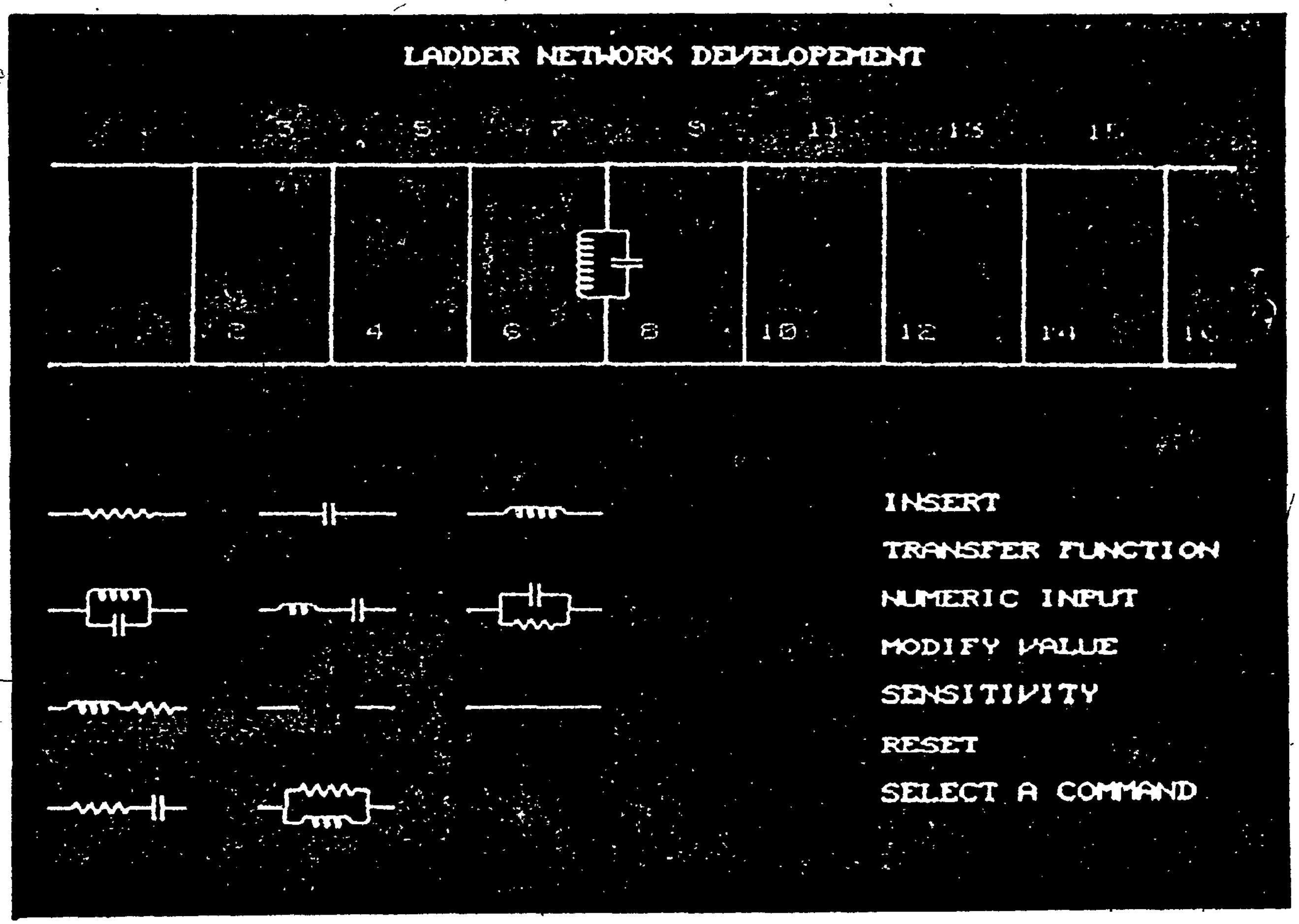


Fig. 2.5 LADNET Display with LC Component in Position 8

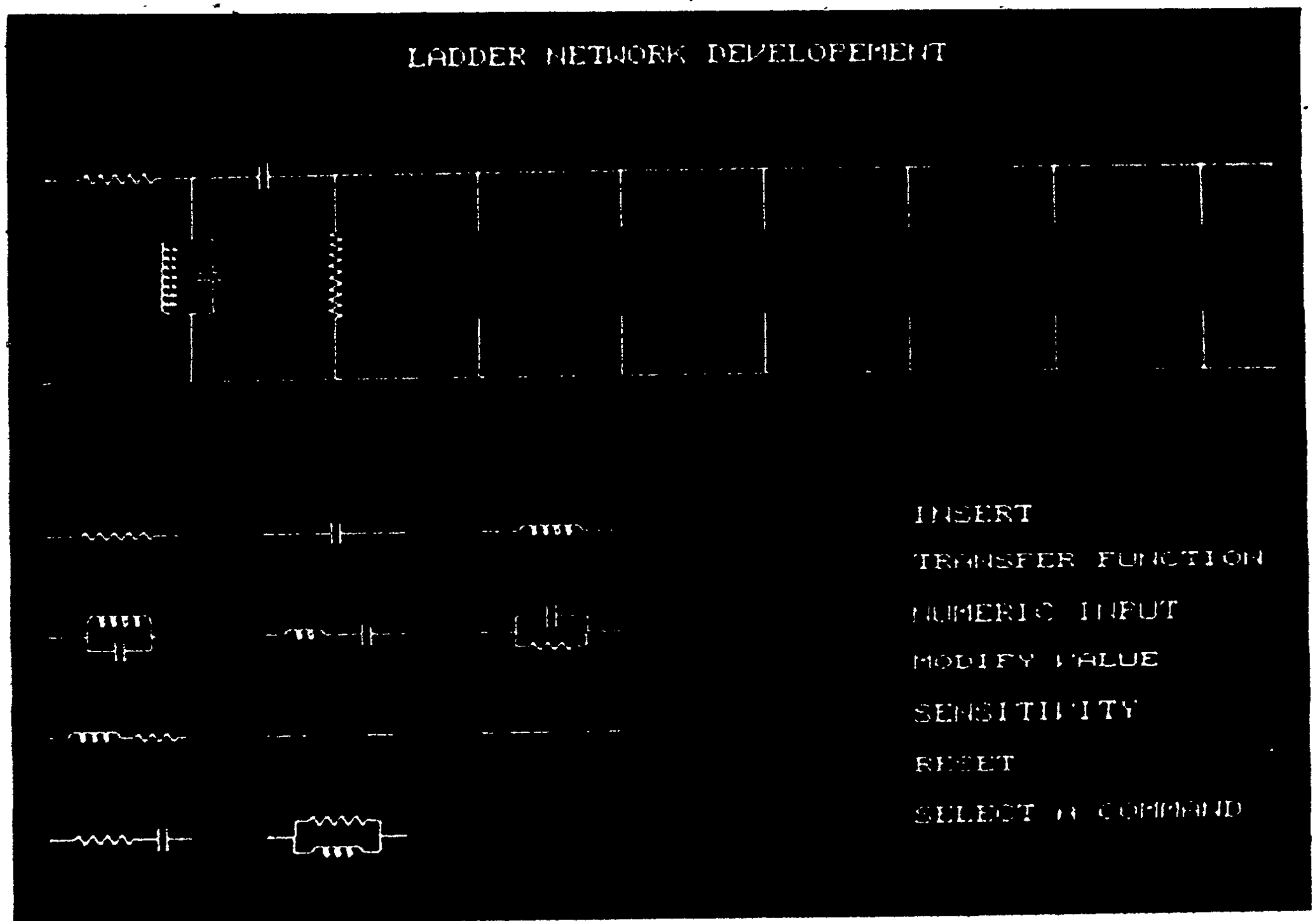


Fig. 2.6 LADNET Display with a Typical Ladder Network

be given their respective values. To do this, we strike the command *NUMERIC INPUT*. This operation results in the display shown in Fig. 2.7. At the bottom of the command menu in Fig. 2.7 a flashing *CONFIRM YES AND NO* command is activated. This feature is included as a safety device. That is, if the light pen strikes a command that is not desired, the designer has the option to get out of it. When the designer strikes either a *YES* or a *NO*, the following occurs:

1. A *YES* strike activates the teletype to enter the component values.
2. A *NO* strike brings the display back to Fig. 2.6.

The output of a *YES* strike is given below.

```
LOCATION  1  IS A SERIES ARM

ELEMENT IS A RESISTOR
ENTER THE VALUE YOU   WANT IN KILO-OHMS
VALUE(KILO-OHMS)= 1.

LOCATION  2  IS A SHUNT ARM

ELEMENTS COMBINATION PARALLEL INDUCTOR AND CAPACITOR
ENTER VALUE FOR INDUCTOR
VALUE(MILLI-HENRIES)= 2.

ENTER VALUE FOR CAPACITOR
VALUE(MICRO-FARADS)=  6.

LOCATION  3  IS A SERIES ARM

 ELEMENT IS A CAPACITOR
ENTER THE VALUE YOU  WANT IN MICRO-FARADS
VALUE(MICRO-FARADS)= 7.

LOCATION  4  IS A SHUNT ARM

ELEMENT IS A RESISTOR
ENTER THE VALUE YOU   WANT IN KILO-OHMS
VALUE(KILO-OHMS)= 1.

LOCATION  5  IS A SERIES ARM

*****WARNING NO ELEMENT WAS INSERTED*****
```

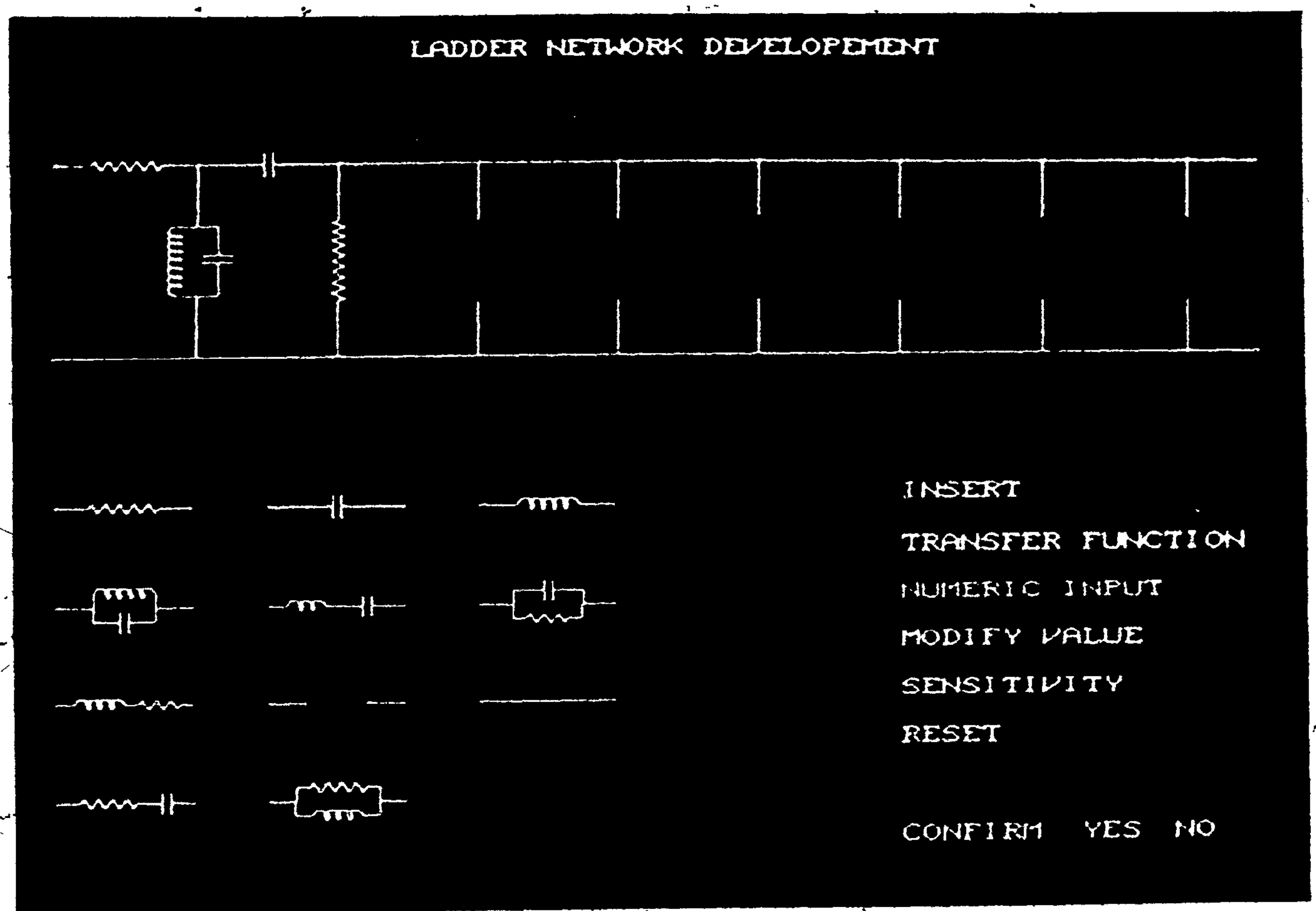


Fig. 2.7 LADNET Display in Confirm A Command Mode

At each printout of a location, the component(s) type is listed for that location and the value is entered for that component(s). A carriage return is pressed to obtain the next line of output. The output will continue until all the components have been given their respective values. The output stops when a component has not been placed into a location. Looking at the output, we can see that location 5 (Fig. 2.6) has no element placed there. This message tells the designer that the ladder network is finished. Once this line of output is completed, the display reverts back to the operating mode of Fig. 2.6. The remaining commands that are going to be discussed, proceed in the same operating manner as the *NUMERIC INPUT* command.

We now have designed the filter and say we wish to modify a component(s) value(s): To do this without going through the *NUMERIC INPUT* command we activate the *MODIFY VALUE* command. What happens in the sequence of operation is the same for the *NUMERIC INPUT* command except that after confirming a *YES*, the word *LOCATION* will appear on the screen (Fig. 2.3). We strike the location of the component whose value(s) we wish to change. Let us strike location 2 of Fig. 2.6. This results in the teletype printing

```
LOCATION  2  IS A SHUNT ARM

ELEMENTS COMBINATION PARALLEL INDUCTOR AND CAPACITOR
ENTER VALUE FOR INDUCTOR
VALUE(MILLI-HENRIES)-

ENTER VALUE FOR CAPACITOR
VALUE(MICRO-FARADS)=
```

We enter the value(s) the same way as we did for *NUMERIC INPUT*.

```
LOCATION  2  IS A SHUNT ARM

ELEMENTS COMBINATION PARALLEL INDUCTOR AND CAPACITOR
ENTER VALUE FOR INDUCTOR
VALUE(MILLI-HENRIES)= 7.

ENTER VALUE FOR CAPACITOR
VALUE(MICRO-FARADS)=  8.
```

Once the value(s) are entered, the display returns to the mode in Fig. 2.6. This ability to change component values can be repeated over again.

The next command after *MODIFY VALUE* which is of great importance is *SENSITIVITY*. This command allows the designer to study the ladder design when a component value is varied by some per cent deviation from it's assigned value. To give an example of this, let us again look to Fig. 2.6. We have entered the values for all the components and say we just finished analyzing the filter response. We now wish to see how the response will change if some component value is slightly varied. Take location 2 (Fig. 2.6), which is an LC component and we wish to vary the value of the inductor by 5% and capacitor by 9%.

To perform this operation we strike the *SENSITIVITY* command. The procedure is the same as for *MODIFY VALUE*, we first confirm the command and then this results in the following output.

```
SENSITIVITY STUDIES ARE MADE BY INSERTING A  FLOATING NUMBER
  BETWEEN + OR - 100 FOR EACH ELEMENT(S) LOCATION
```

We then proceed to strike location 2 of the ladder and the teletype prints the output below. Here we enter the per cent variation of each component and once finished we return to operating mode of Fig. 2.6.

```
LOCATION  2  IS A SHUNT ARM
% VARAITION FOR INDUCTOR=
% VARIATION FOR CAPACITOR=
```

```
LOCATION  2  IS A SHUNT ARM
% VARAITION FOR INDUCTOR=5.
% VARIATION FOR CAPACITOR=9.
```

The remaining two commands *RESET* and *TRANSFER FUNCTION* are control commands which when activated put the design process at the beginning or on to the next step. When *RESET* is activated, this command clears the entire screen of the ladder built, all values of components are set ~~to zero~~ and the graphics is refreshed to the original mode of Fig. 2.2.

The final command which is used to exit from the program is the *TRANSFER FUNCTION* command. When this command is activated the following occur:

1. The teletype prints out the components and their values, along with a question at the end of the print out (see below).

2. The information pertaining to the ladder network in the way of components location and values is stored onto a file on disc. This information is used for the next step of the design process and is also used to regenerate the same ladder network when LADNET is called again.

```
          *****LADDER ELEMENTS AND VALUES*****

LOCATION  1 IS A SERIES ARM
ELFMENT IS A RESISTOR
VALUE(KILO-OHMS)=  1.00000000E+00

LOCATION  2 IS A SHUNT ARM
ELEMENTS COMBINATION PARALLEL INDUCTOR AND CAPACITOR
VALUE(MILLI-HENERIES)=  7.71749973E+00
VALUE(MICRO-FARADS)=  9.50480080E+00

LOCATION  3 IS A SERIES ARM
ELEMENT IS A CAPACITOR
VALUE(MICRO-FARADS)=  7.00000000E+00

LOCATION  4 IS A SHUNT ARM
ELEMENT IS A RESISTOR
VALUE(KILO-OHMS)=  1.00000000E+00

ARE YOU FINISHED?
TYPE IN YES OR NO

YES
```

The printout that is obtained supplies a hard copy of what was designed. Also a picture can be taken to accompany the output.

When the design is absolutely finished, a *YES* is entered on the teletype and the next operation of the design process is given.

```
TO CONTINUE THE LADDER ANALYSIS AND OBTAIN THE
 TRANSFER FUNCTION TYPE IN RUN RK1:TRANF
```

An entry of *NO* allows the designer to continue the ladder design starting at Fig. 2.6.

We now have learned how to build a ladder network using part of the LNA package. This next sequence of the design-analysis process is to obtain the Transfer and Driving-Point functions of the ladder network.

2.4 TRANSFER AND DRIVING POINT-FUNCTIONS

In the previous section, our discussion was based upon the construction of a ladder network utilizing the program LADNET. This discussion not only demonstrated the operation of LADNET, but it also introduced and explained some concepts involving interactive-graphics. This constituted the first step of the design-analysis process. Now, we are prepared to enter the second step.

The second step enables us to obtain the Transfer Function (TF) and the Driving-Point Function (DPF) of a ladder network. This step deals with the computational ability of LNA. In order to obtain the TF and DPF we execute the program TRANF. The program TRANF is based upon the theory of cascading networks using the chain matrix.[6] The theory of chain matrix analysis is quite well known, and we shall now discuss how it was put into practice.

The components that are illustrated in Fig. 2.2 have their respective chain matrices established in Table 2.1. These matrices are contained in the program TRANF. The necessity of having these matrices in the program is to establish the location and values of the components in a ladder network. By establishing these matrices in the program, the calculation of the TF and DPF becomes very structured. When the chain matrices are being multiplied, some mathematical operations must be taken into account.

To point out some of these operations, let us consider the two-port network of Fig. 2.8. In Fig. 2.8 we have a series and a shunt connection of parallel LC components. Let us proceed step by step to obtain the TF and DPF. These steps are as follows:

$$\begin{bmatrix} E_1 \\ I_1 \end{bmatrix} = \begin{bmatrix} 1 & \frac{L_1 S}{L_1 C_1 S^2+1} \\ 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 \\ \frac{L_2 C_2 S^2+1}{L_2 S} & 1 \end{bmatrix} \begin{bmatrix} E_2 \\ -I_2 \end{bmatrix} \qquad 2.4.1$$

TABLE 2.1

CHAIN MATRICES OF COMPONENTS IN FIG. 2.2

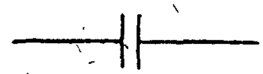
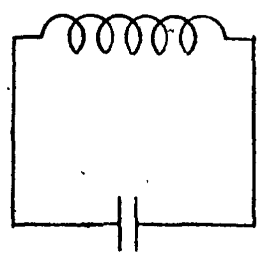
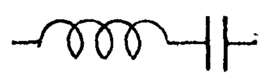
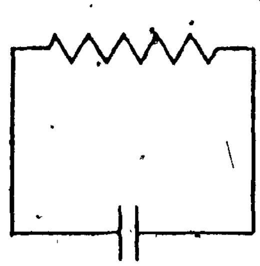
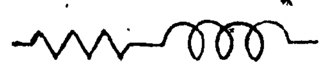
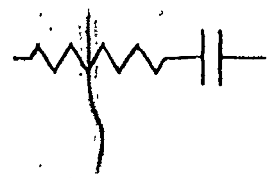
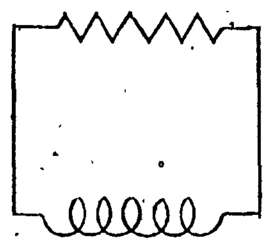
Series	Shunt	
$\begin{bmatrix} 1 & R \\ 0 & 1 \end{bmatrix}$	$\begin{bmatrix} 1 & 0 \\ \frac{1}{R} & 1 \end{bmatrix}$	
$\begin{bmatrix} 1 & LS \\ 0 & 1 \end{bmatrix}$	$\begin{bmatrix} 1 & 0 \\ \frac{1}{LS} & 1 \end{bmatrix}$	
$\begin{bmatrix} 1 & \frac{1}{CS} \\ 0 & 1 \end{bmatrix}$	$\begin{bmatrix} 1 & 0 \\ CS & 1 \end{bmatrix}$	
$\begin{bmatrix} 1 & \frac{LCS^2+1}{LS} \\ 0 & 1 \end{bmatrix}$	$\begin{bmatrix} 1 & 0 \\ \frac{LCS^2+1}{LS} & 1 \end{bmatrix}$	
$\begin{bmatrix} 1 & \frac{LCS^2+1}{LS} \\ 0 & 1 \end{bmatrix}$	$\begin{bmatrix} 1 & 0 \\ \frac{LS}{LCS^2+1} & 1 \end{bmatrix}$	
$\begin{bmatrix} 1 & \frac{R}{RCS+1} \\ 0 & 1 \end{bmatrix}$	$\begin{bmatrix} 1 & 0 \\ \frac{RCS+1}{R} & 1 \end{bmatrix}$	

TABLE 2.1 (Cont.)

$\begin{bmatrix} 1 & R+LS \\ 0 & 1 \end{bmatrix}$	$\begin{bmatrix} 1 & 0 \\ \frac{1}{R+LS} & 1 \end{bmatrix}$	
$\begin{bmatrix} 1 & \frac{RCS+1}{CS} \\ 0 & 1 \end{bmatrix}$	$\begin{bmatrix} 1 & 0 \\ \frac{CS}{RCS+1} & 1 \end{bmatrix}$	
$\begin{bmatrix} 1 & \frac{RLS}{R+LS} \\ 0 & 1 \end{bmatrix}$	$\begin{bmatrix} 1 & 0 \\ \frac{R+LS}{RLS} & 1 \end{bmatrix}$	
[Undefined]	$\begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$	
$\begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$	[Undefined]	

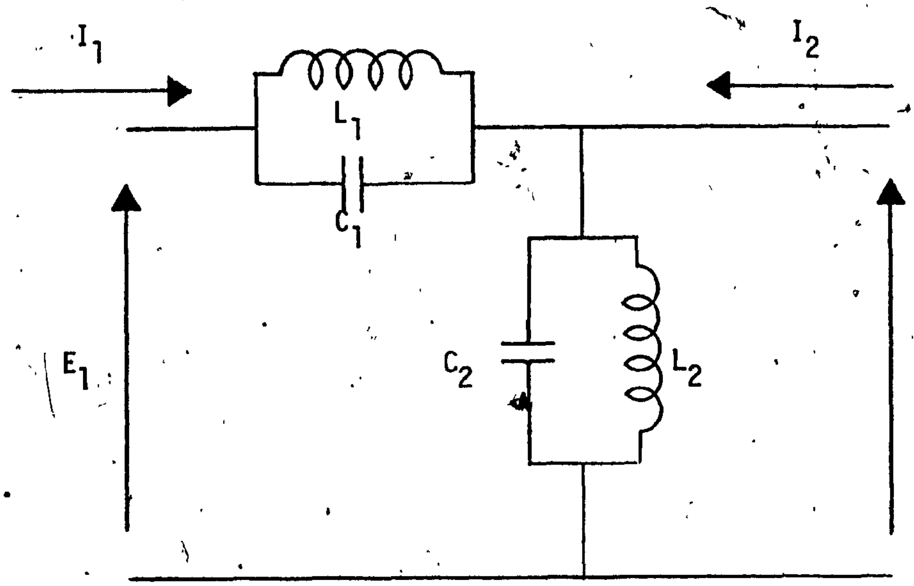


Fig. 2.8 Two-Port LC Network

$$\begin{bmatrix} E_1 \\ I_1 \end{bmatrix} = \begin{bmatrix} 1+\dfrac{L_1S}{L_1C_1S^2+1}\cdot\dfrac{L_2C_2S^2+1}{L_2S} & \dfrac{L_1S}{L_1C_1S^2+1} \\ \dfrac{L_2C_2S^2+1}{L_2S} & 1 \end{bmatrix} \begin{bmatrix} E_2 \\ -I_2 \end{bmatrix} \quad 2.4.2$$

$$\begin{bmatrix} E_1 \\ I_1 \end{bmatrix} = \begin{bmatrix} \dfrac{L_2S(L_1C_1S^2+1)+L_1S(L_2C_2S^2+1)}{L_2S(L_1C_1S^2+1)} & \dfrac{L_1S}{L_1C_1S^2+1} \\ \dfrac{L_2C_2S^2+1}{L_2S} & 1 \end{bmatrix} \begin{bmatrix} E_2 \\ -I_2 \end{bmatrix} \quad 2.4.3$$

$$\begin{bmatrix} E_1 \\ I_1 \end{bmatrix} = \begin{bmatrix} \dfrac{S^2(L_1L_2C_1+L_1L_2C_2)+(L_1+L_2)}{L_2(L_1C_1S^2+1)} & \dfrac{L_1S}{L_1C_1S^2+1} \\ \dfrac{L_2C_2S^2+1}{L_2S} & 1 \end{bmatrix} \begin{bmatrix} E_2 \\ -I_2 \end{bmatrix} \quad 2.4.4$$

Now, we will consider some of the operations that were encountered above when the program TRANF was being developed.

Let us take a closer look at equations 2.4.1 to 2.4.4. The first step (equation 2.4.1) is to establish the respective chain matrices for multiplication. The second step involves two procedures:

a) Multiplication of the two matrices (equation 2.4.2).

b) Grouping of the factors in each element position of the matrix (equation 2.4.3 and equation 2.4.4).

Before proceeding to the final equation 2.4.4, note that in equation 2.4.3, the a_{11} position has a common power of S. This common power of S must be eliminated. The program TRANF keeps track of all powers of S, and that if any common powers of S do occur they are cancelled. The final step is equation 2.4.4 whereby this equation is ready to be used in obtaining the TF and DPF.

Another operation that arose in using the chain matrix is the elimination of common factors. To illustrate this point, let us find the DPF of Fig. 2.8. The DPF is

$$DPF = \frac{E_1}{I_1} = \frac{S^2(L_1L_2C_1+L_1L_2C_2)+(L_1+L_2)}{L_2(L_1C_1S^2+1)} \cdot \frac{L_2S}{L_2C_2S^2+1} \qquad 2.4.5$$

Notice in equation 2.4.5 that L_2 is a common factor which must be removed. When we perform the above procedure to calculate the TF and DPF, the grouping of terms, the elimination of common factors and powers of S are done automatically. These operations have all been incorporated into the program TRANF.

To fully appreciate the capability of TRANF to handle the operations mentioned above, let us substitute $L_1=L_2=L$ and $C_1=C_2=C$ into equation 2.4.4 for Fig. 2.8. The new equation is

$$\begin{bmatrix} E_1 \\ I_1 \end{bmatrix} = \begin{bmatrix} 2 & LS/LCS^2+1 \\ \frac{LCS^2+1}{LS} & 1 \end{bmatrix} \begin{bmatrix} E_2 \\ -I_2 \end{bmatrix} \qquad 2.4.6$$

Note the difference between 2.4.4 and 2.4.6. Now, if the operations concerning the elimination of common factors and powers of S were not taken into account the result would be

$$\begin{bmatrix} E_1 \\ I_1 \end{bmatrix} = \begin{bmatrix} \frac{2L^2CS^3+2LS}{LS(LCS^2+1)} & \frac{LS}{LCS^2+1} \\ \frac{LCS^2+1}{LS} & 1 \end{bmatrix} \begin{bmatrix} E_2 \\ -I_2 \end{bmatrix} \qquad 2.4.7$$

Therefore, the operations of grouping, eliminating common factors and the powers of S play a significant role in obtaining the correct results. This part of the program TRANF dealt only with the mathematical operations of the chain matrix. There is still a further consideration to be made. This consideration involves the numerical capability of the computer to handle the multiplication of the chain matrices.

The numerical capability of the PDP 11/45 computer system lies between the limits of ±.1E ±38. These limits seem impressive enough, but when actual calculations are performed they are inadequate. To illustrate this point let us return to Fig. 2.8 and substitute the following values into equation 2.4.4

$L_1 = 1$ mH

$L_2 = 2$ μH

$C_1 = 10$ nF

$C_2 = 2$ μF

hence we obtain

$$\begin{bmatrix} E_1 \\ I_1 \end{bmatrix} = \begin{bmatrix} \dfrac{4.02\times10^{-14}S^2+1.02\times10^{-3}}{2\times10^{-16}S^2+1} & \dfrac{10^{-3}S}{10^{-11}S^2+1} \\ \dfrac{4\times10^{-11}S^2+1}{2\times10^{-5}S} & 1 \end{bmatrix} \begin{bmatrix} E_2 \\ -I_2 \end{bmatrix} \qquad 2.4.8$$

Notice, how small the coefficients of S are becoming. If we cascade more components of the same type to Fig. 2.8 and substitute typical values underflow of the machine will occur quite rapidly. Overflow will also occur when the coefficients of S become quite large. Therefore, to ease this problem a scaling routine was introduced into the program TRANF to expand the computer's capability.

By introducing a scaling routine, the order of the ladder network using unscaled component values increased. But, even with the scaling routine underflow is still a problem. To overcome this difficulty, the program TRANF can be executed on the CDC 6600 computer whose limits are ±.1E ±300. As one can realize, the capabilities of the CDC computer are far greater than that of the PDP 11/45. By using the CDC 6600, the problem of numerical calculations is completely eliminated.

This problem of overflow and underflow should not imply that the program TRANF and the PDP 11/45 are inadequate to perform the necessary calculations; but what it does imply that one should use the program TRANF and the computer in a sensible manner. The program TRANF can be fully utilized on the PDP 11/45 by having normalized values for the components. By having normalized values, the entire sixteen ladder network branches can be used. This ends the discussion behind the development of TRANF. The software and flow charting of TRANF is given in Appendix III.

In order to obtain the TF and DPF we type in on the teletype RUN RK1:TRANF. The teletype will print a message asking the user for the engagement of the scaling routine

```
 DO YOU WANT TO ENGAGE SCALING ROUTINE?
TYPE IN YES OR NO

NO
```

Once the command *YES* or *NO* are typed in, the computation begins and the results are printed as follows

TRANSFER FUNCTION

COEFFICIENTS	NUMERATOR	DENOMINATOR
S** 0	0.000000E-01	1.000000E+00
S** 1	0.000000E-01	7.007717E-03
S** 2	5.402250E-08	1.813983E-07
S** 3	0.000000E-01	5.134731E-10

```
***DRIVING-POINT IMPEDANCE***

COEFFICIENTS       NUMERATOR          DENOMINATOR
S** 0              5.402250E-05       5.402250E-08
S** 1              3.785744E-07       3.781575E-10
S** 2              9.799589E-12       6.881159E-15
S** 3              2.773910E-14       2.773910E-17

TO CONTINUE THE LADDER NETWORK ANALYSIS PACKAGE
TYPE IN RUN RK1:ANALY TO PERFORM BODE AND NYQUIST PLOTS
STOP --
```

We now have completed the first and second steps of the design-analysis process. In steps one and two, we discussed the operation and development of the programs LADNET and TRANF. These programs enabled us to build a ladder network and then find it's TF and DPF. Now, we are ready to proceed to the third step.

The third stop of the process enables us to study the response of a ladder network established by steps one and two. The response of the ladder network will be studied by using the Bode and Nyquist plots. Also, provisions had been made in the third step whereby one can enter a system function and study it's response by the Bode and Nyquist plots.

CHAPTER 3

PROGRAM ANALY

3.1 INTRODUCTION

In any engineering field, the performance of a design to various tests is important. This performance enables the designer to determine whether or not a design meets or exceeds expected specifications.

In Chapter 3, we will discuss the third step of the design-analysis process which involves the analysis of ladder networks or system functions. This analysis will be done using the Bode and Nyquist plots. From these plots, we can determine the performance of ladder networks and system functions by investigating the magnitude and phase response, as well as the stability of these designs. Our discussion will begin with the development of the program used in the third step.

3.2 BODE AND NYQUIST PLOTS

The program which is utilized in the third step of the design-analysis process is called ANALY. This program incorporates the capabilities of both man-computer interaction and computation. The man-computer interaction proceeds in a similar manner as LADNET. The man-computer interaction is performed by a series of questions and answers through the teletype. The computational ability of the program was developed using the following study.

Various programs have been developed to obtain the Bode plot[7,9,10]. All these programs are based upon calculating the roots of the numerator and denominator polynomials of the TF. These roots are than utilized to calculate the Bode plot. This technique of calculating the roots is found to be adequate for low order polynomials, but inaccuracies are encountered when high order polynomials are involved. To illustrate this point, let us assume the following polynomial

$$S^9+2.4S^8+31.4S^7+75.36S^6+356.16S^5+845.184S^4+1650.934S^3 +3962.2416S^2+2660.5215S+6385.2516 \tag{3.1}$$

whereby the factors are

$$(S^2+11.7)\ (S^2+8.5)\ (S^2+7.3)\ (S+2.4) \tag{3.2}$$

and the roots are

$$\begin{aligned} S_1 &= \pm\ j\ 3.4025 \\ S_2 &= \pm\ j\ 2.9833 \\ S_3 &= \pm\ j\ 2.7019 \\ S_4 &= \pm\ j\ 1.8707 \\ S_5 &= -\ 2.4 \end{aligned} \tag{3.3}$$

To solve for the polynomials of equation 3.1, let us use a universally accepted subroutine called POLRT* which uses the Newton-Raphson technique to calculate the roots. Entering the coefficients of equation 3.1 into the subroutine POLRT, the roots were calculated as follows:

REAL ROOTS	IMAG ROOTS
-2.3898	0.0000
0.1718	-2.3775
0.1718	2.3775
0.3676	-3.4697
0.3676	3.4697
-0.0481	-1.8945
-0.0481	1.8945
-0.4964	-3.2417
-0.4964	3.2417

(3.4)

Note the difference between the roots in equations 3.3 and 3.4. We can see that the roots generated by POLRT have real parts for the imaginary roots. This inaccuracy of calculating the roots results in incorrect Bode plots. In view of these inaccuracies, these programs were not implemented in developing ANALY. The technique that is adopted in ANALY to obtain the Bode and Nyquist plots is based upon the polynomial coefficients of the system function. This technique gives accurate results in obtaining these plots. Let us proceed to discuss the operation of ANALY.

---

*Scientific Subroutine: Part of PDP 11/45 Software System.

The analysis step is initiated by typing in Run RK1:ANALY. This activates the teletype to print-out

```
DO YOU WISH TO ENTER YOUR OWN TRANSFER FUNCTION?
TYPE IN YES OR NO
```

At the beginning, the user has the option to analyze the ladder network TF, or to enter a system function describing some system design. If the user wishes to analyze the ladder network, a NO is entered on the teletype. This allows the program ANALY to read a file on disk containing the TF generated by the program TRANF for the ladder being studied. This NO reply results in the following output

```
ENTER THE STARTING FREQUENCY(IN RAD/SEC)=
ENTER THE FINAL FREQUENCY(IN RAD/SEC)=
```

The computer now requests for the starting and final frequencies of interest to analyze the ladder network. Before we proceed any further, the answer of YES above will enable us to arrive at the same point; but a few operations will have to be performed beforehand. The YES reply results in the following

```
ENTER THE ORDER OF THE TRANSFER FUNCTION
ORDER=
```

The computer is now asking us the order of the rational function we wish to study. To continue the operation, let us take the TF

$$TF(s) = \frac{S^2+1}{S^2 + 2S + 1} \tag{3.5}$$

As we can see, the order is 2 . Therefore, 2 is entered and the teletype prints

```
ENTER THE COEFFICIENTS OF THE TRANSFER FUNCTION
COEFFICIENTS BEING ENTERD FROM LOWEST TO HIGHEST ORDER
COEFFICIENT OF S** 0

NUMERATOR=1.

DENOMINATOR=1.

COEFFICIENT OF S** 1

NUMERATOR=0.

DENOMINATOR=2.

COEFFICIENT OF S** 2

NUMERATOR=1.

DENOMINATOR=1.

DO YOU WANT A PRINT OUT OF THE COEFFICIENTS JUST ENTERED?
TYPE IN YES OR NO
```

We enter (at each stage of the teletype printout) the coefficients of the numerator and denominator polynomials respectively. When all the coefficients have been entered, the computer asks whether a printout is wanted. A NO reply sends us directly to the stage of entering the starting and final frequencies; a YES reply results in a printout of the coefficients below

```
                         ***TRANSFER FUNCTION***
COEFFICIENTS                  NUMERATOR                      DENOMINATOR
S** 0                         1.000000E+00                   1.000000E+00
S** 1                         0.000000E-01                   2.000000E+00
S** 2                         1.000000E+00                   1.000000E+00
ARE YOU SATISFIED?
IF ANSWER IS YES BODE   PLOT BEGINS
IF THE ANSWER IS NO RE-ENTER COEFFICIENTS
TYPE IN YES OR NO
```

At the end of the printout, another question is asked. If the answer is NO, the program ANALY returns to the beginning question

```
DO YOU WISH TO ENTER YOUR OWN TRANSFER FUNCTION?
TYPE IN YES OR NO
```

and a reply of YES enables us to enter the frequencies of interest.

```
ENTER THE STARTING FREQUENCY(IN RAD/SEC)=.1
ENTER THE FINAL FREQUENCY(IN RAD/SEC)=2.
```

In the above output, the frequency range was taken between .1 to 2.0 for equation 3.5. Once the frequency limits have been entered, the computer begins to calculate the Bode and Nyquist plots. The program ANALY calculates 400 data points between the starting and final frequencies. Once the computer has completed the calculations, the teletype is activated and the question is asked

```
WHICH DO YOU WANT?     BODE OR NYQT?
TYPE IN  BODE OR NYQT
```

We now type in either BODE or NYQT (NYQUIST) to obtain the desired plot. If we type in BODE, the BODE plot appears on the screen. If NYQT is typed, the Nyquist plot will appear. At this particular time, we will request the BODE PLOT which is shown in Figure 3.1.

In Fig. 3.1, the upper half illustrates the magnitude plot while the lower half illustrates the phase plot. Notice how the program ANALY can handle the sudden changes in both magnitude and

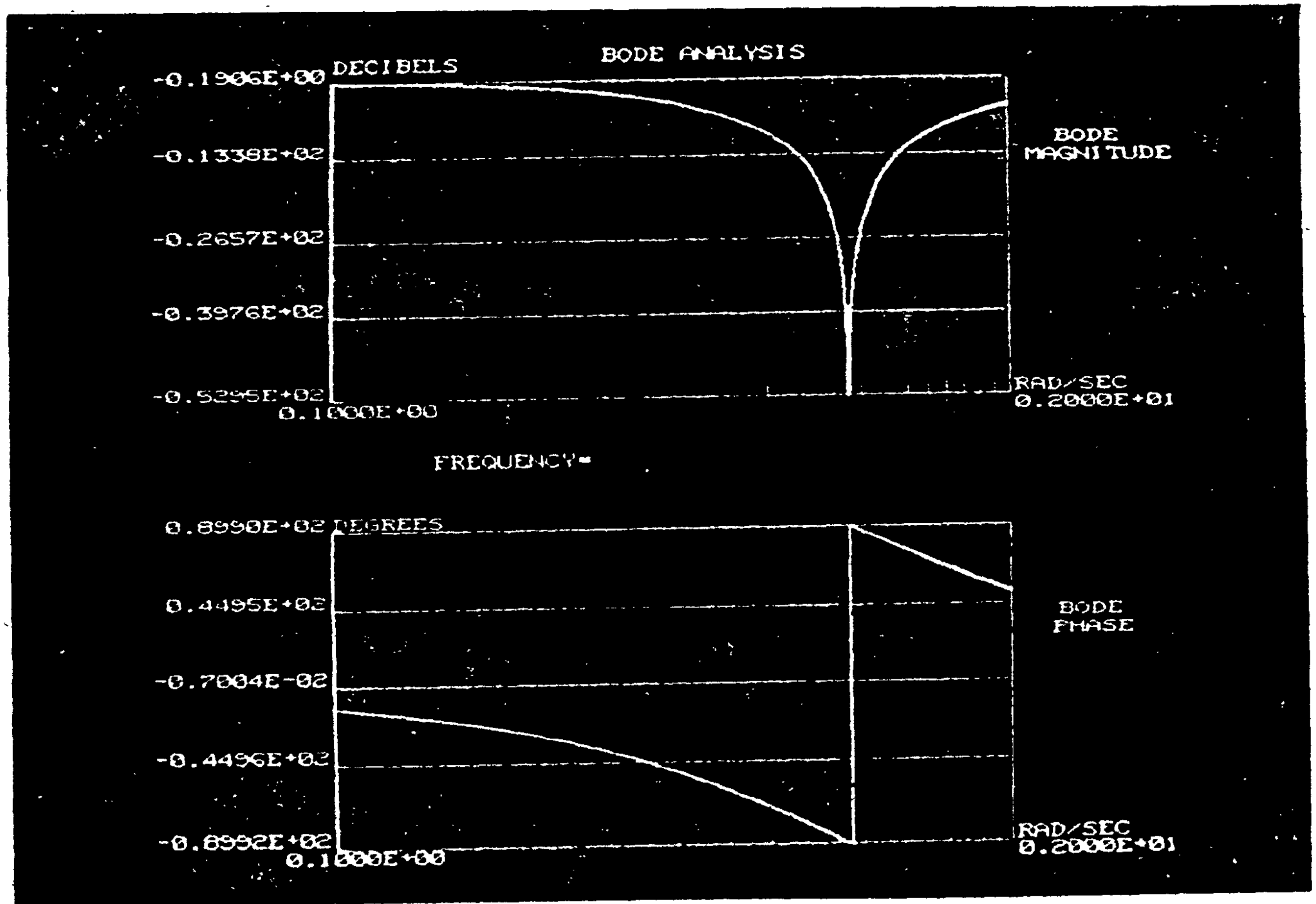


Fig. 3.1 Bode Plot between .1 and 2. rad/sec of Equation 3.5

phase. Once the computer completes the plots, the teletype prints out the following

```
DETAILED EXAMINATION OF THE PLOT IS OBTAINED
BY  TYPING IN AN INTEGER NUMBER FROM 1 TO 401
TO EXIT FROM THIS MODE TYPE IN INTEGER >401
TYPE IN INTEGER
```

The detailed examination of the plot is a feature whereby we can examine the plots by having a cursor moving along the horizontal axis of the plots in Fig. 3.1. The position of the cursor on these plots will give us an output of the magnitude, phase, and frequency for the cursor position. The range specified from 1 to 401 corresponds to the number of data points plotted on the screen. In Fig. 3.1, notice the small vertical lines along the horizontal axis of both the magnitude and phase plots. These lines indicate intervals of 25 data points that are plotted and used as a guide to position the cursor on the screen. To clarify this point, let us examine the plot where the magnitude is the least and the phase angle is changing rapidly. To do this we count the number of divisions and enter the integer 190 which enables the cursor to appear at our desired location (Fig. 3.2).

In Fig. 3.2, the position of cursor gives us the following information

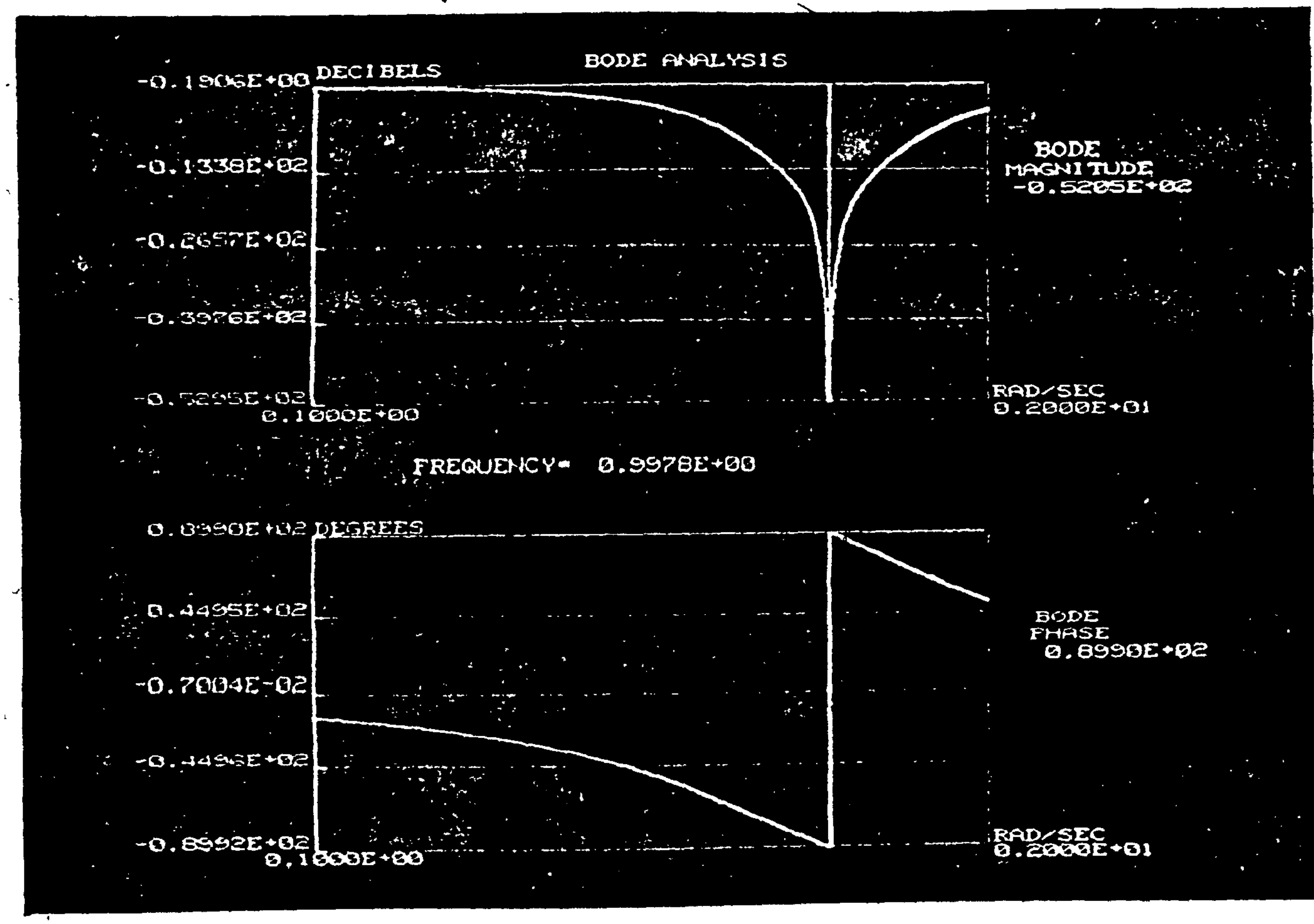


Fig. 3.2 Bode Plot between .1 and .2 rad/sec of Equation 3.5 with Cursor at .9978 rad/sec

FREQUENCY = .9978 HZ

BODE MAGNITUDE = -52.05 DB

PHASE = 89.90 Degrees

Everytime an integer number is entered between the limits (1 to 401), the cursor will move across the plots giving an update on the frequency, magnitude, and phase.This feature enables us to study the plots at critical points. Once we are satisfied with our investigation, we then exit from this mode by typing an integer > 401. When we type in an integer > 401 the teletype prints out

```
DO YOU WANT NYQUIST PLOT?
TYPE IN YES OR NO.
```

Now, the computer requests an answer of YES or NO. A NO reply results in

```
DO YOU WANT A PRINT OUT OF THE BODE PLOT?
TYPE IN YES OR NO
```

This question also arises after the Nyquist plot has been investigated. Therefore, we will consider this output at a later time. A YES reply to the Nyquist plot results in obtaining Fig. 3.3 and the following output

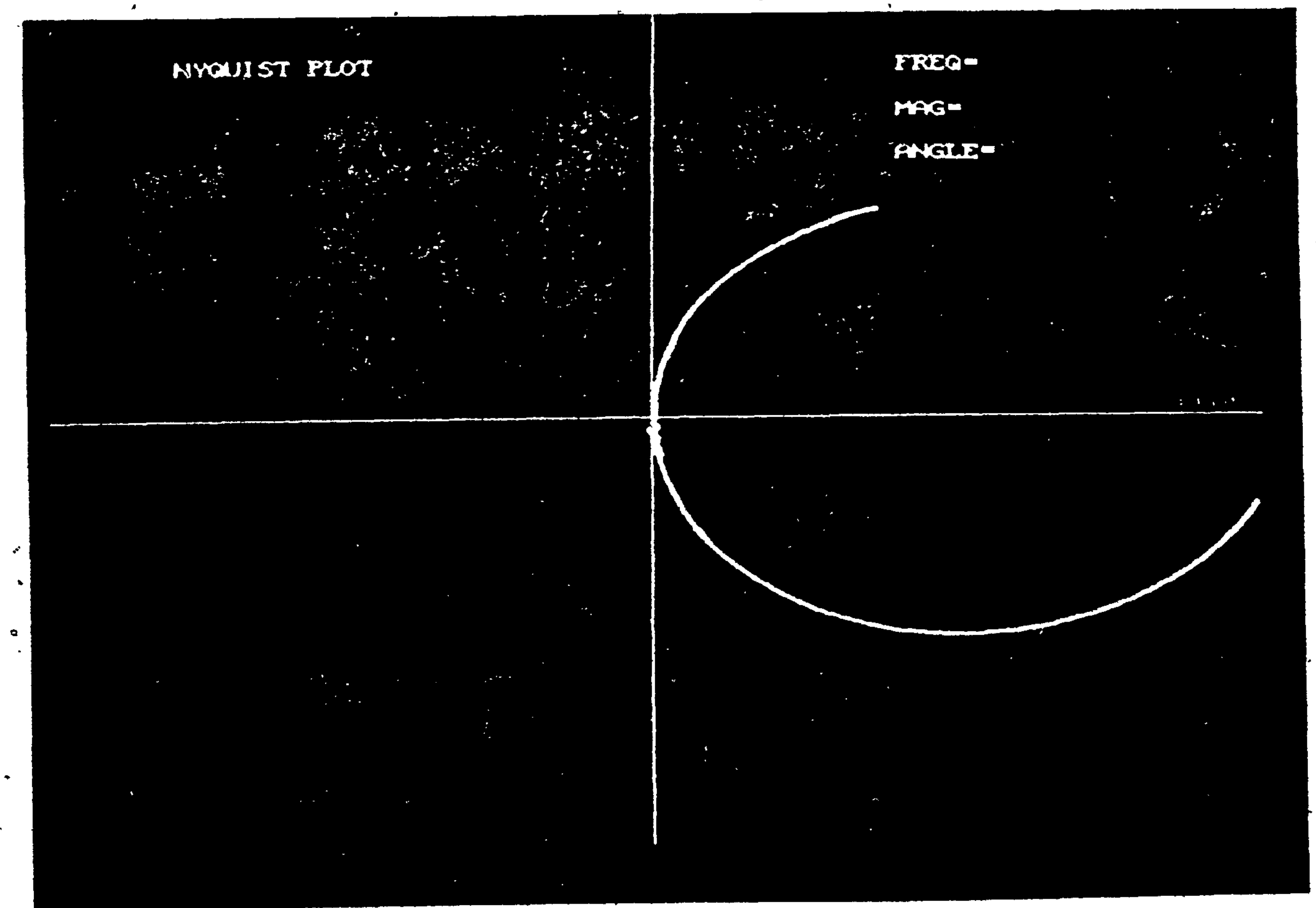


Fig. 3.3 Nyquist Plot between .1 and 2. rad/sec of Equation 3.5

```
DETAILED EXAMINATION OF THE PLOT IS OBTAINED
BY TYPING IN AN INTEGER NUMBER FROM 1 TO 401
TO EXIT FROM  THIS MODE TYPE IN INTEGER >401
TYPE IN INTEGER
```

Again, we can examine the plot in more detail as in the case of the previous plots. Let us enter an integer number 90 and the results are shown in Fig. 3.4. As we can see, we have a cross marker whose movement (as in the previous plot) is controlled by the entry of an integer number. The position of the marker on the plot gives us the frequency, magnitude, and phase. In Fig. 3.4, this information can be found in the upper right hand corner. When the detailed examination is over, we type in an integer number > 401 and the teletype then prints

```
DO YOU WANT A PRINT OUT OF THE BODE PLOT?
TYPE IN YES OR NO
```

We are now given the option whether or not to have a hard copy of what was seen in Fig. 3.2. A YES reply, activates a line printer and the output is shown on the following page. This output shows the TF being

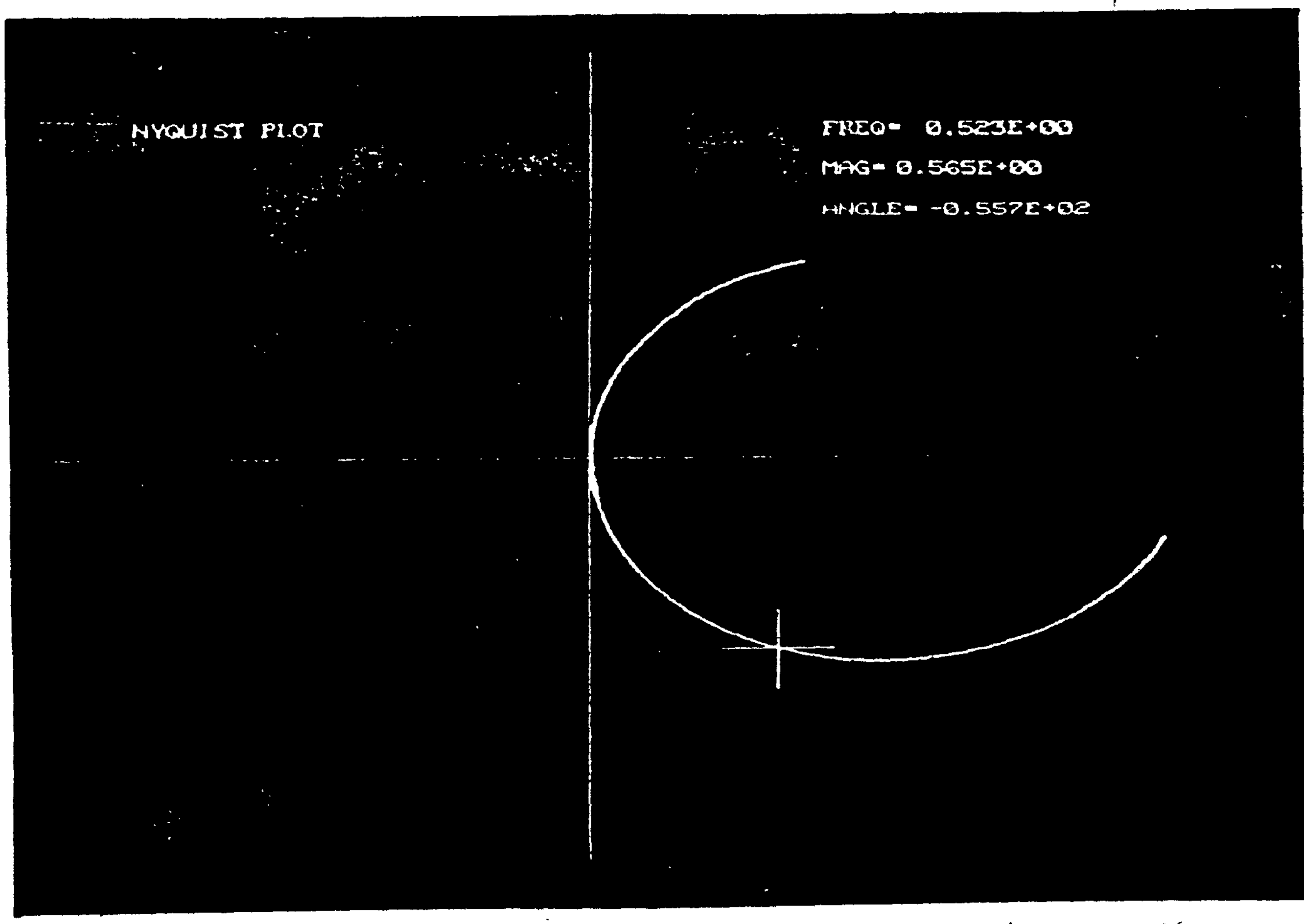


Fig. 3.4 Nyquist Plot between .1 and 2. rad/sec of Equation 3.5 with Cross Marker at .523 rad/sec

TRANSFER FUNCTION

COEFFICIENTS	NUMERATOR	DENOMINATOR
S** 0	1.000000E+00	1.000000E+00
S** 1	0.000000E-01	2.000000E+00
S** 2	1.000000E+00	1.000000E+00

****BODE PLOT****

STARTING FREQUENCY= 1.0000000E-01 RAD/SEC

FINAL FREQUENCY= 2.0000000E+00 RAD/SEC

FREQUENCY	MAGNITUDE	PHASE
1.0000E-01	-1.9062E-01	-1.1966E+01
1.0950E-01	-2.2677E-01	-1.3042E+01
1.1900E-01	-2.6605E-01	-1.4116E+01
1.2850E-01	-3.0848E-01	-1.5188E+01
1.3800E-01	-3.5404E-01	-1.6256E+01
1.4750E-01	-4.0278E-01	-1.7322E+01
1.5700E-01	-4.5460E-01	-1.8385E+01
1.6650E-01	-5.0960E-01	-1.9445E+01
1.7600E-01	-5.6775E-01	-2.0502E+01
1.8550E-01	-6.2905E-01	-2.1555E+01
1.9500E-01	-6.9350E-01	-2.2604E+01
2.0450E-01	-7.6112E-01	-2.3649E+01
2.1400E-01	-8.3190E-01	-2.4691E+01
2.2350E-01	-9.0586E-01	-2.5728E+01
2.3300E-01	-9.8299E-01	-2.6761E+01
2.4250E-01	-1.0633E+00	-2.7790E+01
2.5200E-01	-1.1468E+00	-2.8814E+01
2.6150E-01	-1.2335E+00	-2.9833E+01
2.7100E-01	-1.3235E+00	-3.0848E+01
2.8050E-01	-1.4166E+00	-3.1858E+01
2.9000E-01	-1.5130E+00	-3.2862E+01
2.9950E-01	-1.6127E+00	-3.3862E+01
3.0900E-01	-1.7156E+00	-3.4856E+01
3.1850E-01	-1.8218E+00	-3.5845E+01
3.2800E-01	-1.9314E+00	-3.6828E+01
3.3750E-01	-2.0442E+00	-3.7806E+01
3.4700E-01	-2.1604E+00	-3.8778E+01
3.5650E-01	-2.2800E+00	-3.9745E+01
3.6600E-01	-2.4031E+00	-4.0705E+01
3.7550E-01	-2.5295E+00	-4.1660E+01
3.8500E-01	-2.6594E+00	-4.2608E+01
3.9450E-01	-2.7929E+00	-4.3551E+01
4.0400E-01	-2.9299E+00	-4.4487E+01
4.1350E-01	-3.0705E+00	-4.5417E+01
4.2300E-01	-3.2147E+00	-4.6341E+01
4.3250E-01	-3.3626E+00	-4.7259E+01
4.4200E-01	-3.5143E+00	-4.8170E+01
4.5150E-01	-3.6698E+00	-4.9075E+01
4.6100E-01	-3.8292E+00	-4.9973E+01
4.7050E-01	-3.9925E+00	-5.0865E+01
4.8000E-01	-4.1598E+00	-5.1750E+01
4.8950E-01	-4.3312E+00	-5.2628E+01
4.9900E-01	-4.5068E+00	-5.3500E+01
5.0850E-01	-4.6867E+00	-5.4366E+01
5.1800E-01	-4.8709E+00	-5.5225E+01
5.2750E-01	-5.0596E+00	-5.6077E+01
5.3700E-01	-5.2530E+00	-5.6922E+01
5.4650E-01	-5.4510E+00	-5.7761E+01
5.5600E-01	-5.6539E+00	-5.8593E+01

5.6550E-01	-5.8618E+00	-5.9418E+01
5.7500E-01	-6.0749E+00	-6.0237E+01
5.8450E-01	-6.2933E+00	-6.1048E+01
5.9400E-01	-6.5173E+00	-6.1853E+01
6.0350E-01	-6.7470E+00	-6.2652E+01
6.1300E-01	-6.9826E+00	-6.3444E+01
6.2250E-01	-7.2243E+00	-6.4229E+01
6.3200E-01	-7.4726E+00	-6.5007E+01
6.4150E-01	-7.7275E+00	-6.5778E+01
6.5100E-01	-7.9894E+00	-6.6543E+01
6.6050E-01	-8.2587E+00	-6.7302E+01
6.7000E-01	-8.5356E+00	-6.8054E+01
6.7950E-01	-8.8207E+00	-6.8799E+01
6.8900E-01	-9.1143E+00	-6.9537E+01
6.9850E-01	-9.4169E+00	-7.0269E+01
7.0800E-01	-9.7290E+00	-7.0995E+01
7.1750E-01	-1.0051E+01	-7.1714E+01
7.2700E-01	-1.0384E+01	-7.2426E+01
7.3650E-01	-1.0729E+01	-7.3132E+01
7.4600E-01	-1.1085E+01	-7.3832E+01
7.5550E-01	-1.1455E+01	-7.4526E+01
7.6500E-01	-1.1839E+01	-7.5213E+01
7.7450E-01	-1.2239E+01	-7.5893E+01
7.8400E-01	-1.2655E+01	-7.6568E+01
7.9350E-01	-1.3089E+01	-7.7236E+01
8.0300E-01	-1.3543E+01	-7.7899E+01
8.1250E-01	-1.4018E+01	-7.8555E+01
8.2200E-01	-1.4517E+01	-7.9205E+01
8.3150E-01	-1.5043E+01	-7.9849E+01
8.4100E-01	-1.5599E+01	-8.0487E+01
8.5050E-01	-1.6188E+01	-8.1119E+01
8.6000E-01	-1.6815E+01	-8.1745E+01
8.6950E-01	-1.7485E+01	-8.2365E+01
8.7900E-01	-1.8205E+01	-8.2979E+01
8.8850E-01	-1.8984E+01	-8.3588E+01
8.9800E-01	-1.9832E+01	-8.4191E+01
9.0750E-01	-2.0764E+01	-8.4788E+01
9.1700E-01	-2.1798E+01	-8.5380E+01
9.2650E-01	-2.2962E+01	-8.5966E+01
9.3600E-01	-2.4293E+01	-8.6547E+01
9.4550E-01	-2.5851E+01	-8.7122E+01
9.5500E-01	-2.7732E+01	-8.7691E+01
9.6450E-01	-3.0111E+01	-8.8256E+01
9.7400E-01	-3.3361E+01	-8.8814E+01
9.8350E-01	-3.8548E+01	-8.9368E+01
9.9300E-01	-5.2947E+01	-8.9917E+01
1.0025E+00	-4.2825E+01	8.9632E+01
1.0120E+00	-3.5593E+01	8.9093E+01
1.0215E+00	-3.1782E+01	8.8560E+01
1.0310E+00	-2.9091E+01	8.8032E+01
1.0405E+00	-2.7086E+01	8.7509E+01
1.0500E+00	-2.5473E+01	8.6991E+01
1.0595E+00	-2.4126E+01	8.6478E+01
1.0690E+00	-2.2970E+01	8.5970E+01
1.0785E+00	-2.1960E+01	8.5466E+01
1.0880E+00	-2.1065E+01	8.4968E+01
1.0975E+00	-2.0260E+01	8.4474E+01
1.1070E+00	-1.9532E+01	8.3984E+01
1.1165E+00	-1.8866E+01	8.3499E+01
1.1260E+00	-1.8254E+01	8.3019E+01

1.1355E+00	-1.7688E+01	8.2543E+01
1.1450E+00	-1.7162E+01	8.2072E+01
1.1545E+00	-1.6671E+01	8.1605E+01
1.1640E+00	-1.6211E+01	8.1143E+01
1.1735E+00	-1.5779E+01	8.0685E+01
1.1830E+00	-1.5371E+01	8.0231E+01
1.1925E+00	-1.4986E+01	7.9781E+01
1.2020E+00	-1.4621E+01	7.9335E+01
1.2115E+00	-1.4275E+01	7.8894E+01
1.2210E+00	-1.3945E+01	7.8457E+01
1.2305E+00	-1.3631E+01	7.8024E+01
1.2400E+00	-1.3331E+01	7.7594E+01
1.2495E+00	-1.3044E+01	7.7169E+01
1.2590E+00	-1.2769E+01	7.6748E+01
1.2685E+00	-1.2506E+01	7.6330E+01
1.2780E+00	-1.2253E+01	7.5917E+01
1.2875E+00	-1.2010E+01	7.5507E+01
1.2970E+00	-1.1776E+01	7.5101E+01
1.3065E+00	-1.1550E+01	7.4698E+01
1.3160E+00	-1.1333E+01	7.4300E+01
1.3255E+00	-1.1123E+01	7.3905E+01
1.3350E+00	-1.[illegible]21E+01	7.3513E+01
1.3445E+00	-1.0725E+01	7.3125E+01
1.3540E+00	-1.0536E+01	7.2741E+01
1.3635E+00	-1.0353E+01	7.2360E+01
1.3730E+00	-1.0175E+01	7.1982E+01
1.3825E+00	-1.0003E+01	7.1608E+01
1.3920E+00	-9.8363E+00	7.1237E+01
1.4015E+00	-9.6745E+00	7.0870E+01
1.4110E+00	-9.5173E+00	7.0506E+01
1.4205E+00	-9.3647E+00	7.0145E+01
1.4300E+00	-9.2163E+00	6.9787E+01
1.4395E+00	-9.0721E+00	6.9433E+01
1.4490E+00	-8.9317E+00	6.9081E+01
1.4585E+00	-8.7952E+00	6.8733E+01
1.4680E+00	-8.6622E+00	6.8388E+01
1.4775E+00	-8.5327E+00	6.8046E+01
1.4870E+00	-8.4065E+00	6.7706E+01
1.4965E+00	-8.2835E+00	6.7370E+01
1.5060E+00	-8.1635E+00	6.7037E+01
1.5155E+00	-8.0465E+00	6.6707E+01
1.5250E+00	-7.9323E+00	6.6379E+01
1.5345E+00	-7.8209E+00	6.6054E+01
1.5440E+00	-7.7120E+00	6.5733E+01
1.5535E+00	-7.6057E+00	6.5413E+01
1.5630E+00	-7.5019E+00	6.5097E+01
1.5725E+00	-7.4004E+00	6.4783E+01
1.5820E+00	-7.3012E+00	6.4472E+01
1.5915E+00	-7.2042E+00	6.4164E+01
1.6010E+00	-7.1093E+00	6.3859E+01
1.6105E+00	-7.0165E+00	6.3555E+01
1.6200E+00	-6.9257E+00	6.3255E+01
1.6295E+00	-6.8368E+00	6.2957E+01
1.6390E+00	-6.7498E+00	6.2661E+01
1.6485E+00	-6.6646E+00	6.2369E+01
1.6580E+00	-6.5811E+00	6.2078E+01
1.6675E+00	-6.4993E+00	6.1790E+01
1.6770E+00	-6.4192E+00	6.1504E+01
1.6865E+00	-6.3407E+00	6.1221E+01
1.6960E+00	-6.2637E+00	6.0940E+01

1.7055E+00	-6.1883E+00	6.0661E+01
1.7150E+00	-6.1143E+00	6.0385E+01
1.7245E+00	-6.0417E+00	6.0111E+01
1.7340E+00	-5.9705E+00	5.9839E+01
1.7435E+00	-5.9007E+00	5.9569E+01
1.7530E+00	-5.8322E+00	5.9302E+01
1.7625E+00	-5.7649E+00	5.9037E+01
1.7720E+00	-5.6989E+00	5.8774E+01
1.7815E+00	-5.6341E+00	5.8513E+01
1.7910E+00	-5.5705E+00	5.8254E+01
1.8005E+00	-5.5080E+00	5.7997E+01
1.8100E+00	-5.4466E+00	5.7742E+01
1.8195E+00	-5.3868E+00	5.7490E+01
1.8290E+00	-5.3270E+00	5.7239E+01
1.8385E+00	-5.2688E+00	5.6990E+01
1.8480E+00	-5.2116E+00	5.6744E+01
1.8575E+00	-5.1554E+00	5.6499E+01
1.8670E+00	-5.1001E+00	5.6256E+01
1.8765E+00	-5.0458E+00	5.6015E+01
1.8860E+00	-4.9924E+00	5.5776E+01
1.8955E+00	-4.9398E+00	5.5539E+01
1.9050E+00	-4.8882E+00	5.5304E+01
1.9145E+00	-4.8373E+00	5.5070E+01
1.9240E+00	-4.7874E+00	5.4839E+01
1.9335E+00	-4.7382E+00	5.4609E+01
1.9430E+00	-4.6898E+00	5.4381E+01
1.9525E+00	-4.6422E+00	5.4154E+01
1.9620E+00	-4.5953E+00	5.3930E+01
1.9715E+00	-4.5492E+00	5.3707E+01
1.9810E+00	-4.5036E+00	5.3486E+01
1.9905E+00	-4.4591E+00	5.3266E+01
2.0000E+00	-4.4151E+00	5.3048E+01

analyzed, the starting and final frequencies. This output will produce 200 lines of data containing the frequency, magnitude, and phase between the specified limits.

When the output is complete, the teletype prints out the following

```
DO YOU WANT TO ENTER NEW FREQUENCY LIMITS?
TYPE IN YES OR NO
```

This output will also occur if a NO reply was given to the request of a printout of the Bode plot. We now have the option to repeat the analysis with new frequency limits (YES) or go on to the next step (NO). A response of NO results in

```
DO YOU WANT TO START OVER AGAIN?
TYPE IN YES OR NO
```

The option is now given to us whether we wish to enter a new TF (YES REPLY) or to end the analysis with a response on NO.

Another feature which was programmed into ANALY was the case of incorrect response to the questions asked. If the response to the question is not correct an error message will be typed out.

To clarify this point let us use this question

```
WHICH DO YOU WANT?    BODE OR NYQT?
TYPE IN  BODE OR NYQT

BOTE
```

The user has typed in BOTE, the computer takes this response and prints out

```
*****ILLEGAL COMMAND ENTRY TRY AGAIN*****
```

The user now types in the correct response. This feature has been incorporated into all questions requesting a response. This error message is also incorporated into the specification of the frequency limits. If incorrect limits are inserted as in the case below

```
ENTER THE STARTING FREQUENCY(IN RAD/SEC)-.5
ENTER THE FINAL FREQUENCY(IN RAD/SEC)-.1
```

the teletype will print

```
ERROR YOU HAVE SPECIFIED ILLEGAL FREQUENCY LIMITS
PLEASE TYPE IN CORRECT LIMITS
```

The user must now go back and type in the correct limits.

Now that we know how to use ANALY, let us consider the analysis of the following system function (8)

$$TF(s) = \frac{S^2+2.16}{S^3 + .721S^2 + 1.061S + .437} \quad (3.6)$$

The analysis of this function will proceed in the same manner as in the previous case. This analysis will proceed in a step by step manner with brief explanations given at certain steps.

STEP 1.

```
DO YOU WISH TO ENTER YOUR OWN TRANSFER FUNCTION?
TYPE IN YES OR NO

YES
```

STEP 2.

```
ENTER THE ORDER OF THE TRANSFER FUNCTION
ORDER=3
```

STEP 3.

```
ENTER THE COEFFICIENTS OF THE TRANSFER FUNCTION
COEFFICIENTS BEING ENTERD FROM LOWEST TO HIGHEST ORDER
COEFFICIENT OF S** 0

NUMERATOR=2.16

DENOMINATOR=.437

COEFFICIENT OF S** 1

NUMERATOR=0.

DENOMINATOR=1.061

COEFFICIENT OF S** 2

NUMERATOR=1.

DENOMINATOR=.721
```

```
COEFFICIENT OF S** 3

NUMERATOR=0.

DENOMINATOR=1.

DO YOU WANT A PRINT OUT OF THE COEFFICIENTS JUST   ENTERED?
TYPE IN YES OR NO
```

STEP 4.

```
YES

                     ***TRANSFER FUNCTION***
COEFFICIENTS              NUMERATOR                 DENOMINATOR
S** 0                     2.160000E+00              4.370000E-01
S** 1                     0.000000E-01              1.061000E+00
S** 2                     1.000000E+00              7.210000E-01
S** 3                     0.000000E-01              1.000000E+00
ARE YOU SATISFIED?
IF ANSWER IS YES BODE   PLOT BEGINS
IF THE ANSWER IS NO RE-ENTER COEFFICIENTS
TYPE IN YES OR NO

YES
```

STEP 5.

```
ENTER THE STARTING FREQUENCY(IN RAD/SEC)=.1

ENTER THE FINAL FREQUENCY(IN RAD/SEC)=2.5
```

STEP 6.

```
WHICH DO YOU WANT?     BODE OR NYQT?
TYPE IN  BODE OR NYQT

BODE
```

The answer of Bode results in Fig. 3.5.

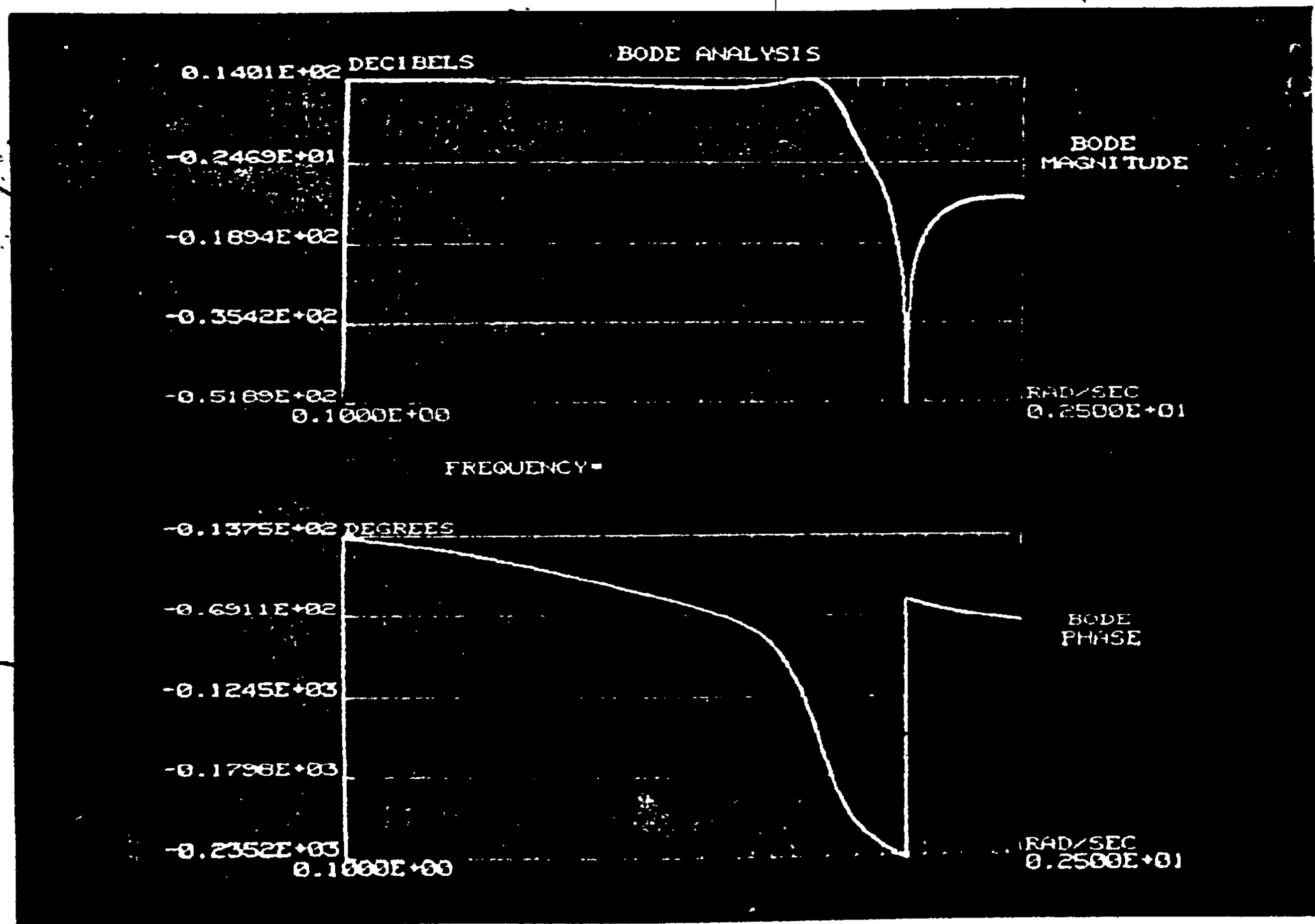


Fig. 3.5 Bode Plot between .1 and 2.5 rad/sec of Equation 3.6

STEP 7.

```
DETAILED EXAMINATION OF THE PLOT IS OBTAINED
BY TYPING IN AN INTEGER NUMBER FROM 1 TO 401
TO EXIT FROM  THIS MODE TYPE IN INTEGER >401
TYPE IN INTEGER
```

STEP 8.

```
139
```

This integer entry results in the cursor being positioned in Fig. 3.6.

STEP 9.

```
232
```

This integer entry results in the cursor being positioned in Fig. 3.7.

STEP 10.

```
DO YOU WANT NYQUIST PLOT?
TYPE IN YES OR NO

YES
```

This answer gives us Fig. 3.8.

STEP 11.

```
DETAILED EXAMINATION OF THE PLOT IS OBTAINED
BY  TYPING IN AN INTEGER NUMBER FROM 1 TO 401
TO EXIT FROM  THIS MODE TYPE IN INTEGER >401
TYPE IN INTEGER
180
```

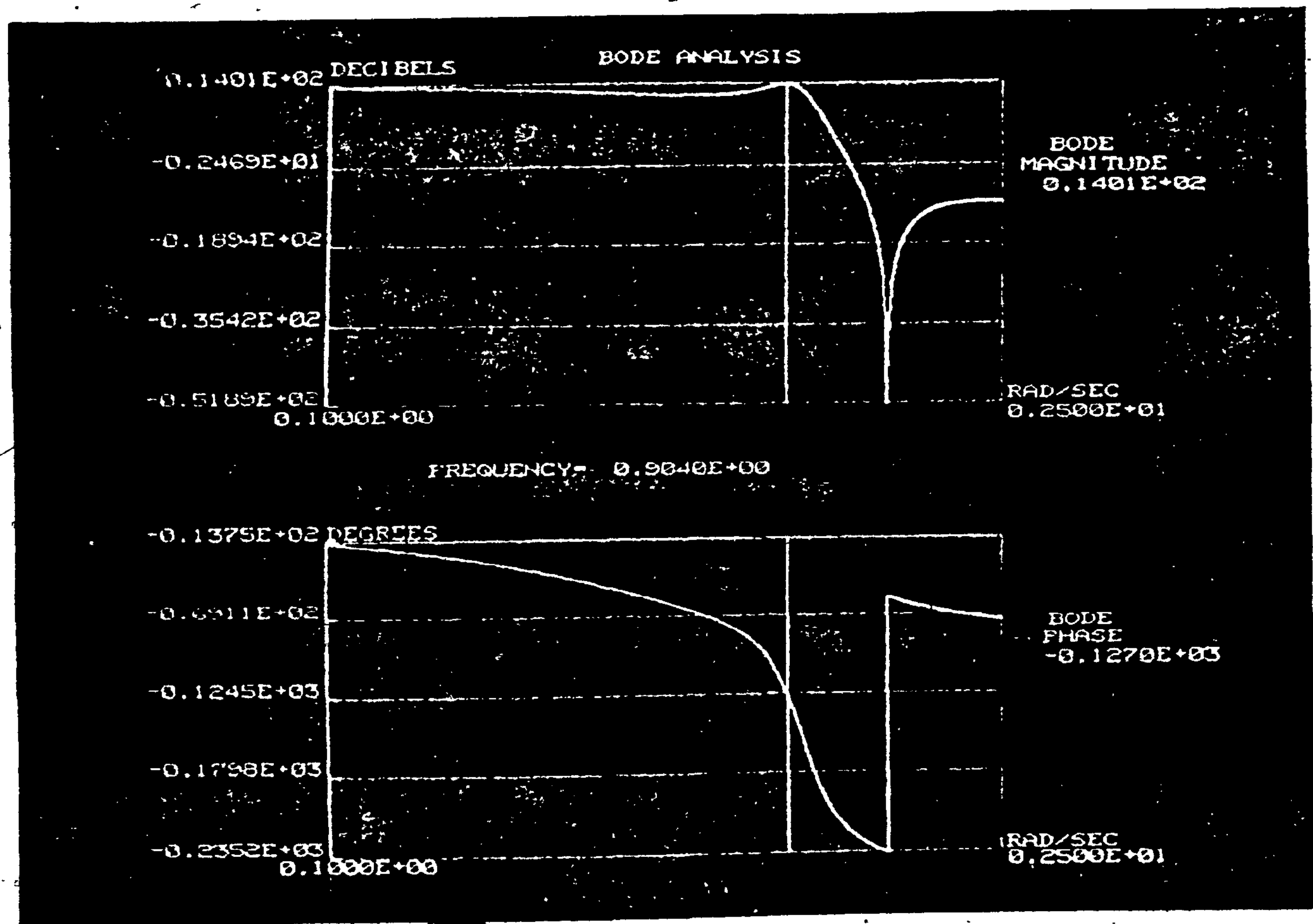


Fig. 3.6 Bode Plot between .1 and 2.5 rad/sec of Equation 3.6 with Cursor at .904 rad/sec

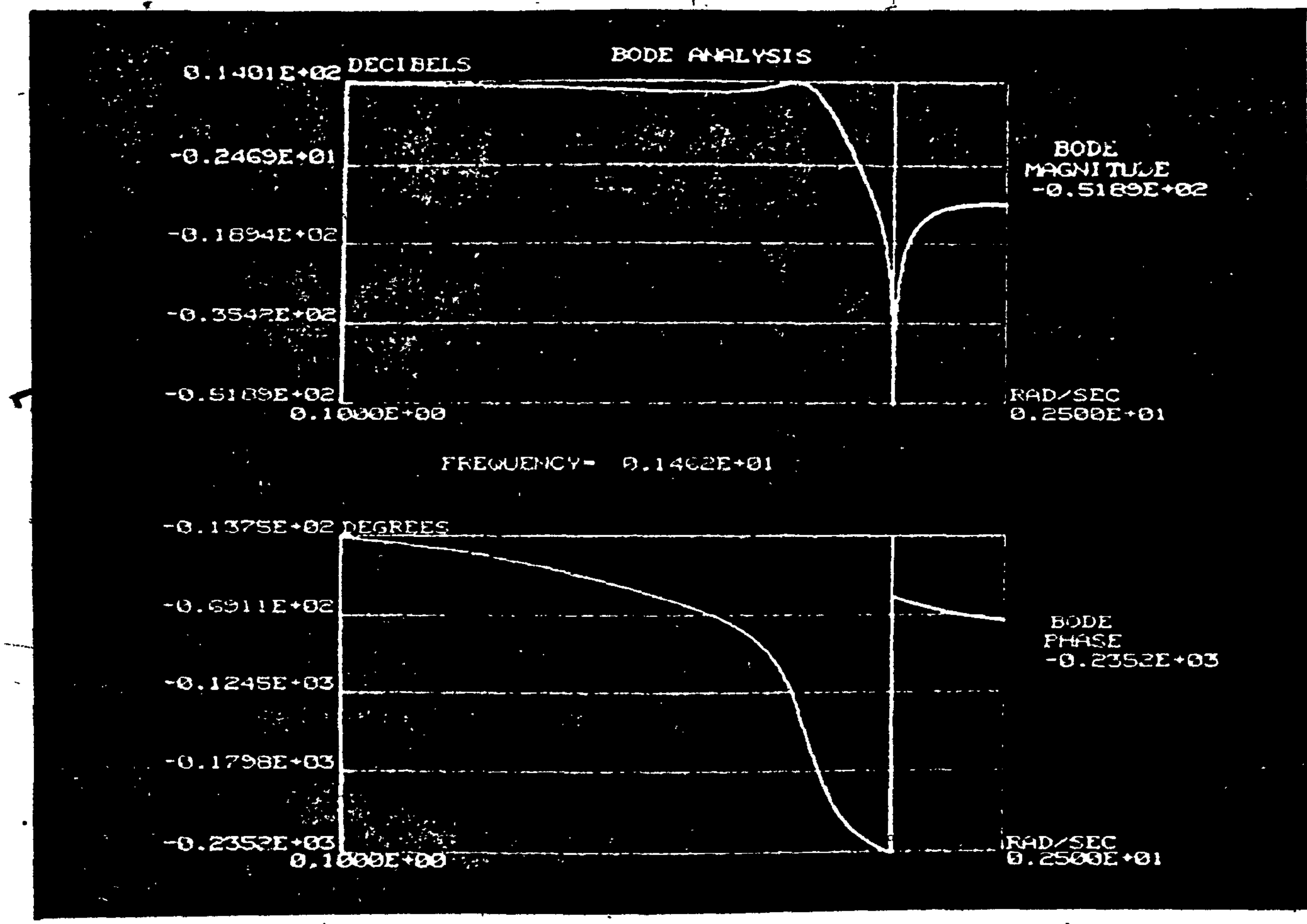


Fig. 3.7 Bode Plot between .1 and 2.5 rad/sec of Equation 3.6 with Cursor at 1.462 rad/sec.

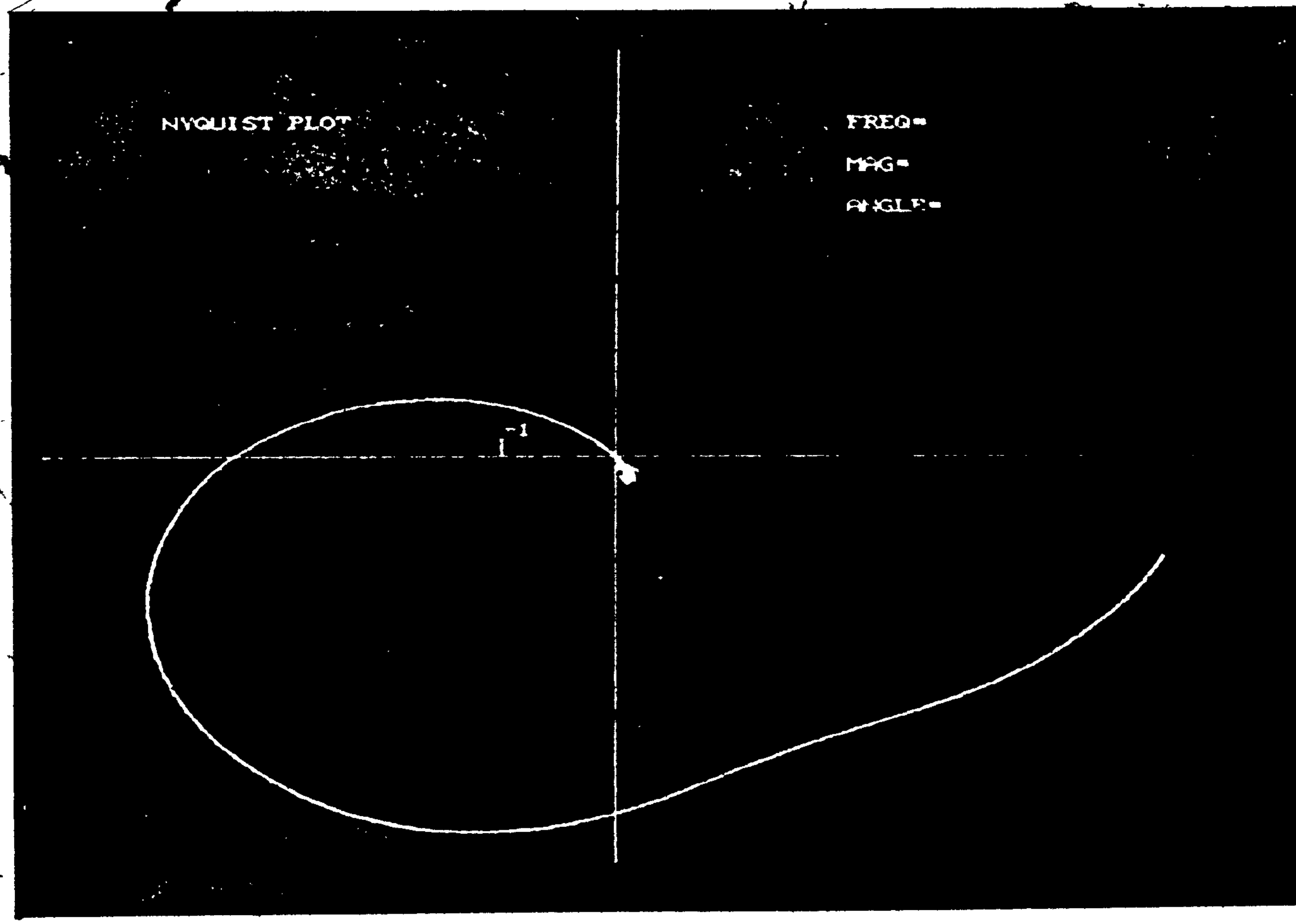


Fig. 3.8 Nyquist Plot between .1 and 2.5 rad/sec of Equation 3.6

This integer gives us Fig. 3.9. Let us now study Fig. 3.9. Notice, how a -1 appears on the horizontal axis. This -1 only appears when the TF that is being studied is such that the corresponding closed-loop transfer function becomes unstable.

STEP 12.

```
DO YOU WANT A PRINT OUT OF THE BODE PLOT?
TYPE IN YES OR NO

YES
```

The output is shown on the following page.

STEP 13.

```
DO YOU WANT TO ENTER NEW FREQUENCY LIMITS?
TYPE IN YES OR NO

NO
```

STEP 14.

```
DO YOU WANT TO START OVER AGAIN?
TYPE IN YES OR NO

NO

STOP --
```

STEP 15.

This completes the analysis. The operation of ANALY has been fully discussed and if more detailed information is needed it is given in Appendix IV.

In the third step of design process, we saw how man-computer interaction and computation were integrated to obtain the Bode and Nyquist plots. By having the knowledge to operate the programs LADNET,

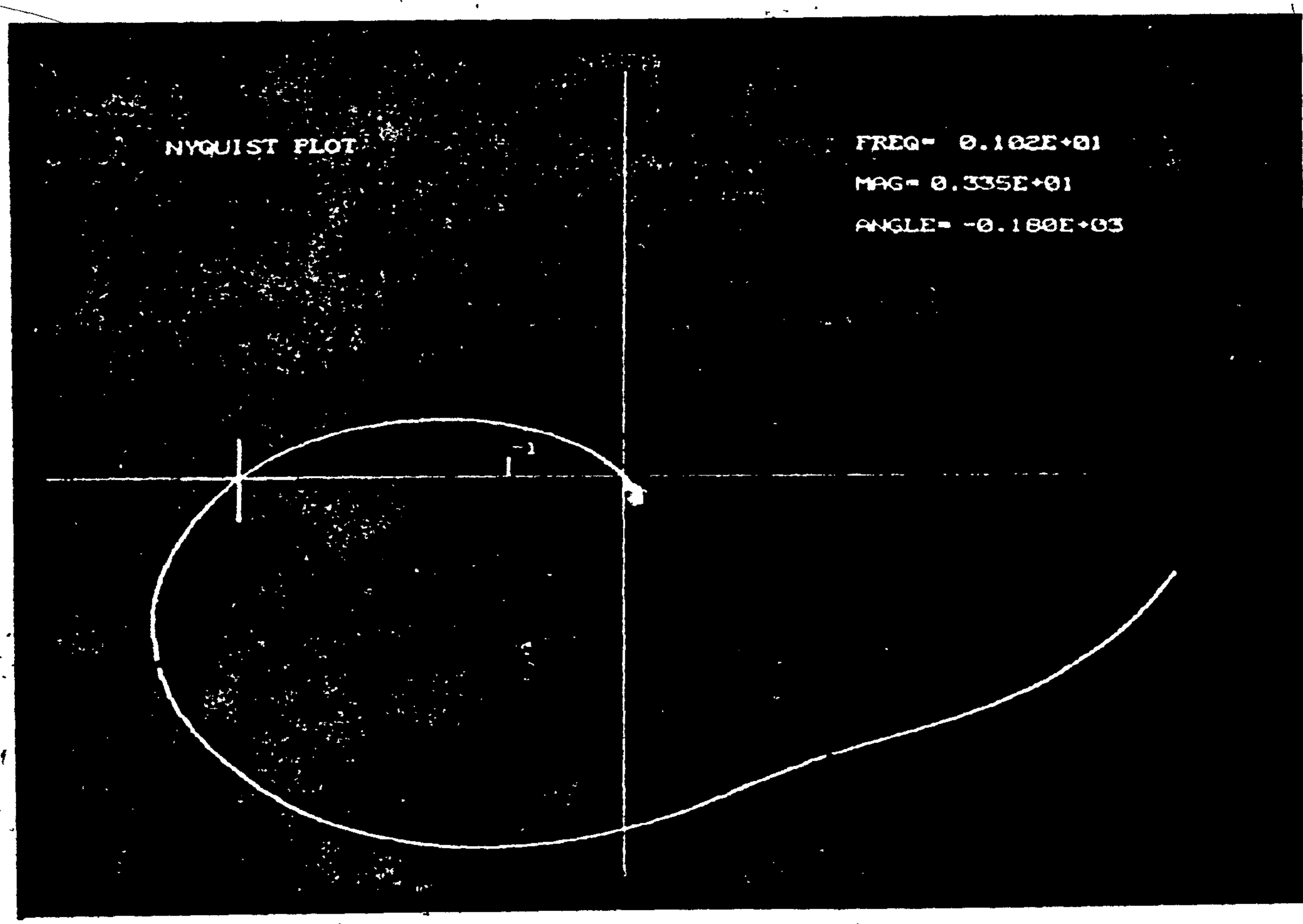


Fig. 3.9 Nyquist Plot between .1 and 2.5 rad/sec of Equation 3.6 with Cross Marker at 1.02 rad/sec

TRANSFER FUNCTION

COEFFICIENTS	NUMERATOR	DENOMINATOR
S** 0	2.160000E+00	4.370000E-01
S** 1	0.000000E-01	1.061000E+00
S** 2	1.000000E+00	7.210000E-01
S** 3	0.000000E-01	1.000000E+00

****BODE PLOT****

STARTING FREQUENCY= 9.9999998E-03 RAD/SEC

FINAL FREQUENCY= 2.5000000E+00 RAD/SEC

FREQUENCY	MAGNITUDE	PHASE
1.0000E-02	1.3875E+01	-2.2575E+00
2.2450E-02	1.3867E+01	-3.9869E+00
3.4900E-02	1.3854E+01	-5.7117E+00
4.7350E-02	1.3836E+01	-7.4299E+00
5.9800E-02	1.3814E+01	-9.1397E+00
7.2250E-02	1.3787E+01	-1.0839E+01
8.4700E-02	1.3756E+01	-1.2527E+01
9.7150E-02	1.3722E+01	-1.4201E+01
1.0960E-01	1.3683E+01	-1.5860E+01
1.2205E-01	1.3641E+01	-1.7502E+01
1.3450E-01	1.3595E+01	-1.9127E+01
1.4695E-01	1.3547E+01	-2.0733E+01
1.5940E-01	1.3495E+01	-2.2320E+01
1.7185E-01	1.3441E+01	-2.3886E+01
1.8430E-01	1.3384E+01	-2.5431E+01
1.9675E-01	1.3326E+01	-2.6954E+01
2.0920E-01	1.3265E+01	-2.8456E+01
2.2165E-01	1.3204E+01	-2.9935E+01
2.3410E-01	1.3141E+01	-3.1392E+01
2.4655E-01	1.3077E+01	-3.2828E+01
2.5900E-01	1.3012E+01	-3.4241E+01
2.7145E-01	1.2947E+01	-3.5632E+01
2.8390E-01	1.2882E+01	-3.7002E+01
2.9635E-01	1.2817E+01	-3.8352E+01
3.0880E-01	1.2752E+01	-3.9681E+01
3.2125E-01	1.2688E+01	-4.0991E+01
3.3370E-01	1.2625E+01	-4.2282E+01
3.4615E-01	1.2563E+01	-4.3555E+01
3.5860E-01	1.2502E+01	-4.4811E+01
3.7105E-01	1.2443E+01	-4.6051E+01
3.8350E-01	1.2386E+01	-4.7276E+01
3.9595E-01	1.2331E+01	-4.8488E+01
4.0840E-01	1.2279E+01	-4.9687E+01
4.2085E-01	1.2228E+01	-5.0875E+01
4.3330E-01	1.2181E+01	-5.2053E+01
4.4575E-01	1.2136E+01	-5.3223E+01
4.5820E-01	1.2095E+01	-5.4387E+01
4.7065E-01	1.2057E+01	-5.5545E+01
4.8310E-01	1.2023E+01	-5.6700E+01
4.9555E-01	1.1993E+01	-5.7853E+01
5.0800E-01	1.1966E+01	-5.9007E+01
5.2045E-01	1.1945E+01	-6.0163E+01
5.3290E-01	1.1927E+01	-6.1325E+01
5.4535E-01	1.1915E+01	-6.2493E+01
5.5780E-01	1.1907E+01	-6.3672E+01
5.7025E-01	1.1905E+01	-6.4863E+01
5.8270E-01	1.1909E+01	-6.6071E+01
5.9515E-01	1.1918E+01	-6.7297E+01
6.0760E-01	1.1934E+01	-6.8546E+01

6.2005E-01	1.1956E+01	-6.9823E+01
6.3250E-01	1.1984E+01	-7.1130E+01
6.4495E-01	1.2020E+01	-7.2474E+01
6.5740E-01	1.2063E+01	-7.3860E+01
6.6985E-01	1.2114E+01	-7.5295E+01
6.8230E-01	1.2172E+01	-7.6783E+01
6.9475E-01	1.2239E+01	-7.8335E+01
7.0720E-01	1.2314E+01	-7.9958E+01
7.1965E-01	1.2397E+01	-8.1662E+01
7.3210E-01	1.2489E+01	-8.3458E+01
7.4455E-01	1.2590E+01	-8.5358E+01
7.5700E-01	1.2699E+01	-8.7378E+01
7.6945E-01	1.2817E+01	-8.9532E+01
7.8190E-01	1.2942E+01	-9.1747E+01
7.9435E-01	1.3073E+01	-9.4225E+01
8.0680E-01	1.3209E+01	-9.6899E+01
8.1925E-01	1.3348E+01	-9.9790E+01
8.3170E-01	1.3487E+01	-1.0293E+02
8.4415E-01	1.3622E+01	-1.0633E+02
8.5660E-01	1.3748E+01	-1.1003E+02
8.6905E-01	1.3857E+01	-1.1405E+02
8.8150E-01	1.3943E+01	-1.1840E+02
8.9395E-01	1.3995E+01	-1.2309E+02
9.0640E-01	1.4002E+01	-1.2812E+02
9.1885E-01	1.3953E+01	-1.3345E+02
9.3130E-01	1.3837E+01	-1.3904E+02
9.4375E-01	1.3644E+01	-1.4480E+02
9.5620E-01	1.3367E+01	-1.5066E+02
9.6865E-01	1.3005E+01	-1.5651E+02
9.8110E-01	1.2560E+01	-1.6224E+02
9.9355E-01	1.2037E+01	-1.6777E+02
1.0060E+00	1.1446E+01	-1.7303E+02
1.0185E+00	1.0798E+01	-1.7797E+02
1.0309E+00	1.0103E+01	-1.8257E+02
1.0433E+00	9.3719E+00	-1.8681E+02
1.0558E+00	8.6136E+00	-1.9070E+02
1.0683E+00	7.8354E+00	-1.9426E+02
1.0807E+00	7.0433E+00	-1.9752E+02
1.0932E+00	6.2414E+00	-2.0050E+02
1.1056E+00	5.4330E+00	-2.0322E+02
1.1160E+00	4.6201E+00	-2.0571E+02
1.1305E+00	3.8038E+00	-2.0799E+02
1.1430E+00	2.9846E+00	-2.1009E+02
1.1554E+00	2.1624E+00	-2.1203E+02
1.1679E+00	1.3365E+00	-2.1381E+02
1.1803E+00	5.0612E-01	-2.1547E+02
1.1927E+00	-3.3021E-01	-2.1700E+02
1.2052E+00	-1.1741E+00	-2.1843E+02
1.2177E+00	-2.0276E+00	-2.1977E+02
1.2301E+00	-2.8931E+00	-2.2101E+02
1.2426E+00	-3.7733E+00	-2.2218E+02
1.2550E+00	-4.6713E+00	-2.2328E+02
1.2674E+00	-5.5910E+00	-2.2432E+02
1.2799E+00	-6.5368E+00	-2.2529E+02
1.2924E+00	-7.5139E+00	-2.2622E+02
1.3048E+00	-8.5267E+00	-2.2709E+02
1.3173E+00	-9.5891E+00	-2.2792E+02
1.3297E+00	-1.0705E+01	-2.2871E+02
1.3421E+00	-1.1889E+01	-2.2946E+02
1.3546E+00	-1.3158E+01	-2.3018E+02

1. 3671E+00	-1. 4535E+01	-2. 3086E+02
1. 3795E+00	-1. 6051E+01	-2. 3151E+02
1. 3920E+00	-1. 7753E+01	-2. 3214E+02
1. 4044E+00	-1. 9717E+01	-2. 3274E+02
1. 4168E+00	-2. 2070E+01	-2. 3332E+02
1. 4293E+00	-2. 5060E+01	-2. 3387E+02
1. 4418E+00	-2. 9282E+01	-2. 3440E+02
1. 4542E+00	-3. 6959E+01	-2. 3491E+02
1. 4667E+00	-4. 6524E+01	-5. 5406E+01
1. 4791E+00	-3. 2966E+01	-5. 5882E+01
1. 4915E+00	-2. 8144E+01	-5. 6342E+01
1. 5040E+00	-2. 5219E+01	-5. 6786E+01
1. 5165E+00	-2. 3150E+01	-5. 7215E+01
1. 5289E+00	-2. 1570E+01	-5. 7631E+01
1. 5414E+00	-2. 0306E+01	-5. 8034E+01
1. 5538E+00	-1. 9264E+01	-5. 8424E+01
1. 5662E+00	-1. 8384E+01	-5. 8803E+01
1. 5787E+00	-1. 7629E+01	-5. 9170E+01
1. 5912E+00	-1. 6972E+01	-5. 9527E+01
1. 6036E+00	-1. 6395E+01	-5. 9874E+01
1. 6161E+00	-1. 5884E+01	-6. 0211E+01
1. 6285E+00	-1. 5427E+01	-6. 0540E+01
1. 6410E+00	-1. 5017E+01	-6. 0859E+01
1. 6534E+00	-1. 4646E+01	-6. 1170E+01
1. 6659E+00	-1. 4310E+01	-6. 1473E+01
1. 6783E+00	-1. 4004E+01	-6. 1769E+01
1. 6908E+00	-1. 3725E+01	-6. 2057E+01
1. 7032E+00	-1. 3469E+01	-6. 2338E+01
1. 7157E+00	-1. 3233E+01	-6. 2612E+01
1. 7281E+00	-1. 3017E+01	-6. 2880E+01
1. 7406E+00	-1. 2817E+01	-6. 3142E+01
1. 7530E+00	-1. 2632E+01	-6. 3398E+01
1. 7655E+00	-1. 2461E+01	-6. 3648E+01
1. 7779E+00	-1. 2303E+01	-6. 3893E+01
1. 7904E+00	-1. 2155E+01	-6. 4132E+01
1. 8028E+00	-1. 2019E+01	-6. 4367E+01
1. 8153E+00	-1. 1891E+01	-6. 4596E+01
1. 8277E+00	-1. 1773E+01	-6. 4821E+01
1. 8401E+00	-1. 1663E+01	-6. 5041E+01
1. 8526E+00	-1. 1560E+01	-6. 5256E+01
1. 8651E+00	-1. 1464E+01	-6. 5467E+01
1. 8775E+00	-1. 1375E+01	-6. 5675E+01
1. 8900E+00	-1. 1291E+01	-6. 5878E+01
1. 9024E+00	-1. 1214E+01	-6. 6077E+01
1. 9148E+00	-1. 1141E+01	-6. 6273E+01
1. 9273E+00	-1. 1073E+01	-6. 6465E+01
1. 9398E+00	-1. 1010E+01	-6. 6653E+01
1. 9522E+00	-1. 0951E+01	-6. 6838E+01
1. 9647E+00	-1. 0896E+01	-6. 7020E+01
1. 9771E+00	-1. 0845E+01	-6. 7198E+01
1. 9895E+00	-1. 0798E+01	-6. 7374E+01
2. 0020E+00	-1. 0753E+01	-6. 7546E+01
2. 0145E+00	-1. 0712E+01	-6. 7715E+01
2. 0269E+00	-1. 0674E+01	-6. 7882E+01
2. 0394E+00	-1. 0639E+01	-6. 8046E+01
2. 0518E+00	-1. 0606E+01	-6. 8207E+01
2. 0642E+00	-1. 0576E+01	-6. 8365E+01
2. 0767E+00	-1. 0548E+01	-6. 8521E+01
2. 0891E+00	-1. 0523E+01	-6. 8674E+01
2. 1016E+00	-1. 0499E+01	-6. 8825E+01

2.1141E+00	-1.0478E+01	-6.8974E+01
2.1265E+00	-1.0458E+01	-6.9120E+01
2.1390E+00	-1.0441E+01	-6.9264E+01
2.1514E+00	-1.0425E+01	-6.9406E+01
2.1639E+00	-1.0411E+01	-6.9546E+01
2.1763E+00	-1.0398E+01	-6.9684E+01
2.1888E+00	-1.0387E+01	-6.9819E+01
2.2012E+00	-1.0377E+01	-6.9953E+01
2.2136E+00	-1.0368E+01	-7.0085E+01
2.2261E+00	-1.0361E+01	-7.0214E+01
2.2385E+00	-1.0355E+01	-7.0342E+01
2.2510E+00	-1.0351E+01	-7.0469E+01
2.2635E+00	-1.0347E+01	-7.0593E+01
2.2759E+00	-1.0345E+01	-7.0716E+01
2.2884E+00	-1.0343E+01	-7.0837E+01
2.3008E+00	-1.0343E+01	-7.0956E+01
2.3133E+00	-1.0343E+01	-7.1074E+01
2.3257E+00	-1.0344E+01	-7.1190E+01
2.3382E+00	-1.0347E+01	-7.1305E+01
2.3506E+00	-1.0350E+01	-7.1418E+01
2.3630E+00	-1.0353E+01	-7.1530E+01
2.3755E+00	-1.0358E+01	-7.1640E+01
2.3879E+00	-1.0363E+01	-7.1749E+01
2.4004E+00	-1.0369E+01	-7.1856E+01
2.4129E+00	-1.0376E+01	-7.1963E+01
2.4253E+00	-1.0383E+01	-7.2067E+01
2.4378E+00	-1.0391E+01	-7.2171E+01
2.4502E+00	-1.0400E+01	-7.2273E+01
2.4627E+00	-1.0409E+01	-7.2374E+01
2.4751E+00	-1.0418E+01	-7.2474E+01
2.4876E+00	-1.0428E+01	-7.2572E+01
2.5000E+00	-1.0439E+01	-7.2670E+01

TRANF, and ANALY we are now prepared to do an entire analysis of a ladder network. This ends our discussion in the development and operation of the LNA package.

In Chapter 4, we will study a 10th order Elliptic Band-Pass filter using the acquired knowledge of the LNA package. In addition to this study, we will also consider the stability of a system function employing the features built into ANALY.

CHAPTER 4

ANALYSIS OF 10TH ORDER ELLIPTIC BAND-PASS FILTER AND SYSTEM FUNCTION

4.1 INTRODUCTION

In Chapters 2 and 3, our discussion was concerned with the development and operation of the LNA package. This discussion enabled us to obtain the necessary knowledge to utilize LNA in an analysis study. The LNA package will be utilized in the analysis of a 10th order Elliptic Band-Pass filter. This analysis will deal with the construction of the filter, the calculation of the TF and DPF, and the response of the filter due to designed component values, as well as the change in response due to variations in the component values. In addition, we will analyze a system function using the feature incorporated into the program ANALY. The analysis of the system function shall determine the range of the gain factor for which the system will be stable.

4.2 LNA OF A 10TH ORDER ELLIPTICAL BAND-PASS FILTER

The Elliptic Band-Pass filter that is going to be analyzed is illustrated in Fig. 4.1. This filter will be analyzed using normalized component values. This approach is taken so that overloading the computer will not occur. The filter components are calculated according to the following conditions[11]:

$R_1 = R_7 = 1$ ohm

Centre frequency $\omega_0 = 1$ rad/sec.

$Q = 2$

Selectivity factor = .99

Band-Pass ripple = 1 db

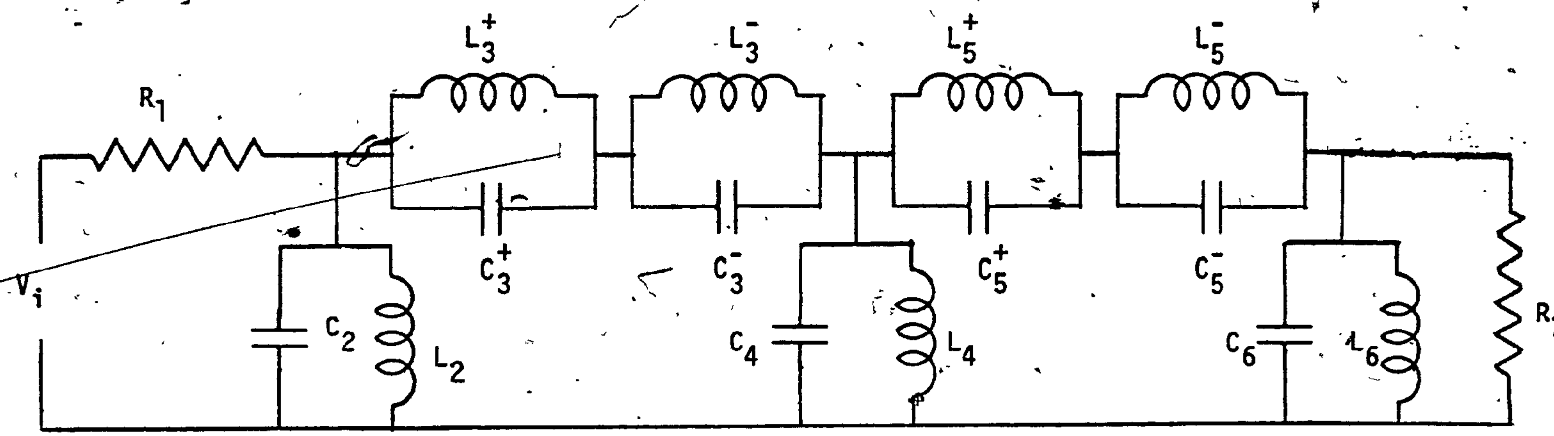


FIG 4.1 10th Order Elliptic Band-Pass Filter

The component values using the above conditions were calculated to be as follows (Fig. 4.1).[11]

L_2 = .3913281678 H

C_2 = 2.554 F

L_3^+ = .1085257638 H

C_3^+ = 5.22834929 F

L_3^- = .1912649566 H

C_3^- = 9.214401862 F

L_4 = .4153858935 H

C_4 = 2.4074 F

L_5^+ = .0165702979 H

C_5^+ = 36.60667366 F

L_5^- = .0273174233 H

C_5^- = 60.34894521 F

L_6 = 1.093613298 H

C_6 = .9144 F

Having calculated the component values and establishing the filter configuration (Fig. 4.1), we are ready to perform the analysis.

We begin the analysis by constructing the filter and entering the component values through the program LADNET. The program LADNET is entered into the computer and the display of Fig. 4.2 appears on the CRT. We enter the components on the ladder by following the procedure outlined in Chapter 2. This procedure is shown in Fig. 4.3 to 4.5 and the procedure is repeated for each subsequent component of the filter.

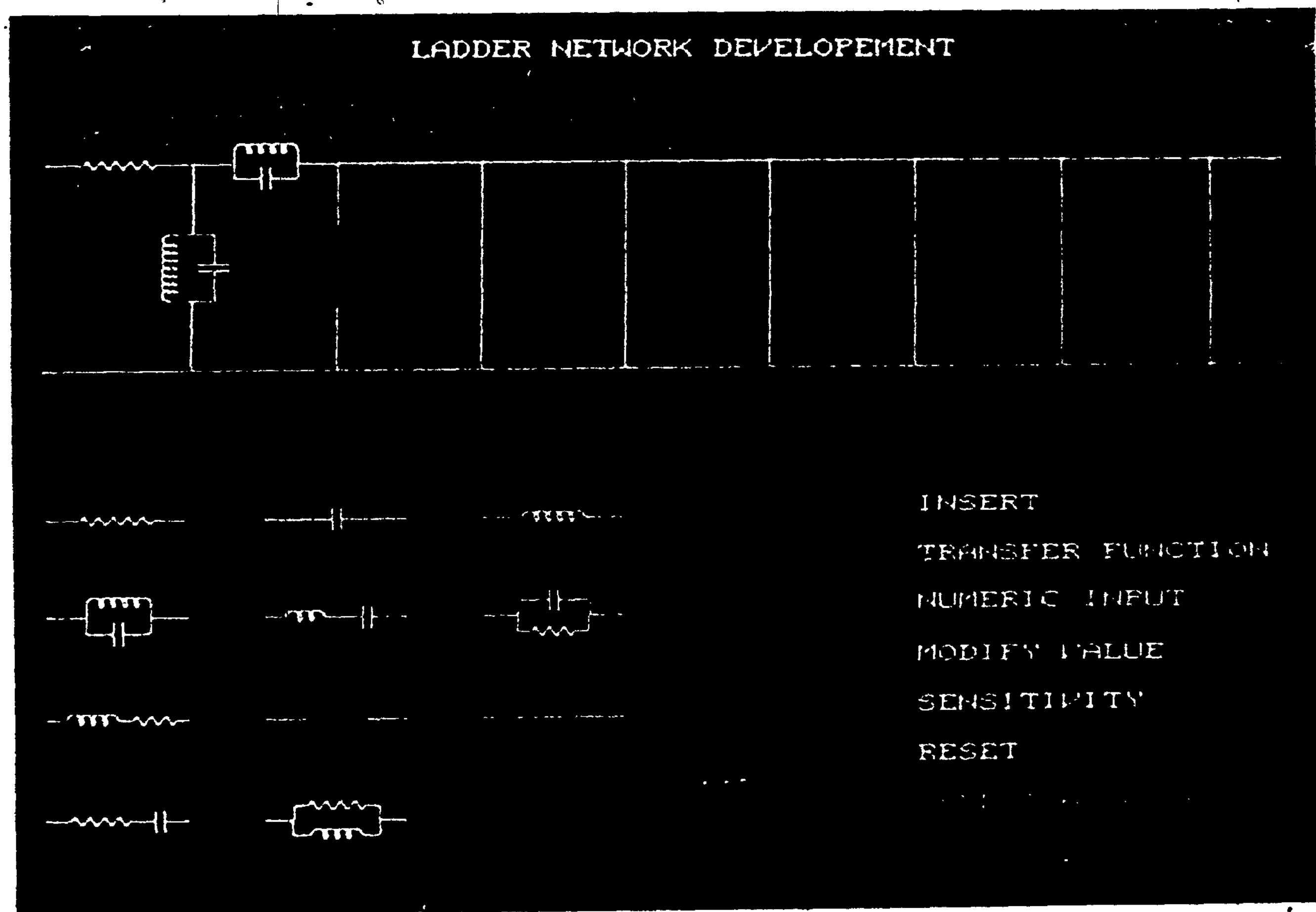


Fig. 4.8 LADNET Display with Open-Circuit in Position 4 of 10th Order Elliptic Band-Pass Filter

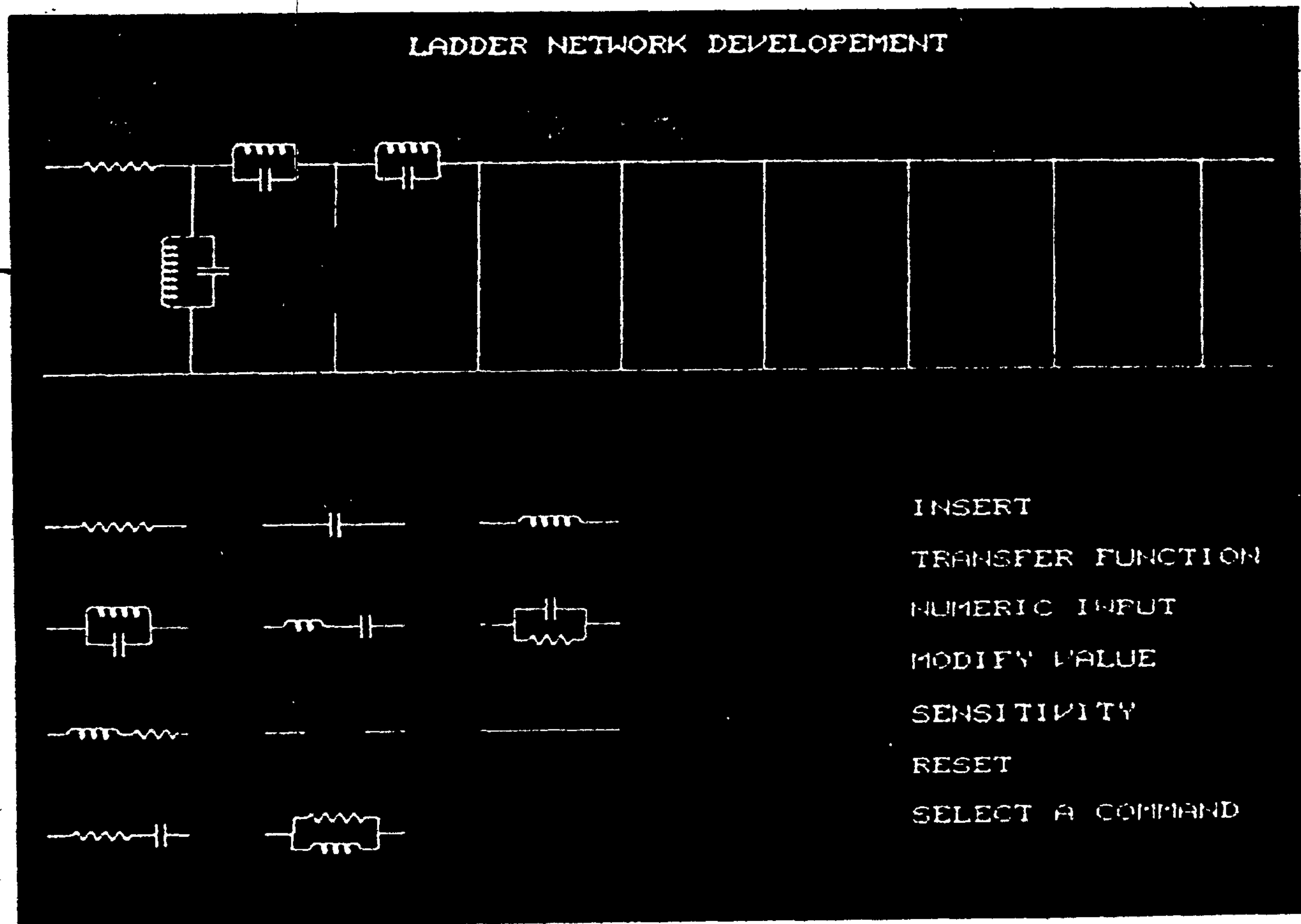


Fig. 4.9. LADNET Display with L_3C_3 in Position 5 of 10th Order Elliptic Band-Pass Filter

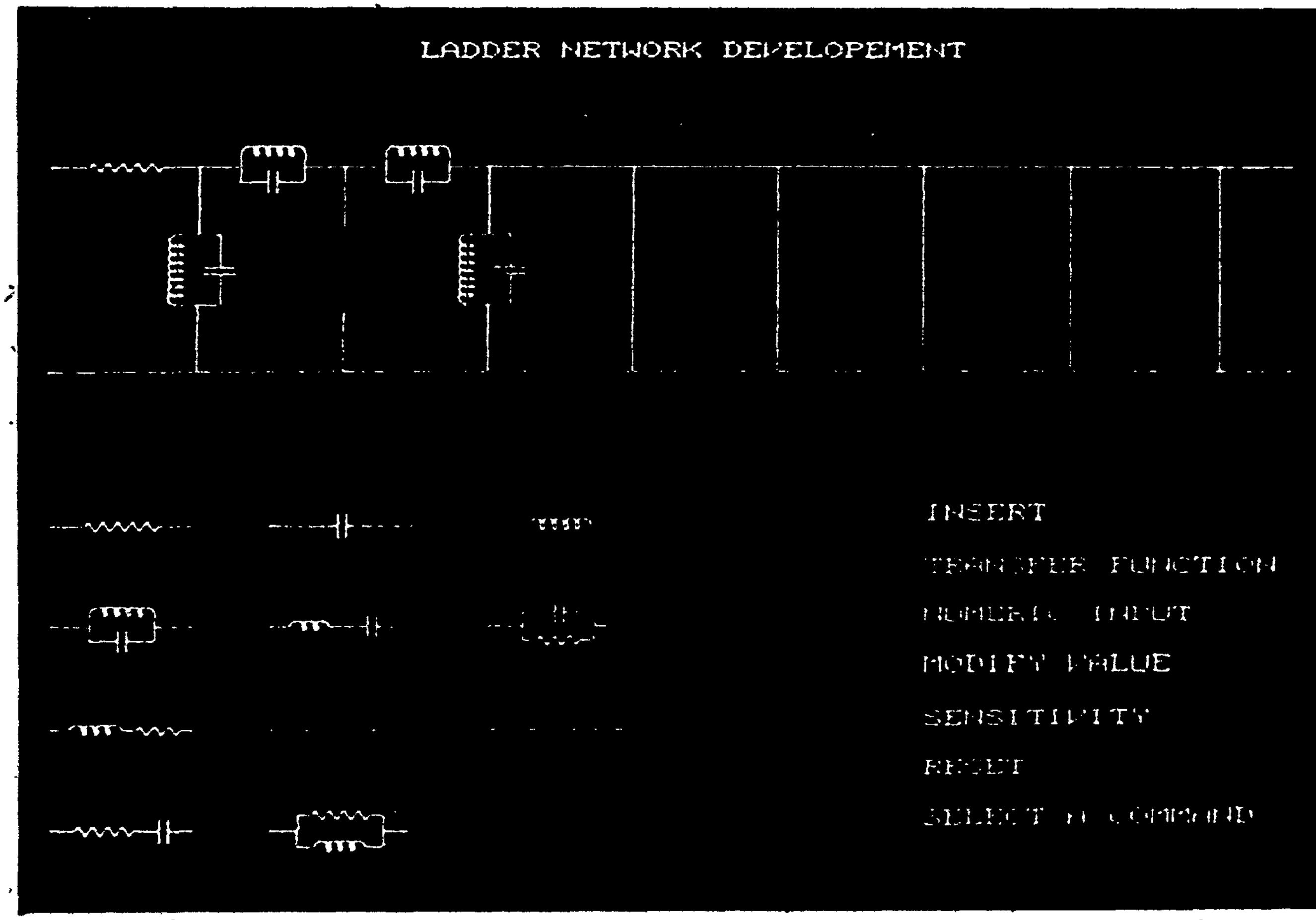


Fig. 4.10 LADNET Display with L_4C_4 in Position 6 of 10th Order Elliptic Band-Pass Filter

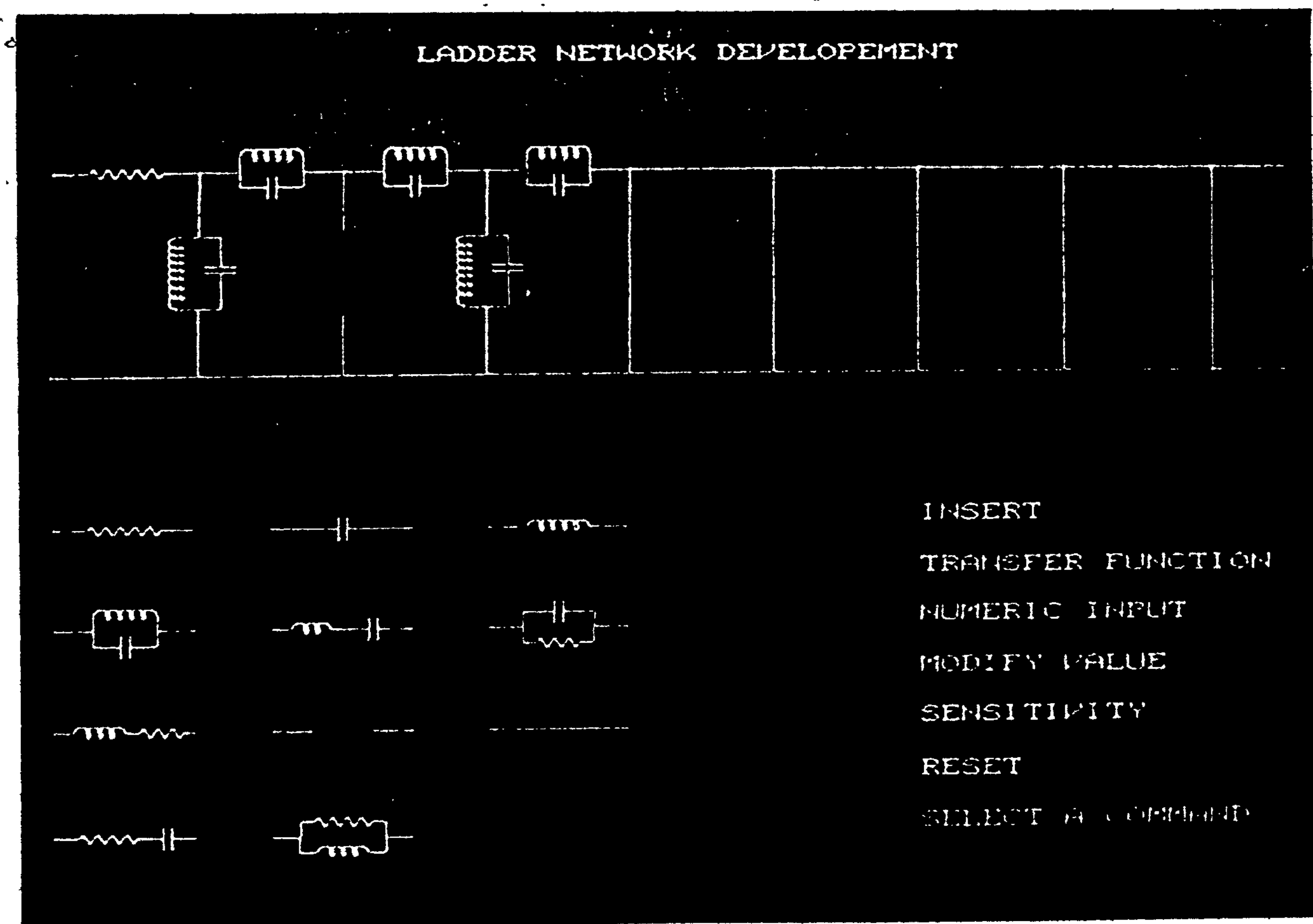


Fig. 4.11 LADNET Display with $L_5^+C_5^+$ in Position 7 of 10th Order Elliptic Band-Pass Filter

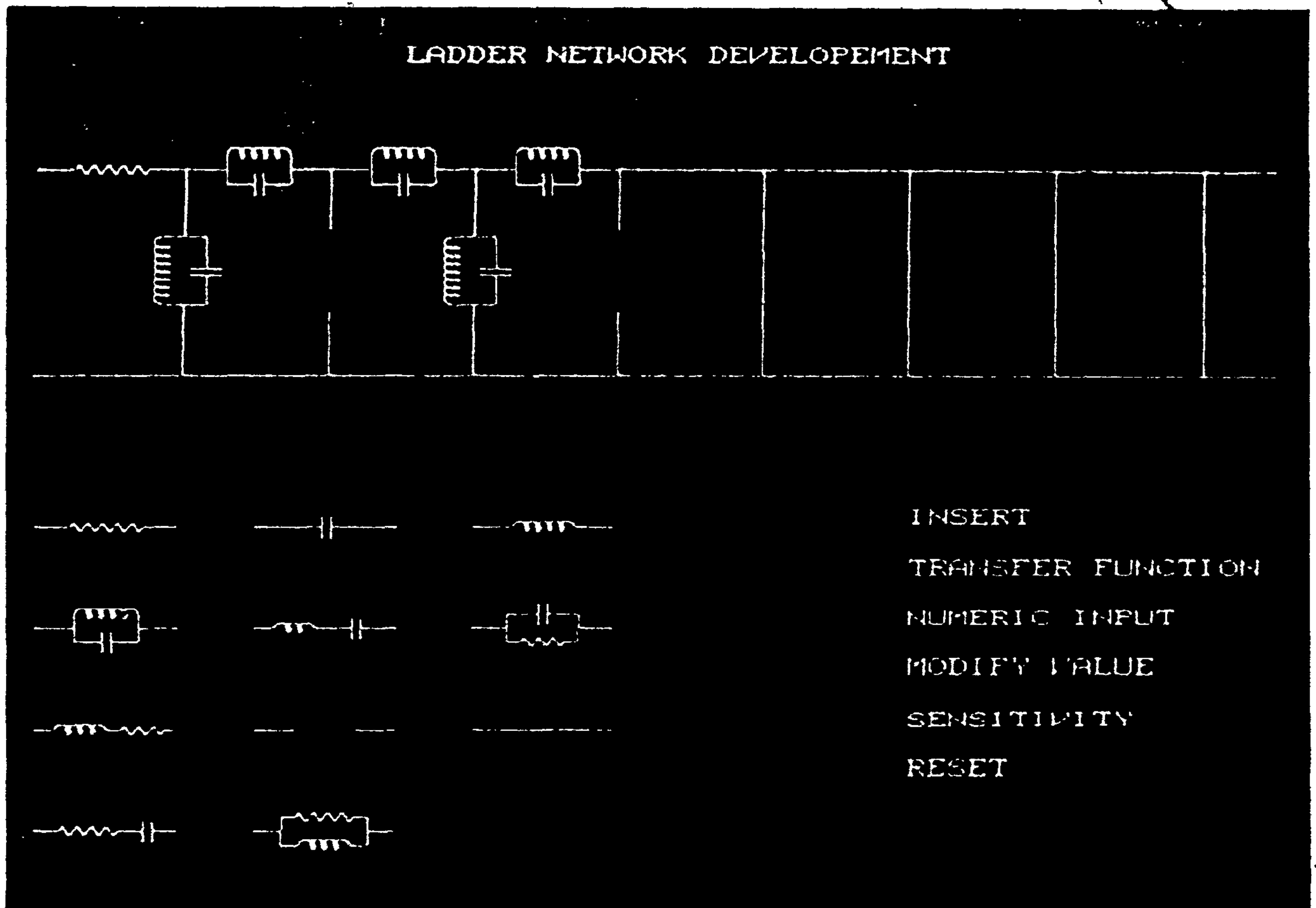


Fig. 4.12 LADNET Display with Open-Circuit in Position 8 of 10th Order Elliptic Band-Pass Filter

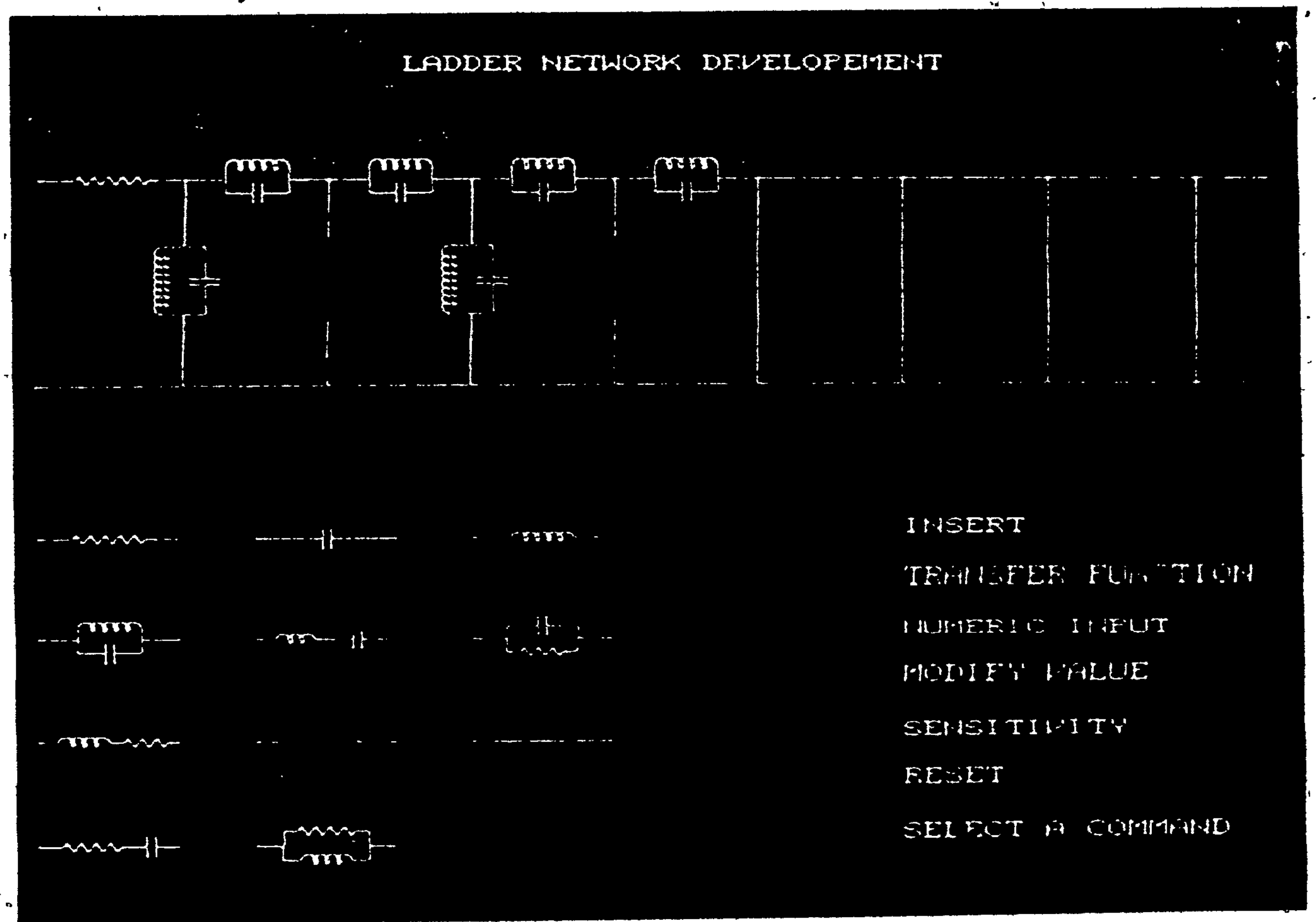


Fig. 4.13 LADNET Display with $L_5^-C_5^-$ in Position 9 of 10th Order Elliptic Band-Pass Filter

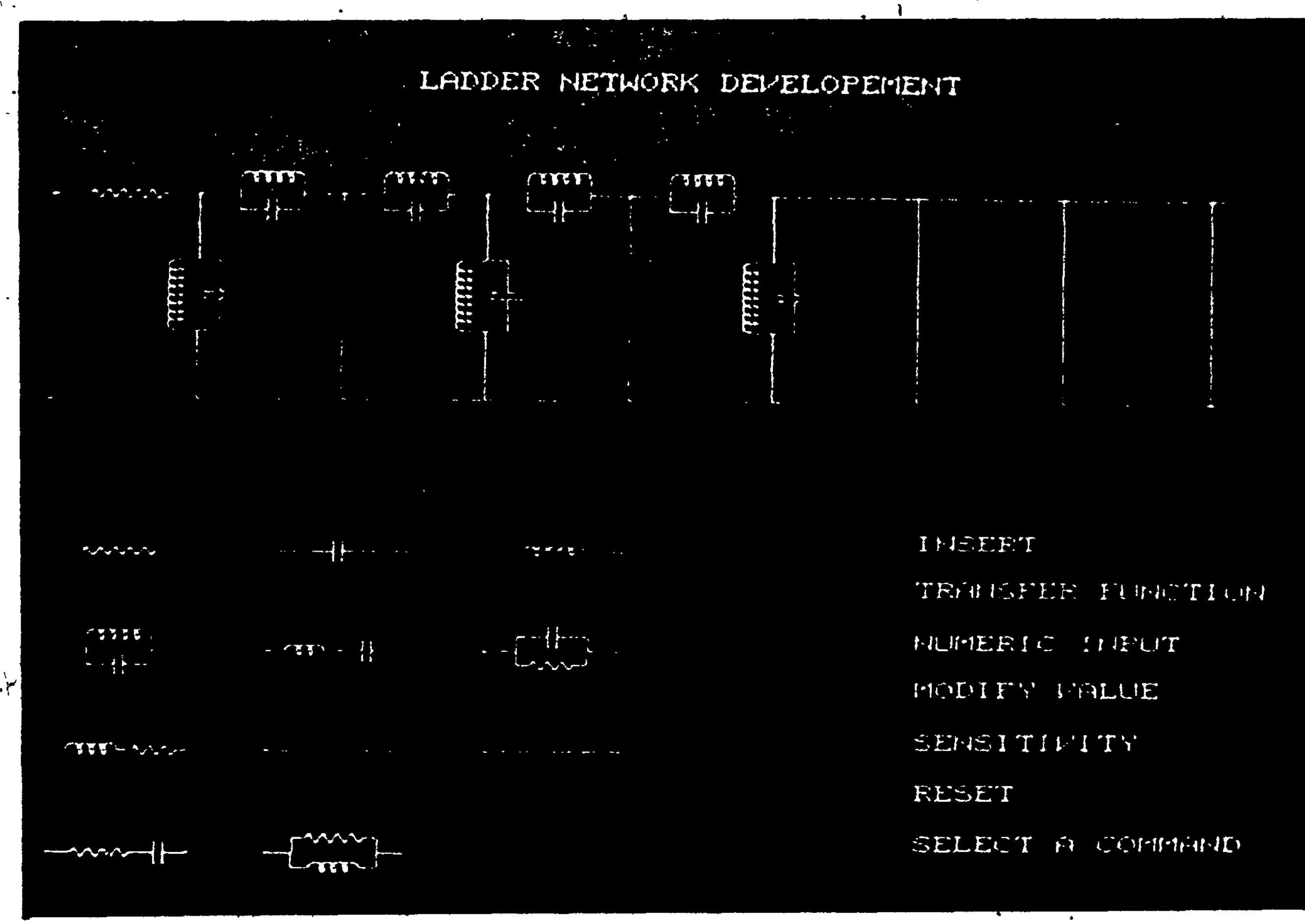


Fig. 4.14 LANDET Display with L_6C_6 in Position 10 of 10th Order Elliptic Band-Pass Filter

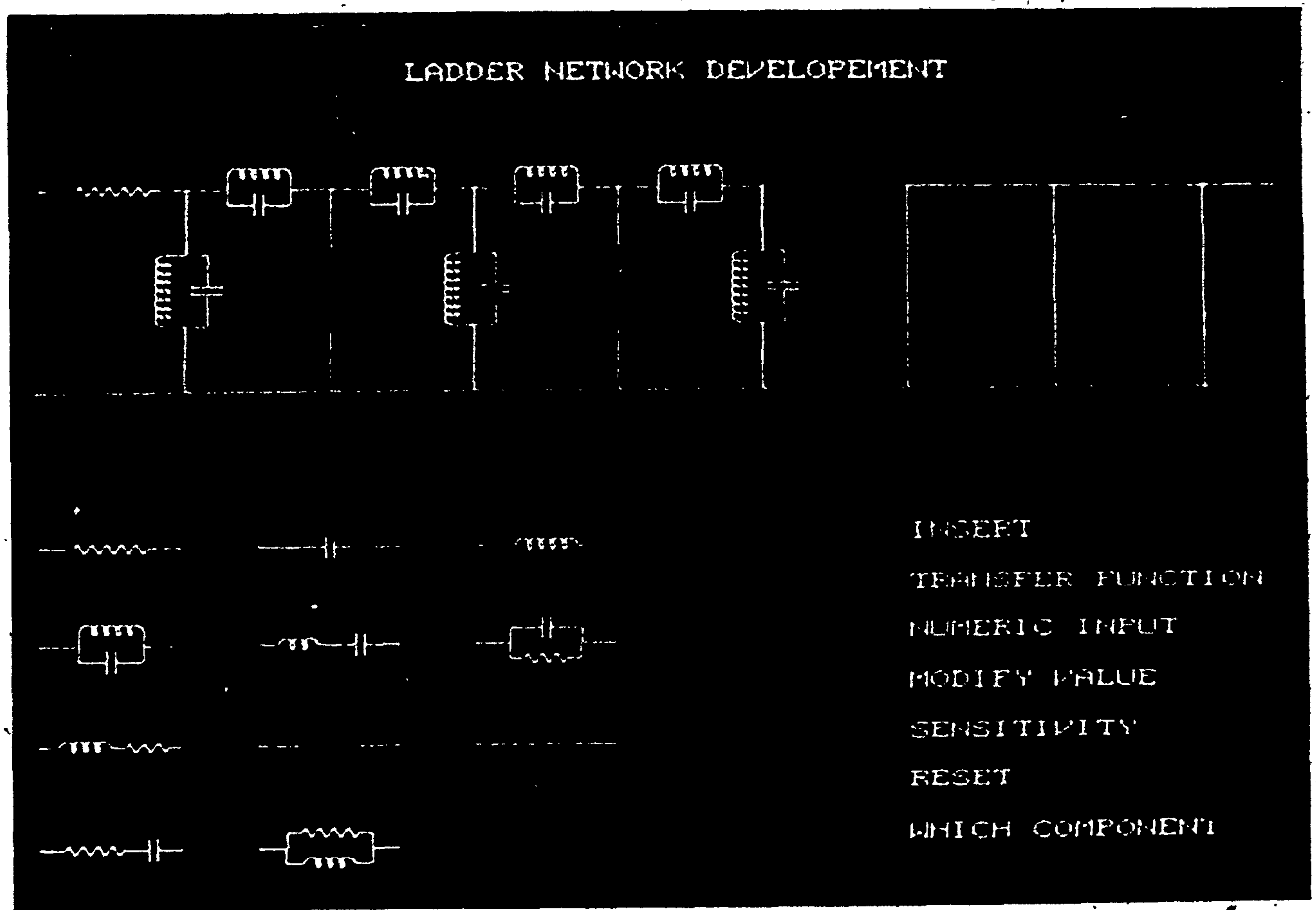


Fig. 4.15 LADNET Display in Component Insert Mode for Insertion of Short-Circuit in Position 11 of 10th Order Elliptic Band-Pass Filter

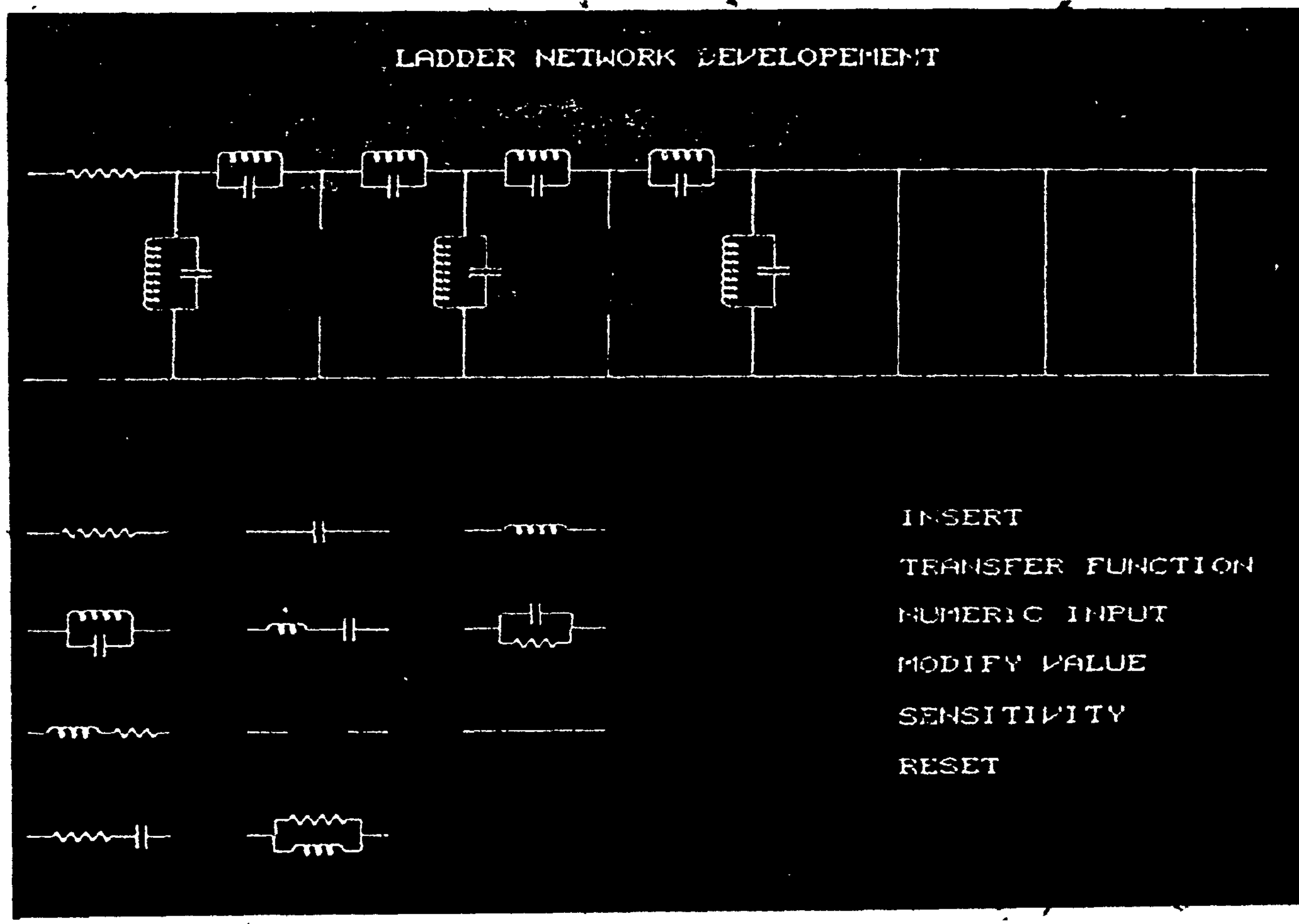


Fig. 4.16 LADNET Display with Short-Circuit in Position 11 of 10th Order Elliptic Band-Pass Filter

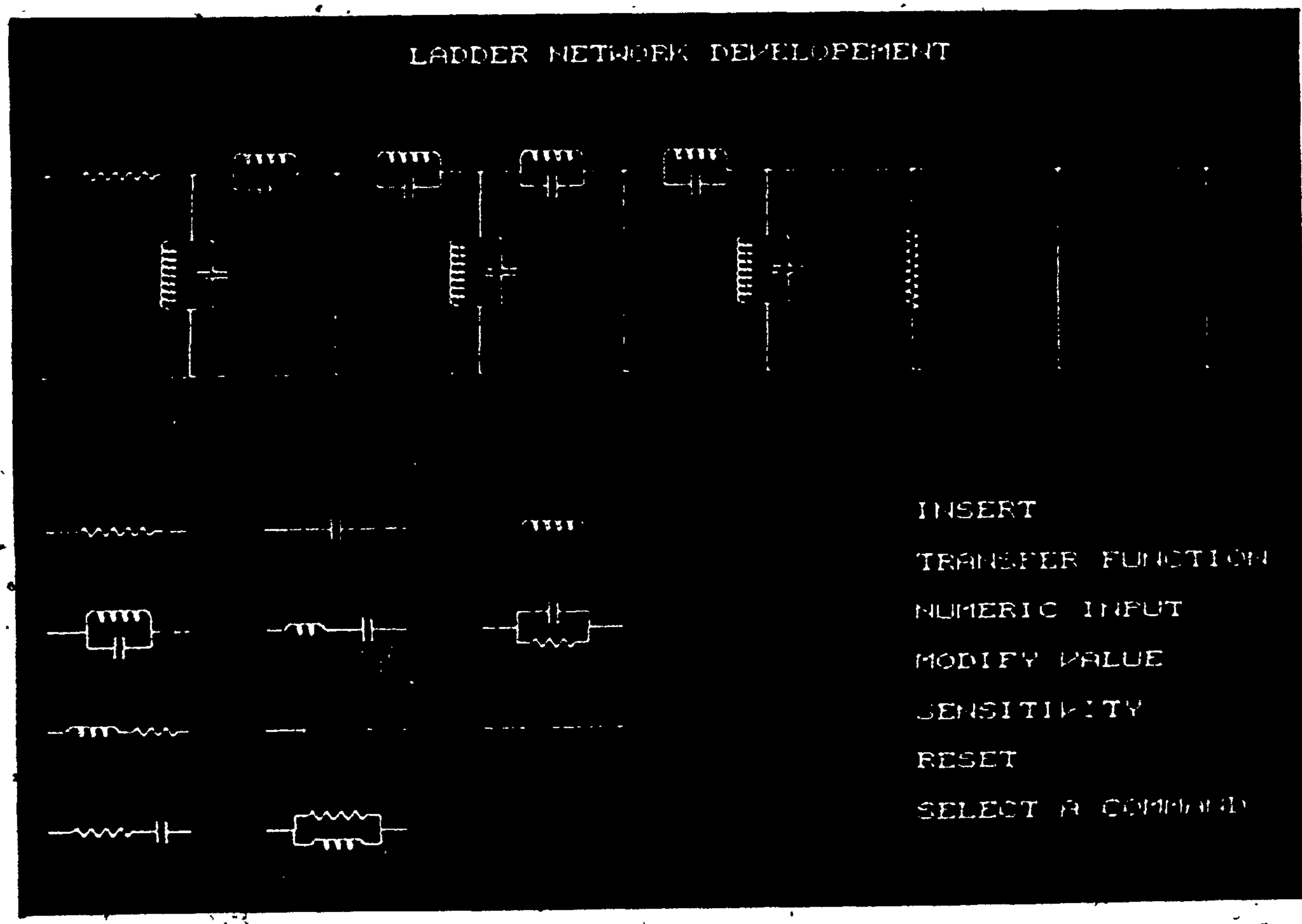


Fig. 4.17 LADNET Display with Complete 10th Order Elliptic Band-Pass Filter

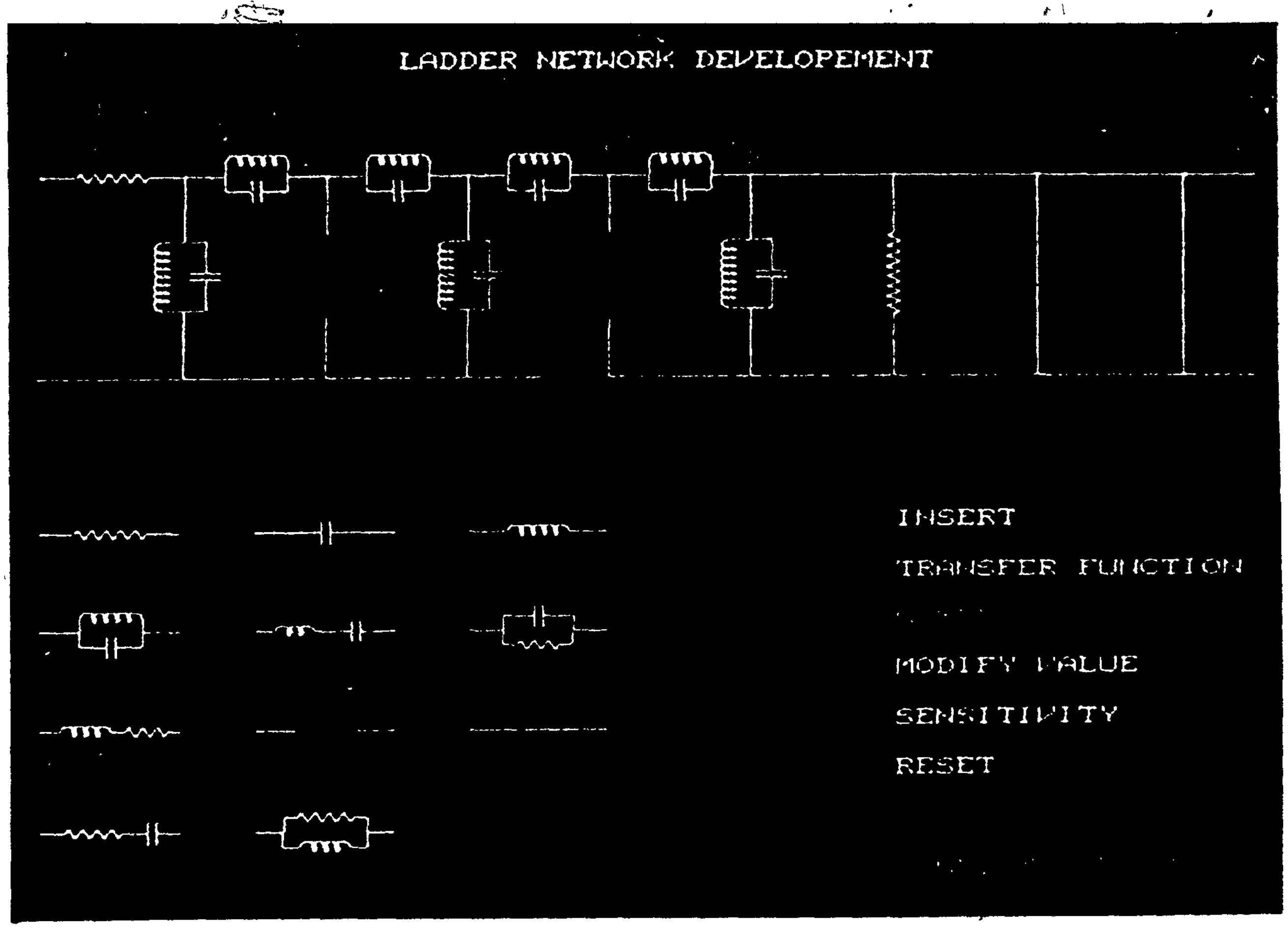


Fig. 4.18 LADNET Display of 10th Order Elliptic Band-Pass Filter in Confirm Mode of Numeric Input Command

```
LOCATION  4  IS A SHUNT ARM

THIS IS AN OPEN CIRCUIT WHOSE ADMITTANCE IS= 0.0

LOCATION  5  IS A SERIES ARM

ELEMENTS COMBINATION PARALLEL INDUCTOR AND CAPACITOR
ENTER VALUE FOR INDUCTOR
VALUE(MILLI-HENRIES)= 191.2649566

ENTER VALUE FOR CAPACITOR
VALUE(MICRO-FARADS)=  9214401.862

LOCATION  6  IS A SHUNT ARM

ELEMENTS COMBINATION PARALLEL INDUCTOR AND CAPACITOR
ENTER VALUE FOR INDUCTOR
VALUE(MILLI-HENRIES)= 415.3858935

ENTER VALUE FOR CAPACITOR
VALUE(MICRO-FARADS)=  2407400.

LOCATION  7  IS A SERIES ARM

ELEMENTS COMBINATION PARALLEL INDUCTOR AND CAPACITOR
ENTER VALUE FOR INDUCTOR
VALUE(MILLI-HENRIES)= 16.5702979

ENTER VALUE FOR CAPACITOR
VALUE(MICRO-FARADS)=  36606673.66

LOCATION  8  IS A SHUNT ARM

THIS IS AN OPEN CIRCUIT WHOSE ADMITTANCE IS= 0.0

LOCATION  9  IS A SERIES ARM

ELEMENTS COMBINATION PARALLEL INDUCTOR AND CAPACITOR
ENTER VALUE FOR INDUCTOR
VALUE(MILLI-HENRIES)= 27.3174233

ENTER VALUE FOR CAPACITOR
VALUE(MICRO-FARADS)=  60348945.21
```

```
LOCATION 10  IS A SHUNT ARM

ELEMENTS COMBINATION PARALLEL INDUCTOR AND CAPACITOR
ENTER VALUE FOR INDUCTOR
VALUE(MILLI-HENRIES)= 1093.613298

ENTER VALUE FOR CAPACITOR
VALUE(MICRO-FARADS)=  914400.

LOCATION 11  IS A SERIES ARM

THIS IS A SHORT CIRCUIT WHOSE IMPEDANCE IS = 0.0

LOCATION 12  IS A SHUNT ARM

ELEMENT IS A RESISTOR
ENTER THE VALUE YOU   WANT IN KILO-OHMS
VALUE(KILO-OHMS)= .001

LOCATION 13  IS A SERIES ARM

*****WARNING NO ELEMENT WAS INSERTED*****
```

The component values are entered and we are now prepared to obtain the TF and DPF. We strike the command *TRANSFER FUNCTION* (Fig. 4.17) which results in Fig. 4.19. Again, we confirm the command and the teletype prints out the following.

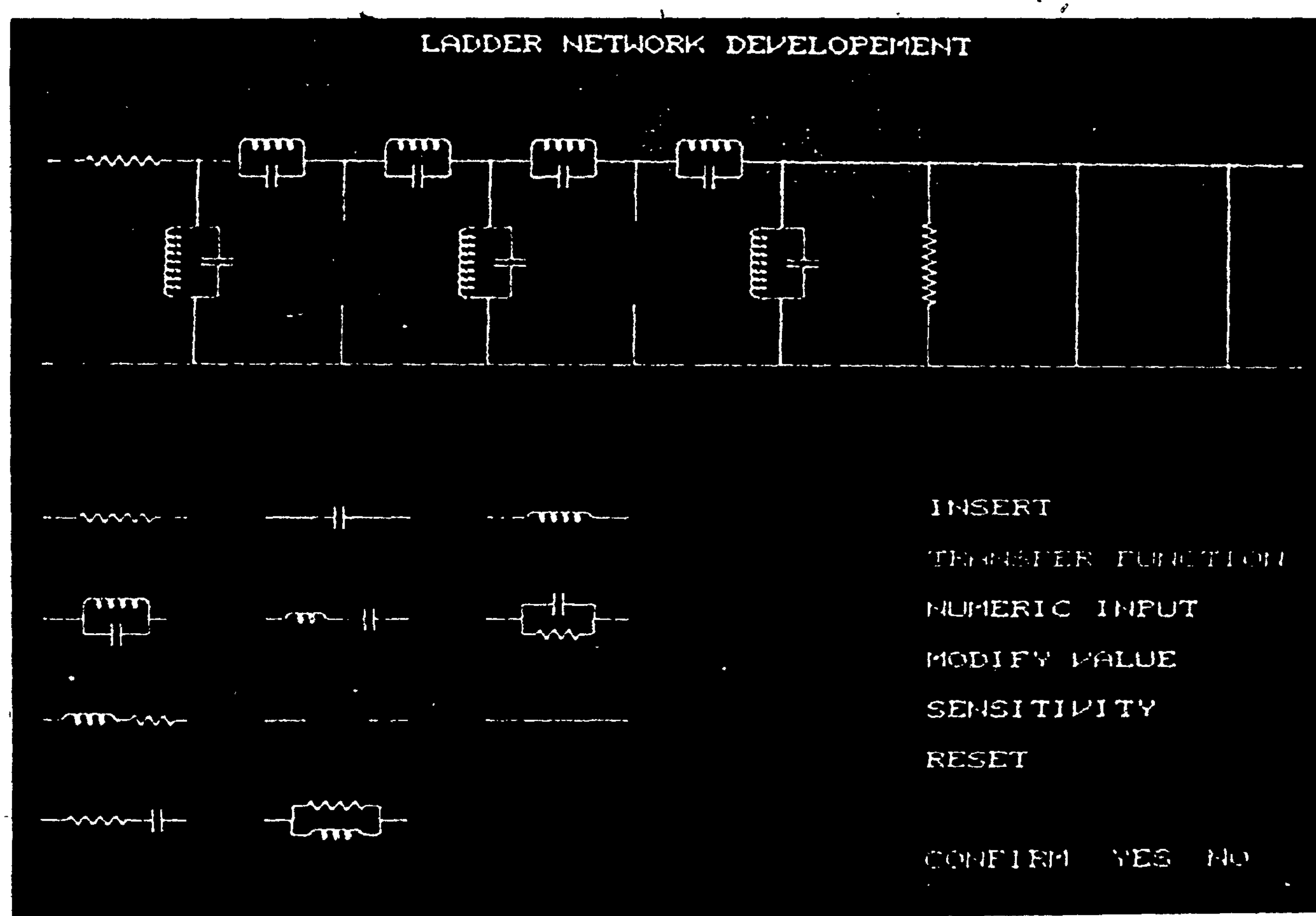


Fig. 4.19 LADNET Display of 10th Order Elliptic Band-Pass Filter in Confirm Mode of Transfer Function Command

```
*****LADDER ELEMENTS AND VALUES*****

LOCATION  1 IS A SERIES ARM
ELEMENT IS A RESISTOR
VALUE(KILO-OHMS)=  1.00000005E-03

LOCATION  2 IS A SHUNT ARM
ELEMENTS COMBINATION PARALLEL INDUCTOR AND CAPACITOR
VALUE(MILLI-HENERIES)=  3.91328156E+02
VALUE(MICRO-FARADS)=  2.55400000E+06

LOCATION  3 IS A SERIES ARM
ELEMENTS COMBINATION PARALLEL INDUCTOR AND CAPACITOR
VALUE(MILLI-HENERIES)=  1.08525764E+02
VALUE(MICRO-FARADS)=  5.22834950E+06

LOCATION  4 IS A SHUNT ARM
THIS IS AN OPEN CIRCUIT WHOSE ADMITTANCE IS =0.0

LOCATION  5 IS A SERIES ARM
ELEMENTS COMBINATION PARALLEL INDUCTOR AND CAPACITOR
VALUE(MILLI-HENERIES)=  1.91264954E+02
VALUE(MICRO-FARADS)=  9.21440200E+06

LOCATION  6 IS A SHUNT ARM
ELEMENTS COMBINATION PARALLEL INDUCTOR AND CAPACITOR
VALUE(MILLI-HENERIES)=  4.15385895E+02
VALUE(MICRO-FARADS)=  2.40740000E+06

LOCATION  7 IS A SERIES ARM
ELEMENTS COMBINATION PARALLEL INDUCTOR AND CAPACITOR
VALUE(MILLI-HENERIES)=  1.65702972E+01
VALUE(MICRO-FARADS)=  3.66066720E+07
```

```
LOCATION  8 IS A SHUNT ARM
THIS IS AN OPEN CIRCUIT WHOSE ADMITTANCE IS =0.0

LOCATION  9 IS A SERIES ARM
ELEMENTS COMBINATION PARALLEL INDUCTOR AND CAPACITOR
VALUE(MILLI-HENERIES)=  2.73174229E+01
VALUE(MICRO-FARADS)=  6.03489440E+07

LOCATION 10 IS A SHUNT ARM
ELEMENTS COMBINATION PARALLEL INDUCTOR AND CAPACITOR
VALUE(MILLI-HENERIES)=  1.09361328E+03
VALUE(MICRO-FARADS)=  9.14400000E+05

LOCATION 11 IS A SERIES ARM
THIS IS A SHORT CIRCUIT WHOSE IMPEDANCE IS =0.0

LOCATION 12 IS A SHUNT ARM
ELEMENT IS A RESISTOR
VALUE(KILO-OHMS)=  1.00000005E-03

ARE YOU FINISHED?
TYPE IN YES OR NO
```

This output is checked in order that the components and their values are correct. If we are satisfied, a *YES* reply is given to the question in the above output. This reply gives us the following message.

```
TO CONTINUE THE LADDER ANALYSIS AND OBTAIN THE
 TRANSFER FUNCTION TYPE IN RUN RK1:TRANF
```

If a reply of *NO* was given, we would return to Fig. 4.17 and make the proper corrections.

We follow the message above, and type in RUN RK1:TRANF which results in the teletype to print

```
DO YOU WANT TO ENGAGE SCALING ROUTINE?
TYPE IN YES OR NO

NO
```

Since the filter is normalized, we do not need the scaling routine. We enter a NO and the computation of the TF and DPF begins. When the computation is completed, the teletype prints out the TF and DPF as below.

TRANSFER FUNCTION

COEFFICIENTS	NUMERATOR	DENOMINATOR
S** 0	0.000000E-01	2.304034E-01
S** 1	2.649790E-02	1.094303E-01
S** 2	0.000000E-01	1.271931E+00
S** 3	1.214919E-01	4.828747E-01
S** 4	0.000000E-01	2.679184E+00
S** 5	1.922177E-01	7.513314E-01
S** 6	0.000000E-01	2.678996E+00
S** 7	1.214919E-01	4.828435E-01
S** 8	0.000000E-01	1.271670E+00
S** 9	2.649790E-02	1.094163E-01
S**10	0.000000E-01	2.303268E-01

DRIVING-POINT IMPEDANCE

COEFFICIENTS	NUMERATOR	DENOMINATOR
S** 0	1.729365E-02	1.729365E-02
S** 1	8.213633E-03	4.106710E-03
S** 2	9.546880E-02	9.472227E-02
S** 3	3.624368E-02	1.812087E-02
S** 4	2.010946E-01	1.986741E-01
S** 5	5.639354E-02	2.819438E-02
S** 6	2.010805E-01	1.986600E-01
S** 7	3.624134E-02	1.811852E-02
S** 8	9.544917E-02	9.470264E-02
S** 9	8.212587E-03	4.105665E-03
S**10	1.728790E-02	1.728790E-02

```
TO CONTINUE THE LADDER NETWORK ANALYSIS PACKAGE
TYPE IN RUN RK1:ANALY TO PERFORM BODE AND NYQUIST PLOTS
STOP --
```

Having obtained the TF and DPF, we proceed to analyze the filter by typing in RUN RK1:ANALY.

The teletype prints out the following:

```
DO YOU WISH TO ENTER YOUR OWN TRANSFER FUNCTION?
TYPE IN YES OR NO

NO
```

A NO is entered, and the teletype prints

```
ENTER THE STARTING FREQUENCY(IN RAD/SEC)=
ENTER THE FINAL FREQUENCY(IN RAD/SEC)=
```

We enter the frequency limits below and the computer begins to calculate the Bode and Nyquist plots.

```
ENTER THE STARTING FREQUENCY(IN RAD/SEC)=.1
ENTER THE FINAL FREQUENCY(IN RAD/SEC)=1.9
```

When the calculations are completed the following question is printed.

```
WHICH DO YOU WANT?    BODE OR NYQT?
TYPE IN  BODE OR NYQT

BODE
```

We type in BODE which gives us the plots shown in Fig. 4.20. The plots of Fig. 4.20 are inappropriate for proper analysis, and therefore

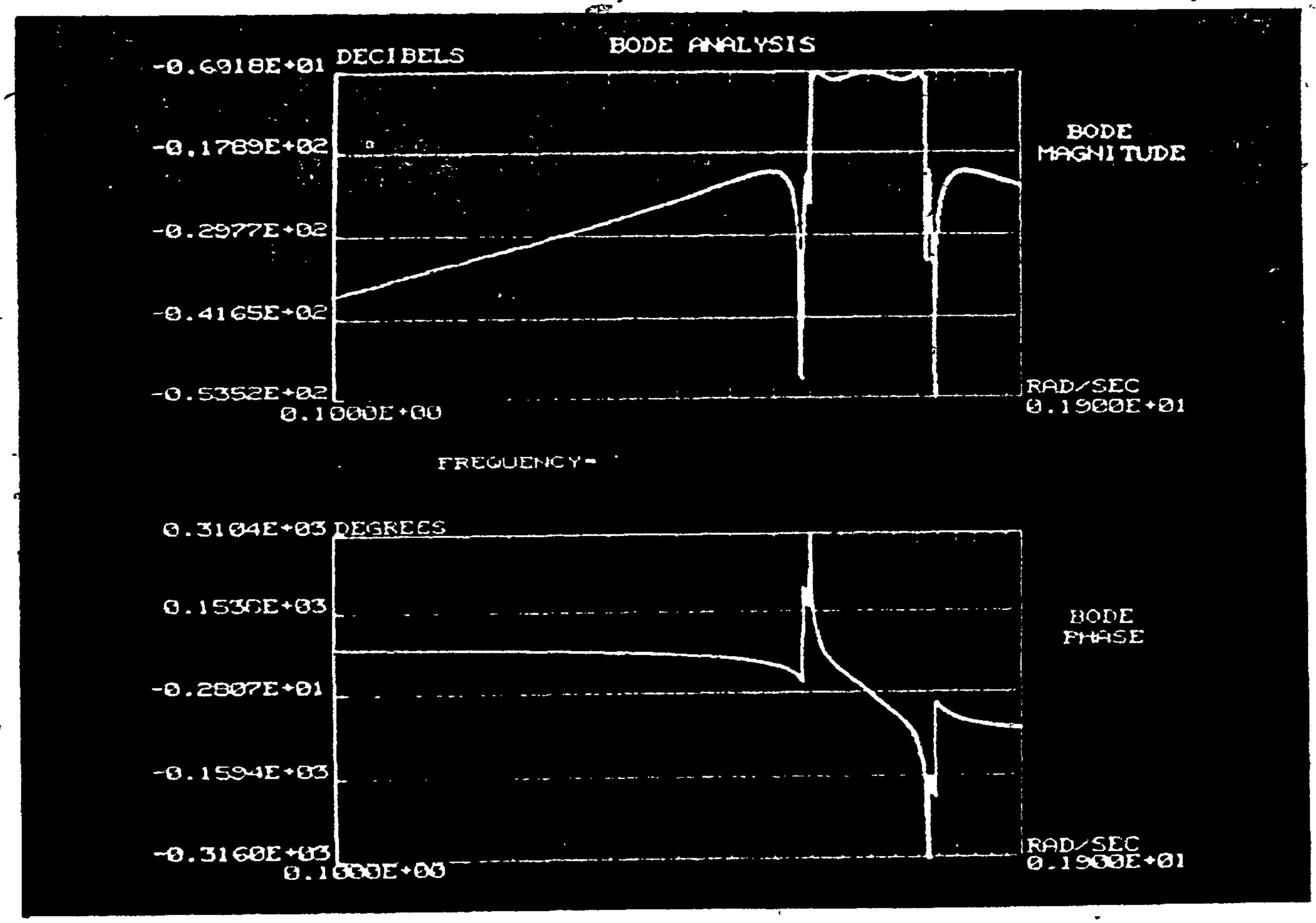


Fig. 4.20 Bode Plot between .1 and 1.9 rad/sec of 10th Order Elliptic Band-Pass Filter

they are further expanded by entering new frequency limits below.

```
ENTER THE STARTING FREQUENCY(IN RAD/SEC)=.5417
ENTER THE FINAL FREQUENCY(IN RAD/SEC)=1.9
```

These new limits result in Fig. 4.21. The plots of Fig. 4.21 represents the response of the filter; the upper portion is the magnitude plot and the lower portion is the phase plot. The plots of Fig. 4.21 can be further investigated by placing cursors at various points of the plots. Figs. 4.22 to 4.24 show where the cursors have been placed to indicate the magnitude, phase, and frequency.

Let us go back to Fig. 4.21 and study different sections of the plots more closely. The first section to be considered is the response of the filter before the pass-band region. This section is shown in Fig. 4.25. We analyze Fig. 4.25 by placing a cursor at the first dip in the response. This is illustrated in Fig. 4.26. The second section of interest is the pass-band region and this is shown in Fig. 4.27. Again, we place a cursor in the mid section of Fig. 4.27 and this is shown in Fig. 4.28. The last section to be analyzed is the response after the pass-band region which is shown in Fig. 4.29. We place a cursor at the last dip of the response in Fig. 4.29 and this is shown in Fig. 4.30.

We have made a detailed analysis of the filter response by way of the Bode plot. We continue to study the filter by obtaining

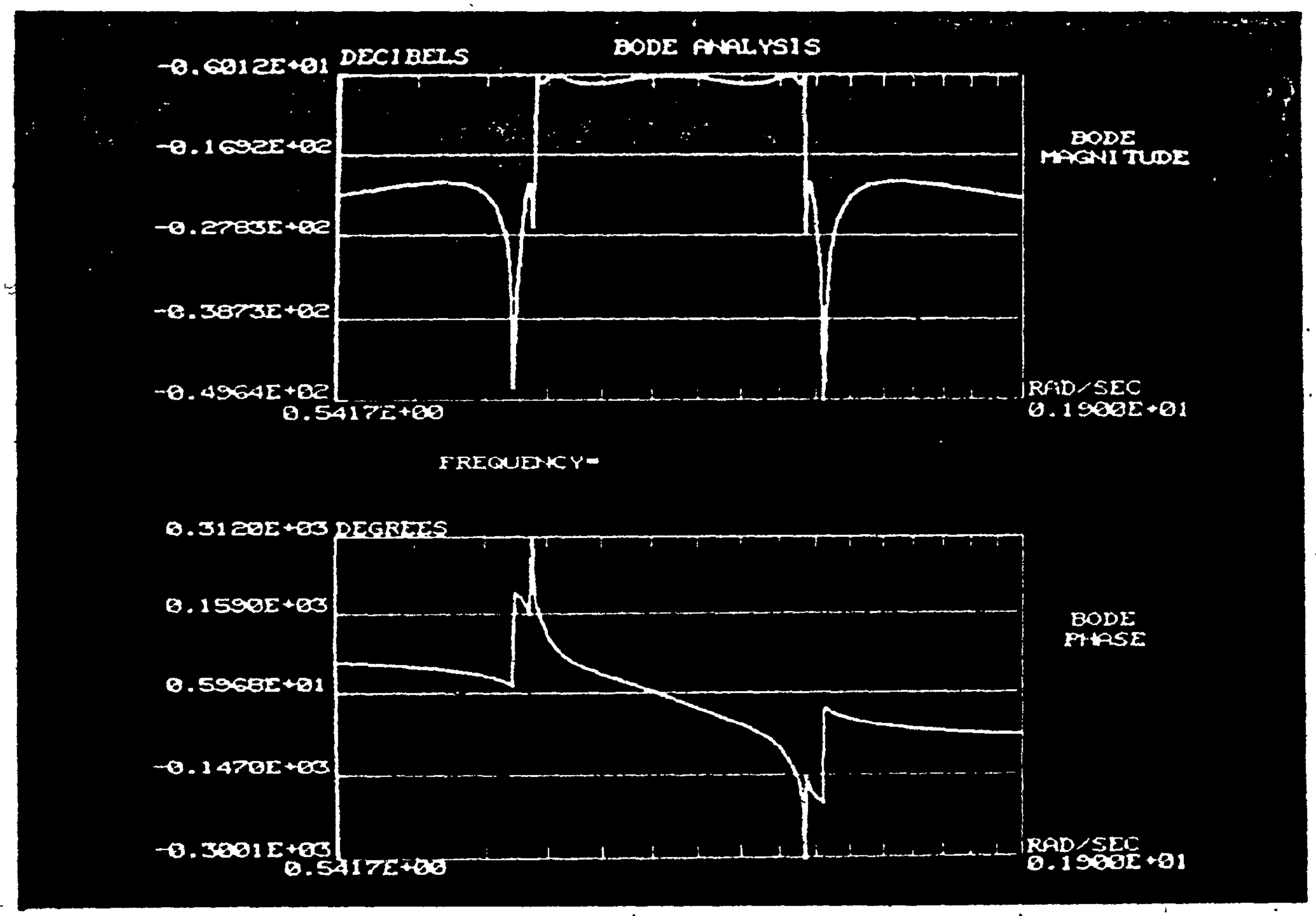


Fig. 4.21 Bode Plot between .5417 and 1.9 rad/sec of 10th Order Elliptic Band-Pass Filter

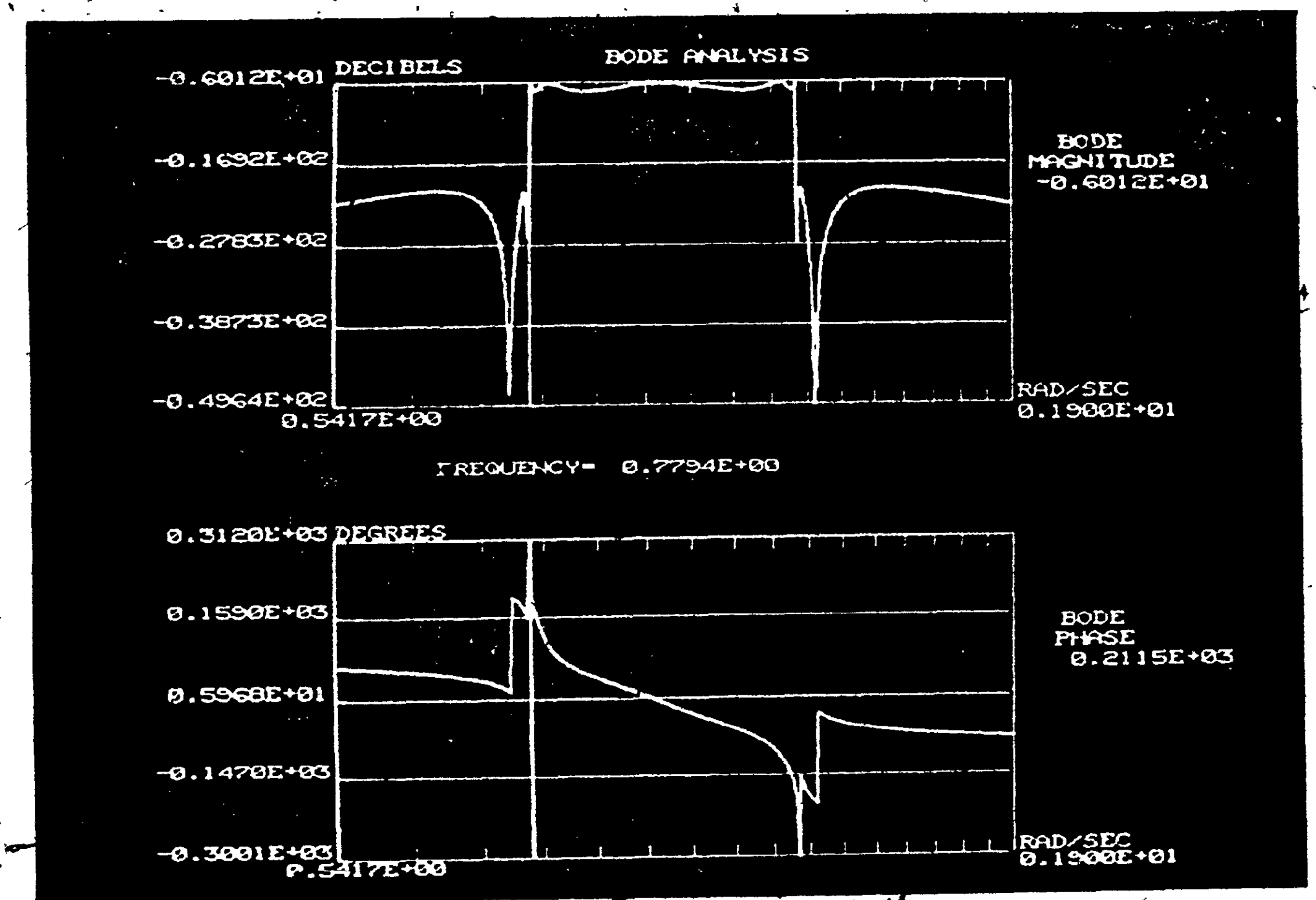


Fig. 4.22 Bode Plot between .5417 and 1.9 rad/sec of 10th Order Elliptic Band-Pass Filter with Cursor at .7794 rad/sec

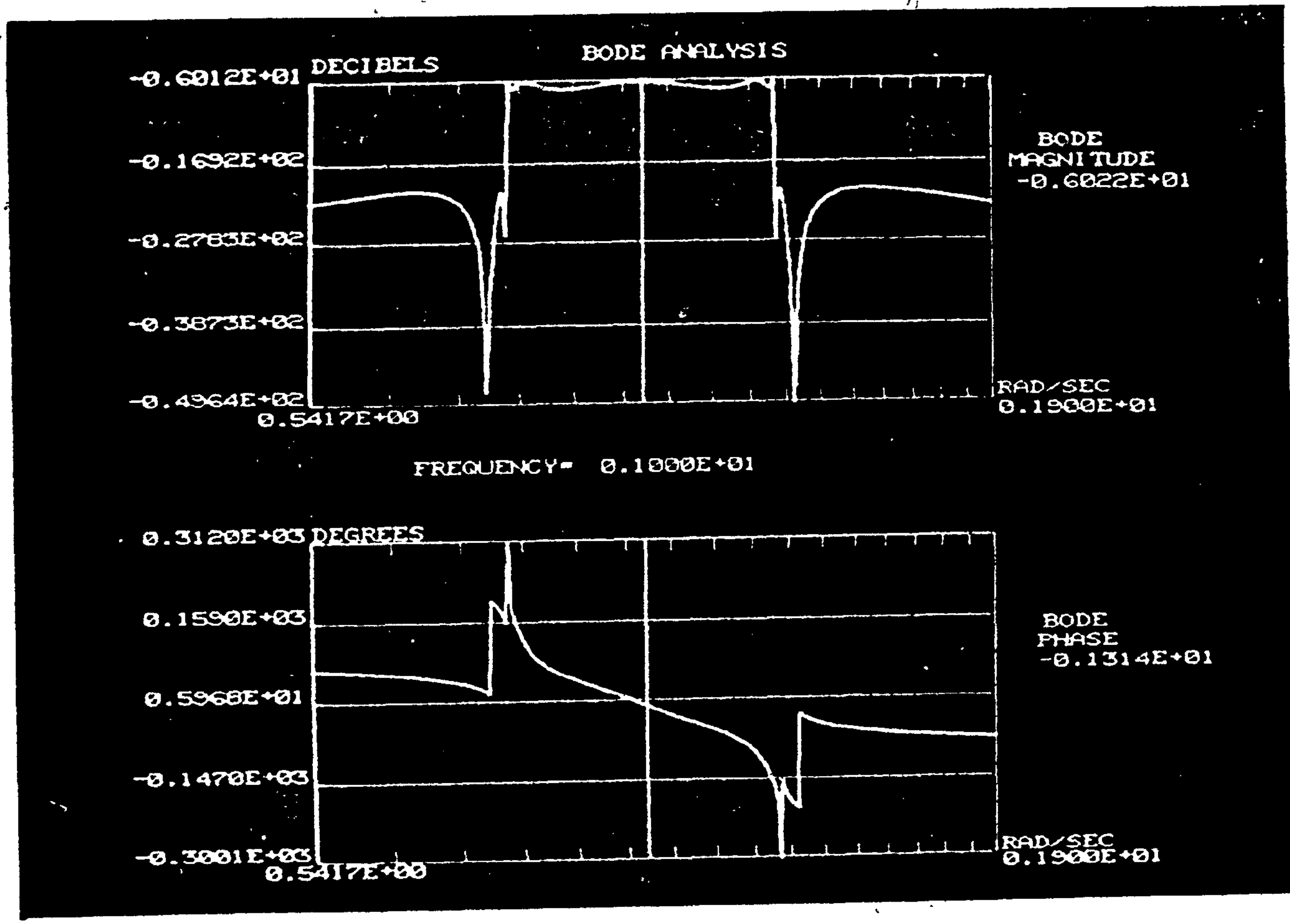


Fig. 4.23 Bode Plot between .5417 and 1.9 rad/sec of 10th Order Elliptic Band-Pass Filter with Cursor at 1. rad/sec

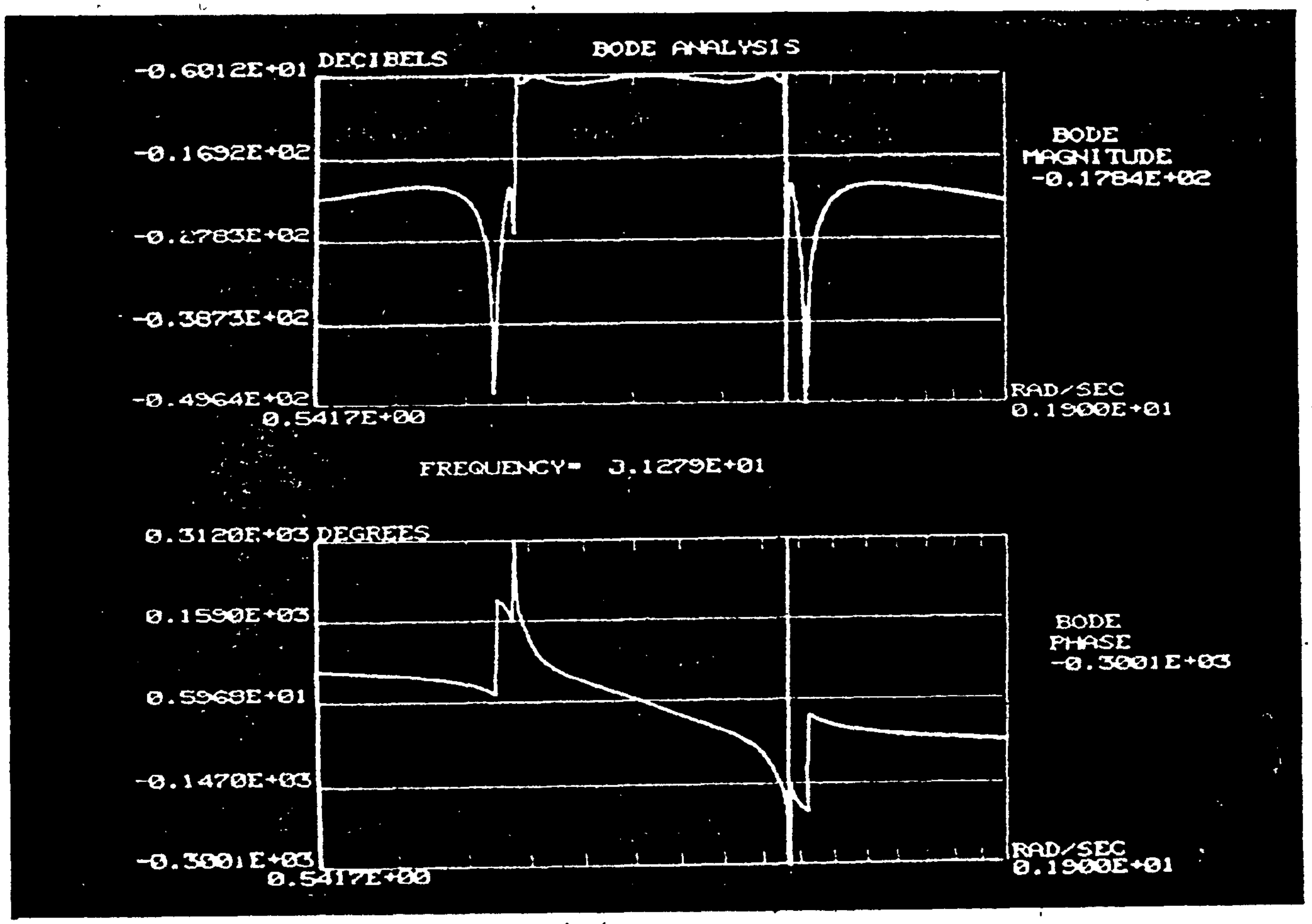


Fig. 4.24 Bode Plot between .5417 and 1.9 rad/sec of 10th Order Elliptic Band-Pass Filter with Cursor at 1.279 rad/sec

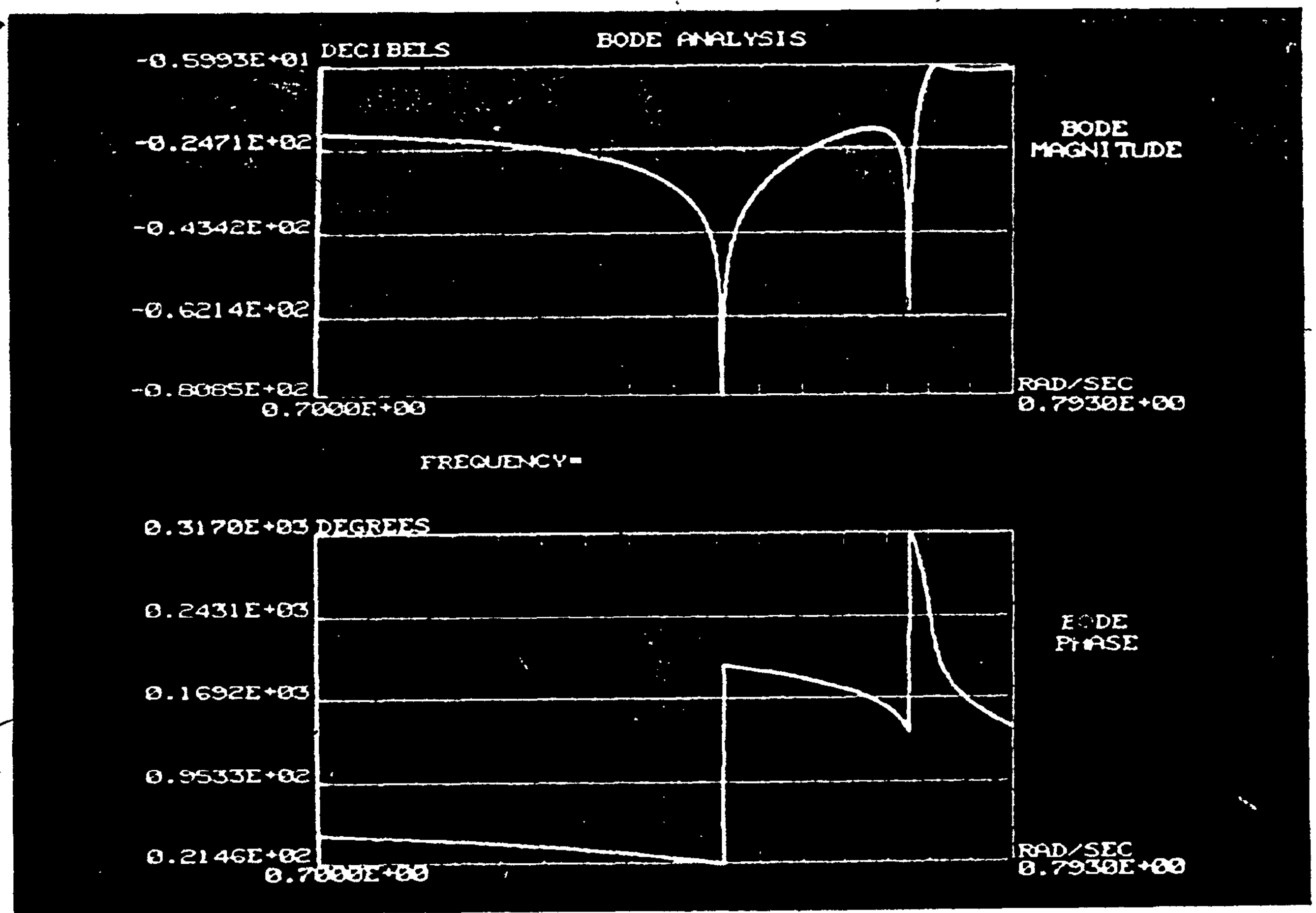


Fig. 4.25 Bode Plot between .7 and .793 rad/sec of 10th Order Elliptic Band-Pass Filter

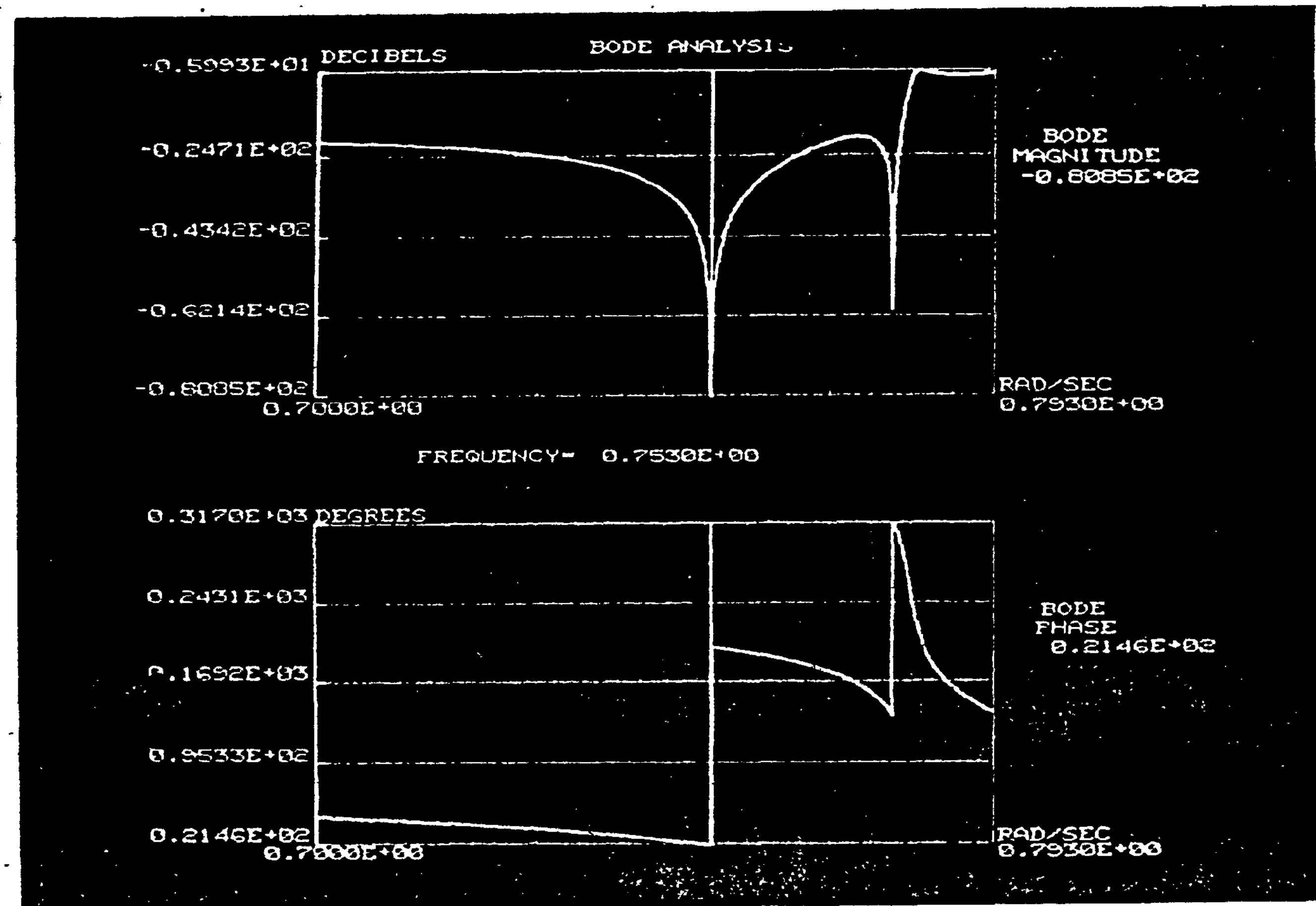


Fig. 4.26 Bode Plot between .7 and .793 rad/sec of 10th Order Elliptic Band-Pass Filter with Cursor at .753 rad/sec

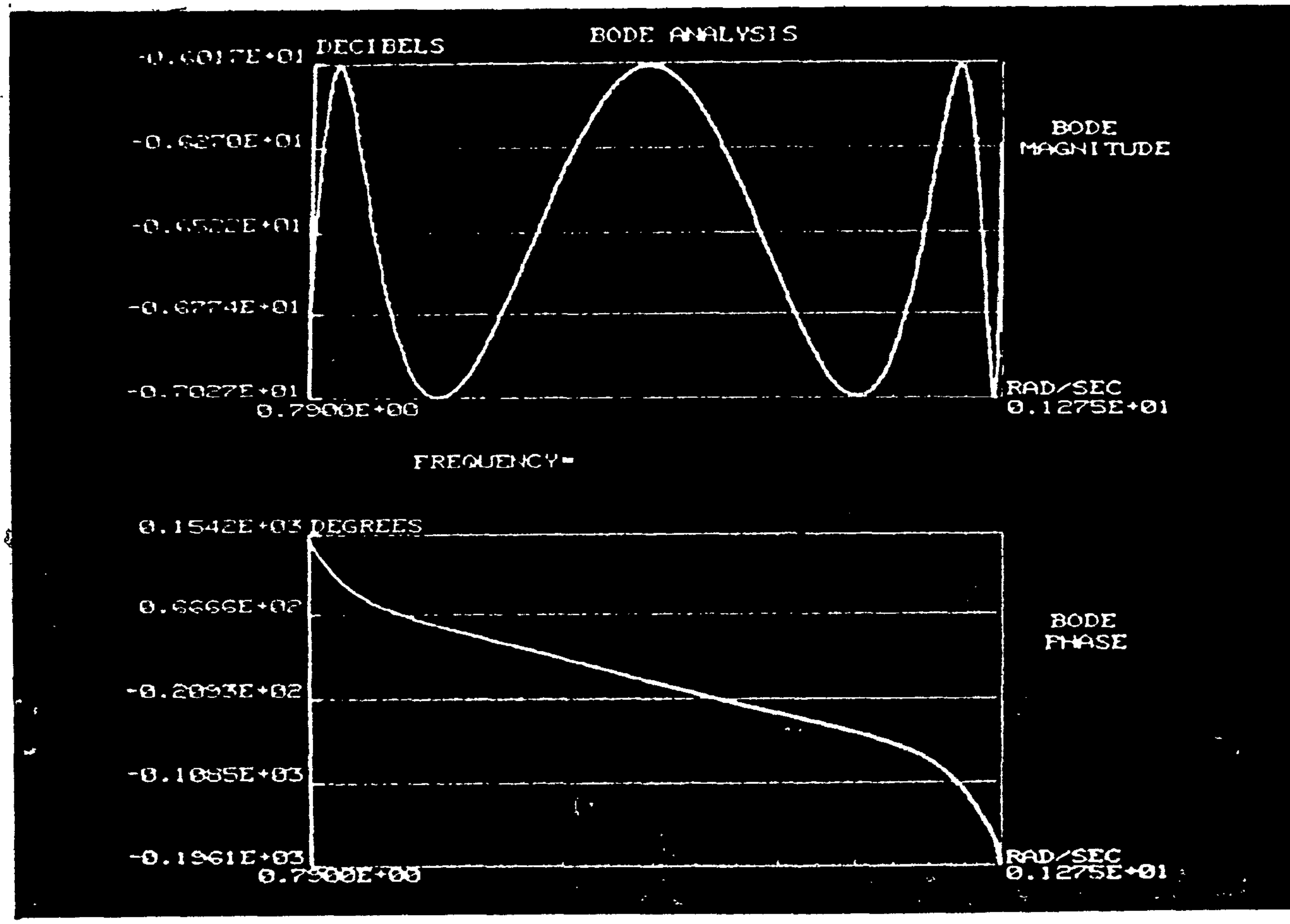


Fig. 4.27 Bode Plot between .79 and 1.275 rad/sec of 10th Order Elliptic Band-Pass Filter

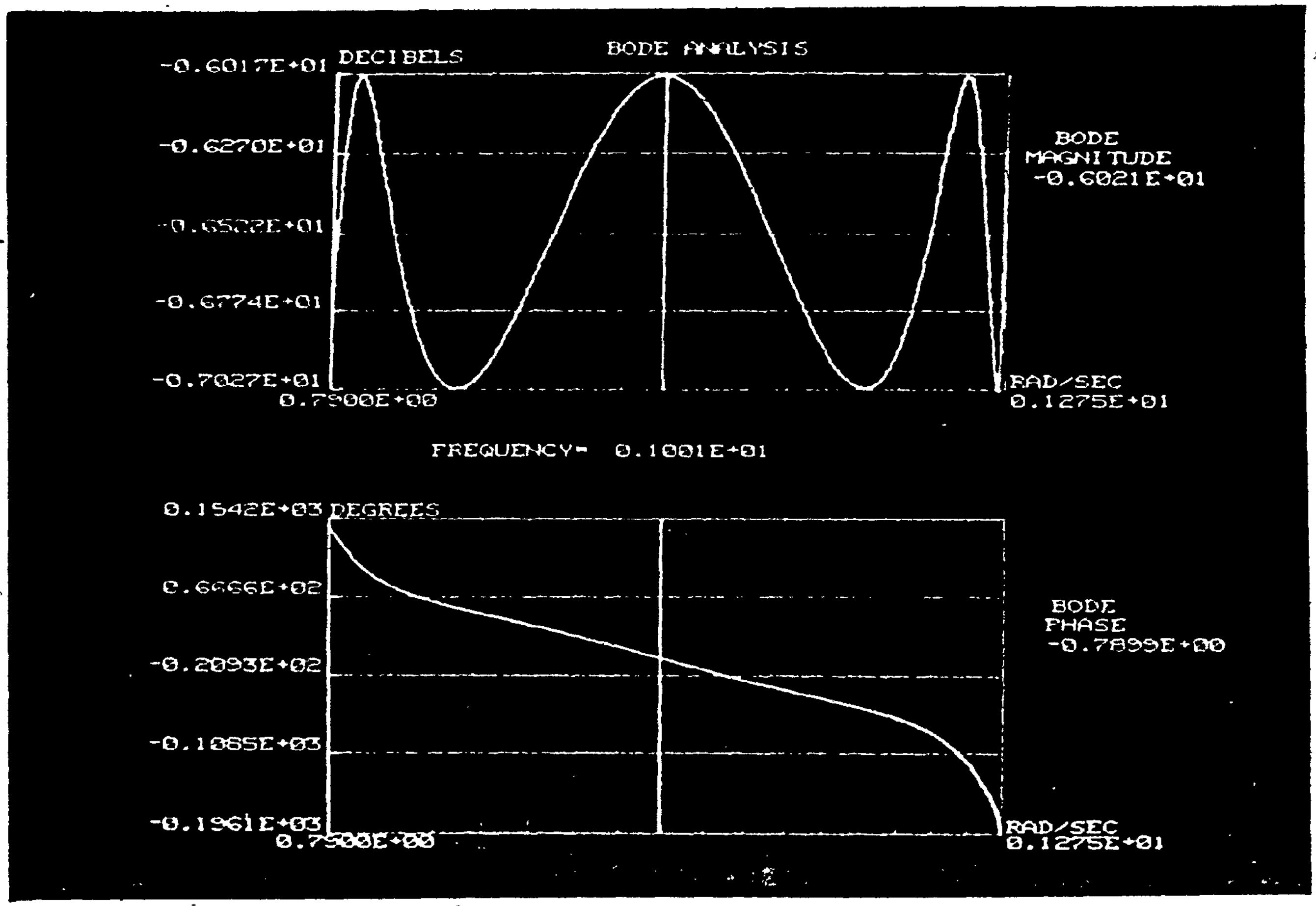


Fig. 4.28 Bode Plot between .79 and 1.275 rad/sec of 10th Order Elliptic Band-Pass Filter with Cursor at 1.001 rad/sec

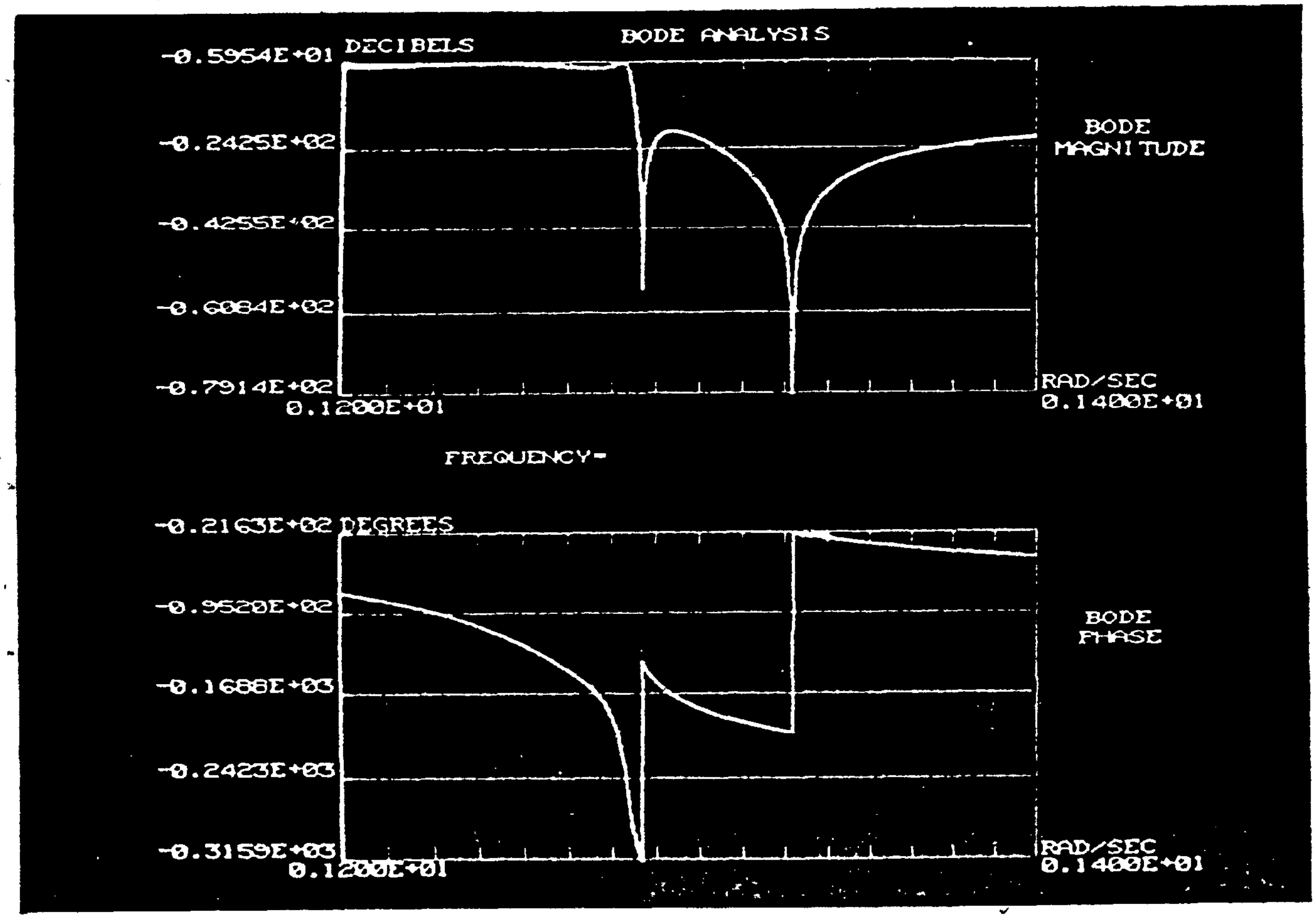


Fig. 4.29 Bode Plot between 1.2 and 1.4 rad/sec of 10th Order Elliptic Band-Pass Filter

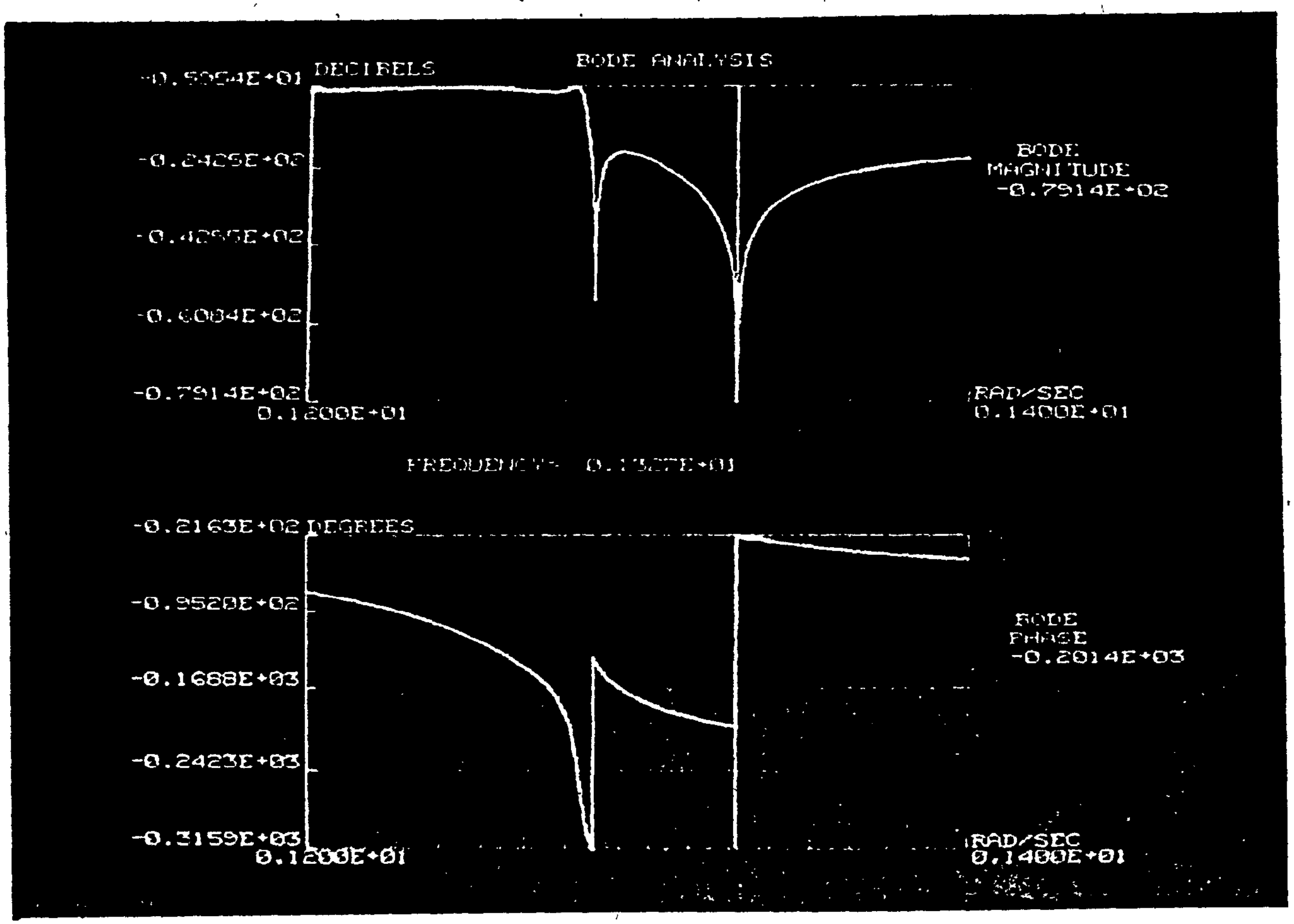


Fig. 4.30 Bode Plot between 1.2 and 1.4 rad/sec of 10th Order Elliptic Band-Pass Filter with Cursor at 1.327 rad/sec

its Nyquist plot. Using the same frequency limits as that of Fig. 4.21, we obtain the Nyquist plot shown in Fig. 4.31. At this point of the analysis, we obtain a printout of the Bode and Nyquist plots of Fig. 4.21 and Fig. 4.31 by following the procedure in Chapter 3. These printouts are given in Appendix V.

4.3 SENSITIVITY STUDY OF 10TH ORDER ELLIPTIC BAND-PASS FILTER

The filter study is continued by investigating the response of the filter due to component variations. To perform this study, we return to the program LADNET. We run LADNET and Fig. 4.18 appears on the CRT. We vary the component values by striking the command *SENSITIVITY*. We confirm it and the teletype prints:

```
SENSITIVITY STUDIES ARE MADE BY INSERTING A  FLOATING
NUMBER BETWEEN + OR - 100 FOR EACH ELEMENT(S) LOCATION
```

The response of the filter will be studied when the inductors are varied by 5% and capacitors by -5%. We proceed to enter the variations by striking each component. These variations are given below:

```
LOCATION  2  IS A SHUNT ARM
% VARAITION FOR INDUCTOR=5.
% VARIATION FOR CAPACITOR=-5.
```

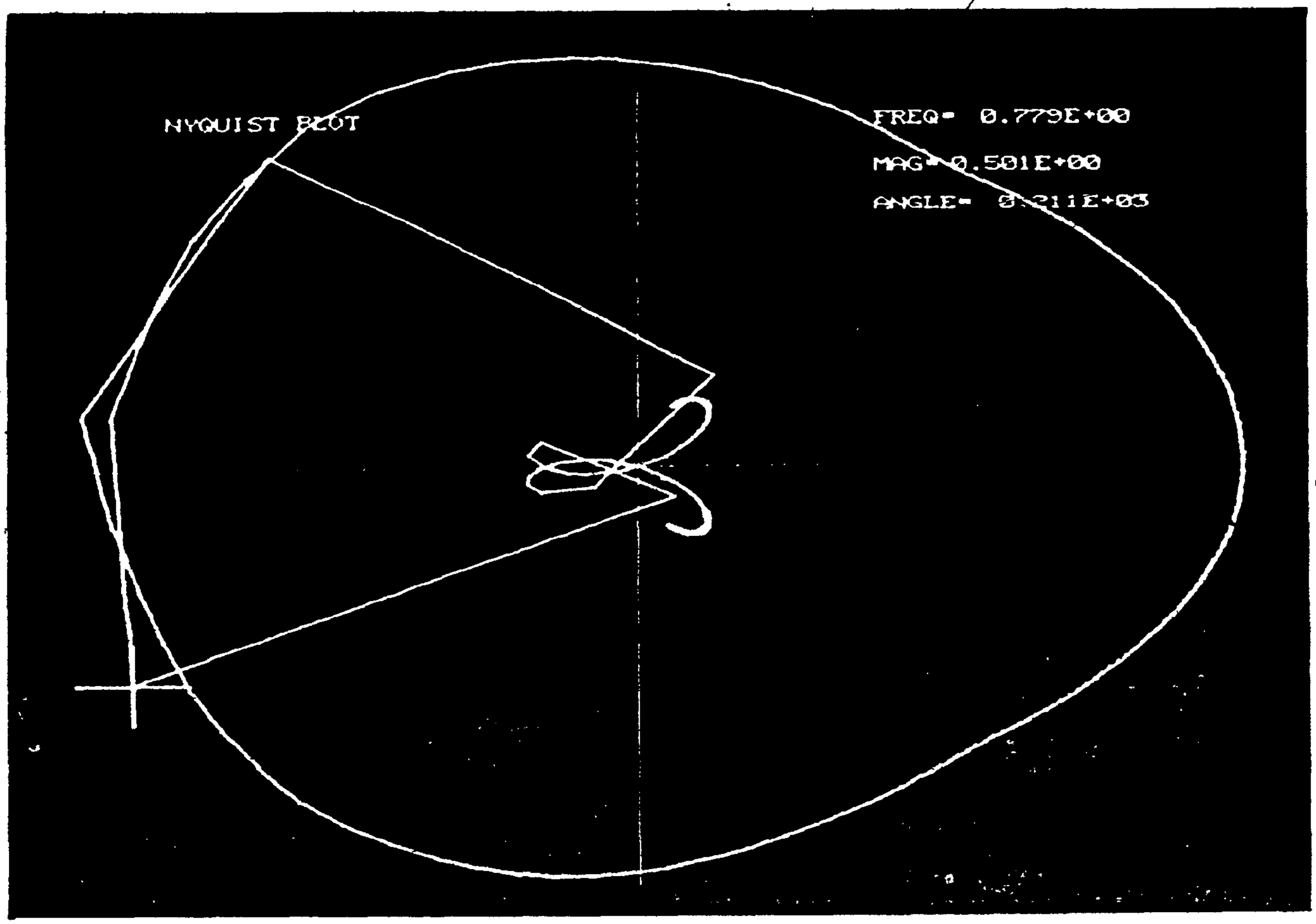


Fig. 4.31 Nyquist Plot between .5417 and 1.9 rad/sec of 10th Order Elliptic Band-Pass with Cross Marker at .779 rad/sec

LOCATION 3 IS A SERIES ARM
% VARAITION FOR INDUCTOR=5.
% VARIATION FOR CAPACITOR=-5.

LOCATION 5 IS A SERIES ARM
% VARAITION FOR INDUCTOR=5.
% VARIATION FOR CAPACITOR=-5.

LOCATION 6 IS A SHUNT ARM
% VARAITION FOR INDUCTOR=5.
% VARIATION FOR CAPACITOR=-5.

LOCATION 7 IS A SERIES ARM
% VARAITION FOR INDUCTOR=5.
% VARIATION FOR CAPACITOR=-5.

LOCATION 9 IS A SERIES ARM
% VARAITION FOR INDUCTOR=5.
% VARIATION FOR CAPACITOR=-5.

LOCATION 10 IS A SHUNT ARM
% VARAITION FOR INDUCTOR=5.
% VARIATION FOR CAPACITOR=-5.

Once the above step is completed, we strike the command *TRANSFER FUNCTION*, confirm it, and obtain the output below.

```
****LADDER ELEMENTS AND VALUES*****

LOCATION  1 IS A SERIES ARM
ELEMENT IS A RESISTOR
VALUE(KILO-OHMS)=  1.00000005E-03

LOCATION  2 IS A SHUNT ARM
ELEMENTS COMBINATION PARALLEL INDUCTOR AND CAPACITOR
VALUE(MILLI-HENERIES)=  4.10894531E+02
VALUE(MICRO-FARADS)=  2.42630000E+06

LOCATION  3 IS A SERIES ARM
ELEMENTS COMBINATION PARALLEL INDUCTOR AND CAPACITOR
VALUE(MILLI-HENERIES)=  1.13952049E+02
VALUE(MICRO-FARADS)=  4.96693250E+06

LOCATION  4 IS A SHUNT ARM
THIS IS AN OPEN CIRCUIT WHOSE ADMITTANCE IS =0.0

LOCATION  5 IS A SERIES ARM
ELEMENTS COMBINATION PARALLEL INDUCTOR AND CAPACITOR
VALUE(MILLI-HENERIES)=  2.00828186E+02
VALUE(MICRO-FARADS)=  8.75368200E+06

LOCATION  6 IS A SHUNT ARM
ELEMENTS COMBINATION PARALLEL INDUCTOR AND CAPACITOR
VALUE(MILLI-HENERIES)=  4.36155182E+02
VALUE(MICRO-FARADS)=  2.28703000E+06

LOCATION  7 IS A SERIES ARM
ELEMENTS COMBINATION PARALLEL INDUCTOR AND CAPACITOR
VALUE(MILLI-HENERIES)=  1.73988113E+01
VALUE(MICRO-FARADS)=  3.47763400E+07

LOCATION  8 IS A SHUNT ARM
THIS IS AN OPEN CIRCUIT WHOSE ADMITTANCE IS =0.0
```

```
LOCATION  9 IS A SERIES ARM.
ELEMENTS COMBINATION PARALLEL INDUCTOR AND CAPACITOR
VALUE(MILLI-HENERIES)=  2.8683292?E+01
VALUE(MICRO-FARADS)=  5.73315000E+07

LOCATION 10 IS A SHUNT ARM
ELEMENTS COMBINATION PARALLEL INDUCTOR AND CAPACITOR
VALUE(MILLI-HENERIES)=  1.14829395E+03
VALUE(MICRO-FARADS)=  8.68680062E+05

LOCATION 11 IS A SERIES ARM
THIS IS A SHORT CIRCUIT WHOSE IMPEDANCE IS =0.0

LOCATION 12 IS A SHUNT ARM
ELEMENT IS A RESISTOR
VALUE(KILO-OHMS)=  1.00000005E-03

ARE YOU FINISHED?
TYPE IN YES OR NO

YES


 TO CONTINUE THE LADDER ANALYSIS AND OBTAIN THE

 TRANSFER FUNCTION TYPE IN RUN RK1:TRANF
```

We enter the program TRANF and obtain the new TF and DPF below:

TRANSFER FUNCTION

COEFFICIENTS	NUMERATOR	DENOMINATOR
S** 0	0.000000E-01	7.430742E-01
S** 1	8.973133E-02	3.705698E-01
S** 2	0.000000E-01	4.095219E+00
S** 3	4.103864E-01	1.631098E+00
S** 4	0.000000E-01	8.608384E+00
S** 5	6.476677E-01	2.531570E+00
S** 6	0.000000E-01	8.586261E+00
S** 7	4.083369E-01	1.622847E+00
S** 8	0.000000E-01	4.063747E+00
S** 9	8.883736E-02	3.668312E-01
S**10	0.000000E-01	7.335880E-01

DRIVING-POINT IMPEDANCE

COEFFICIENTS	NUMERATOR	DENOMINATOR
S** 0	1.159497E-01	1.159497E-01
S** 1	5.782391E-02	2.891121E-02
S** 2	6.390202E-01	6.335018E-01
S** 3	2.545173E-01	1.272518E-01
S** 4	1.343257E+00	1.325409E+00
S** 5	3.950275E-01	1.974970E-01
S** 6	1.339805E+00	1.322001E+00
S** 7	2.532299E-01	1.266000E-01
S** 8	6.341091E-01	6.286320E-01
S** 9	5.724054E-02	2.861589E-02
S**10	1.144694E-01	1.144694E-01

TO CONTINUE THE LADDER NETWORK ANALYSIS PACKAGE
TYPE IN RUN RK1:ANALY TO PERFORM BODE AND NYQUIST PLOTS
STOP --

We activate ANALY and proceeding in the same manner as discussed previously, we obtain the new plots. Using the same frequency limits as for Fig. 4.21, the new Bode plot is shown in Fig. 4.32. Comparing the plots of Figs. 4.21 and 4.32, we can see that the response has changed. To determine how much change has occurred, let us study the Bode plot of Fig. 4.32 as we did in Fig. 4.21.

We take the plots of Fig. 4.32 and expand the lower section of the response in Fig. 4.33. The cursor in Fig. 4.33 is placed at the same point as that of Fig. 4.26. Notice, the slight shift in the notch between Figs. 4.33 and Fig. 4.26. The next section is the pass-band region which is shown in Fig. 4.34. The response in the

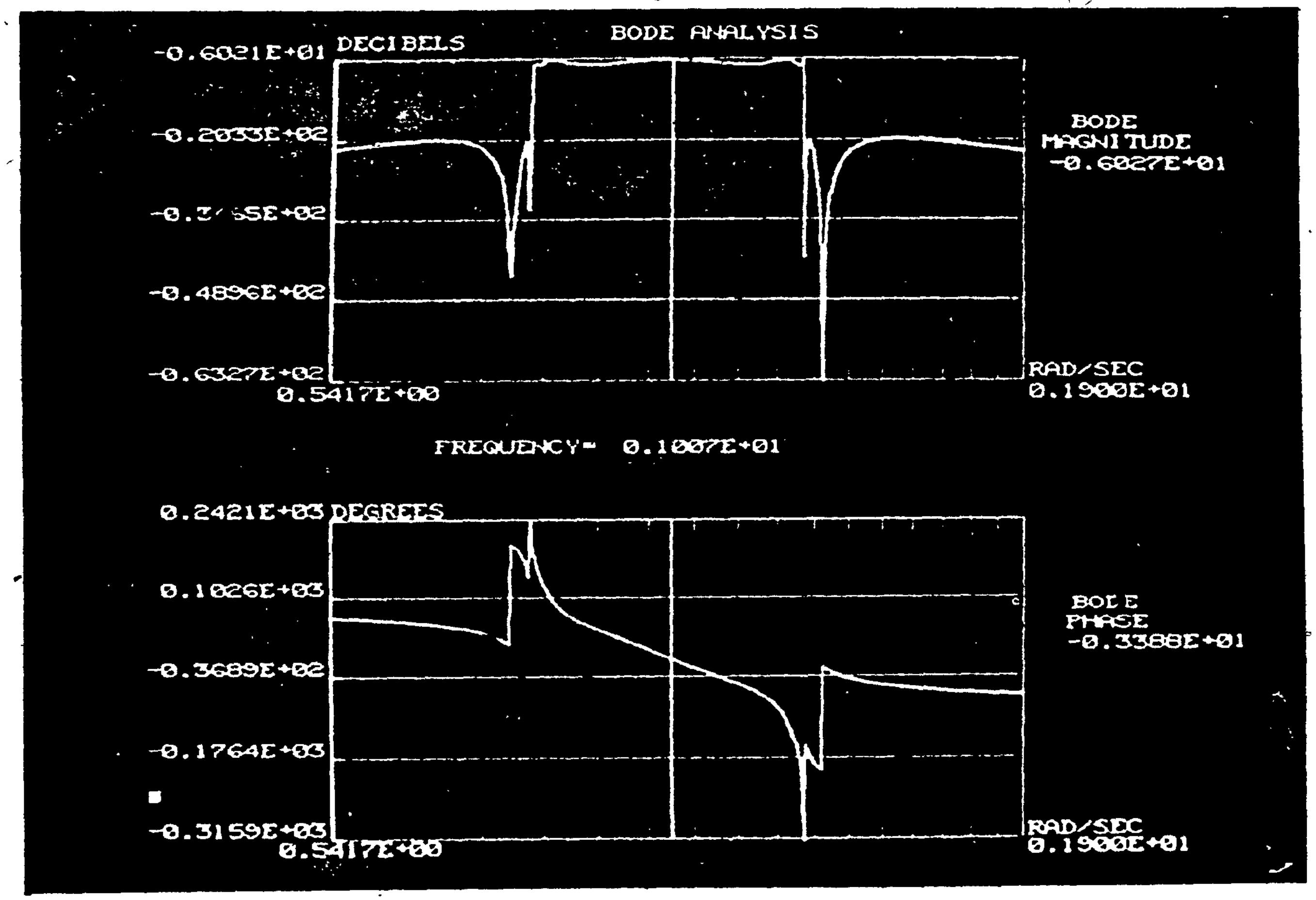


Fig. 4.32 Bode Plot between .5417 and 1.9 rad/sec of 10th Order Elliptic Band-Pass Filter with 5% Variation in Inductor Values and -5% Variation in Capacitor Values Cursor at 1.007 rad/sec

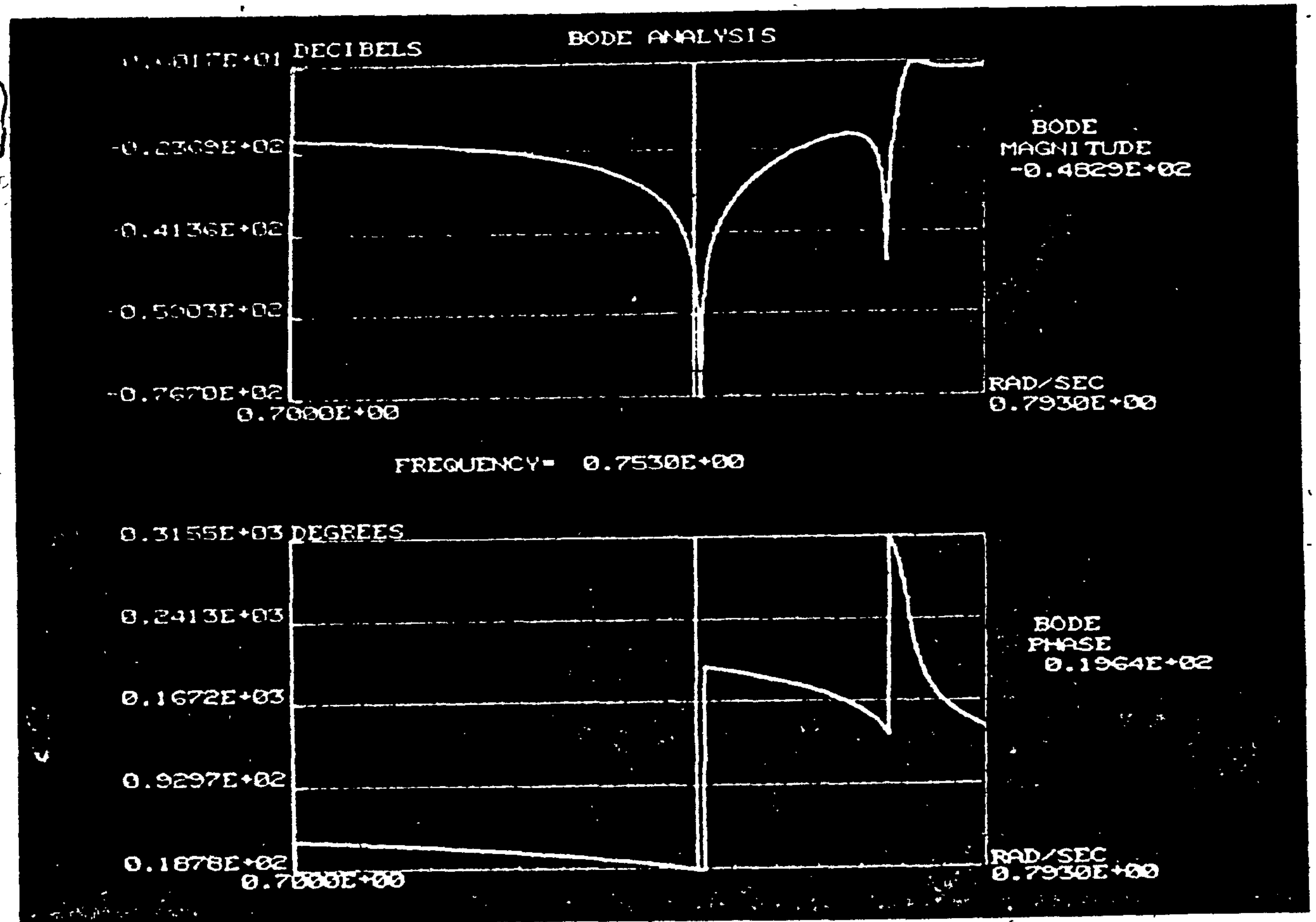


Fig. 4.33 Bode Plot between .7 and .793 rad/sec of 10th Order Elliptic Band-Pass Filter with 5% Variation in Inductor Values and -5% Variation in Capacitor Values Cursor at .753 rad/sec

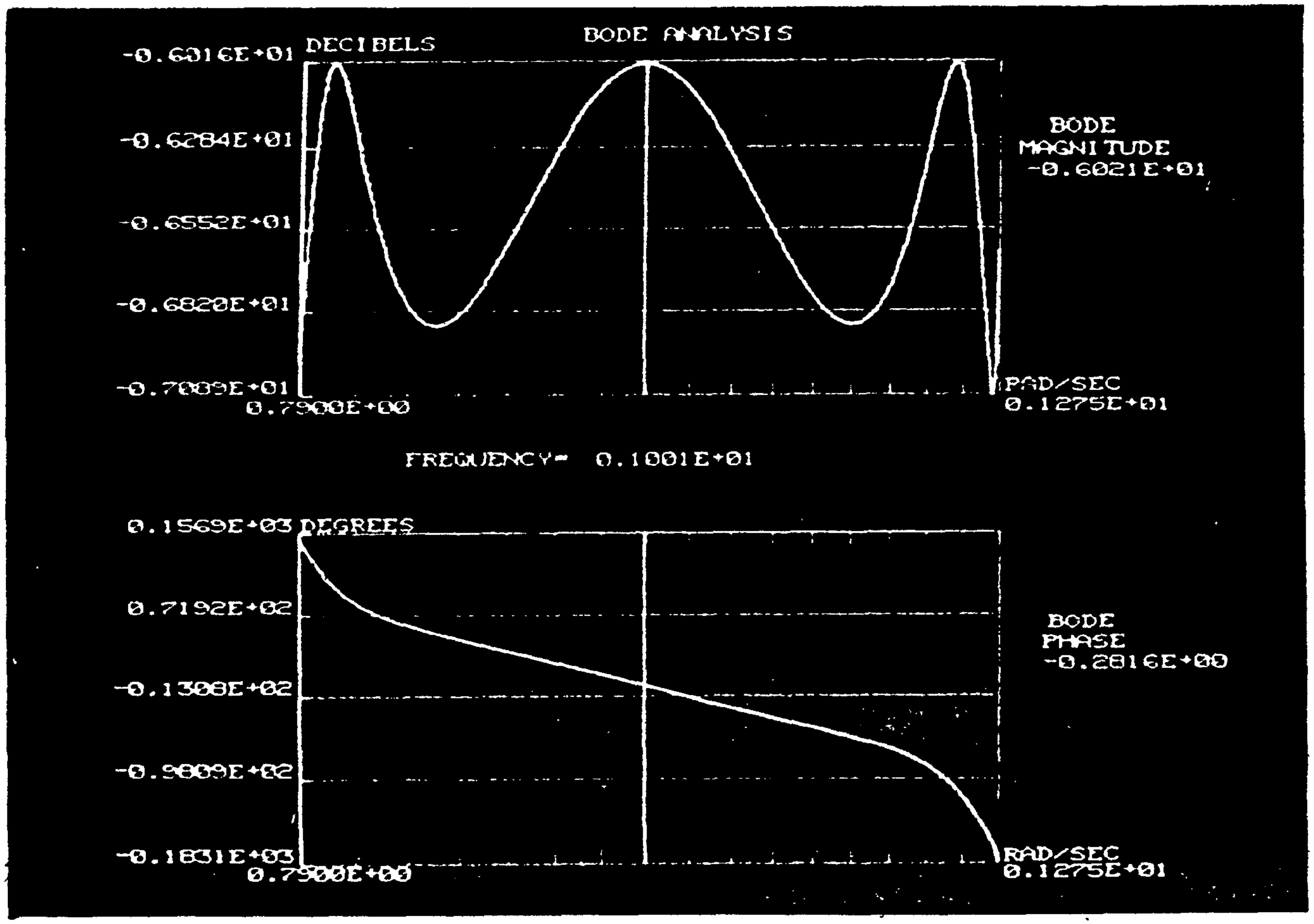


Fig. 4.34 Bode Plot between .79 and 1.275 rad/sec of 10th Order Elliptic Band-Pass Filter with 5% Variation in Inductor Values and -5% Variation in Capacitor Values Cursor at 1.001 rad/sec

pass-band shown in Fig. 4.34 has changed from the plot shown in Fig. 4.28. We finally expand the upper section of Fig. 4.32 in Fig. 4.35. The response of Fig. 4.34 has also changed with respect to Fig. 4.30.

Having completed the analysis of the filter, we proceed to analyze the stability of a system function using the program ANALY of the LNA package.

4.4 STABILITY OF A SYSTEM FUNCTION USING ANALY

The system function that we are going to study is given by its open-loop transfer function as:

$$TF(s) = \frac{K(1.4S+1)\ (S+1)}{S^3(1.8S+1)^2} \qquad (4.1)$$

Then the corresponding closed-loop transfer function will be conditionally stable depending upon the gain value K . To determine this value of K , we must find the Nyquist plot of equation 4.1.

To obtain the Nyquist plot, we go directly to the program ANALY which allows us to enter the coefficients of the numerator and denominator terms of equation 4.1. To begin our analysis we set K=1, and enter RUN RK1:ANALY on the teletype.

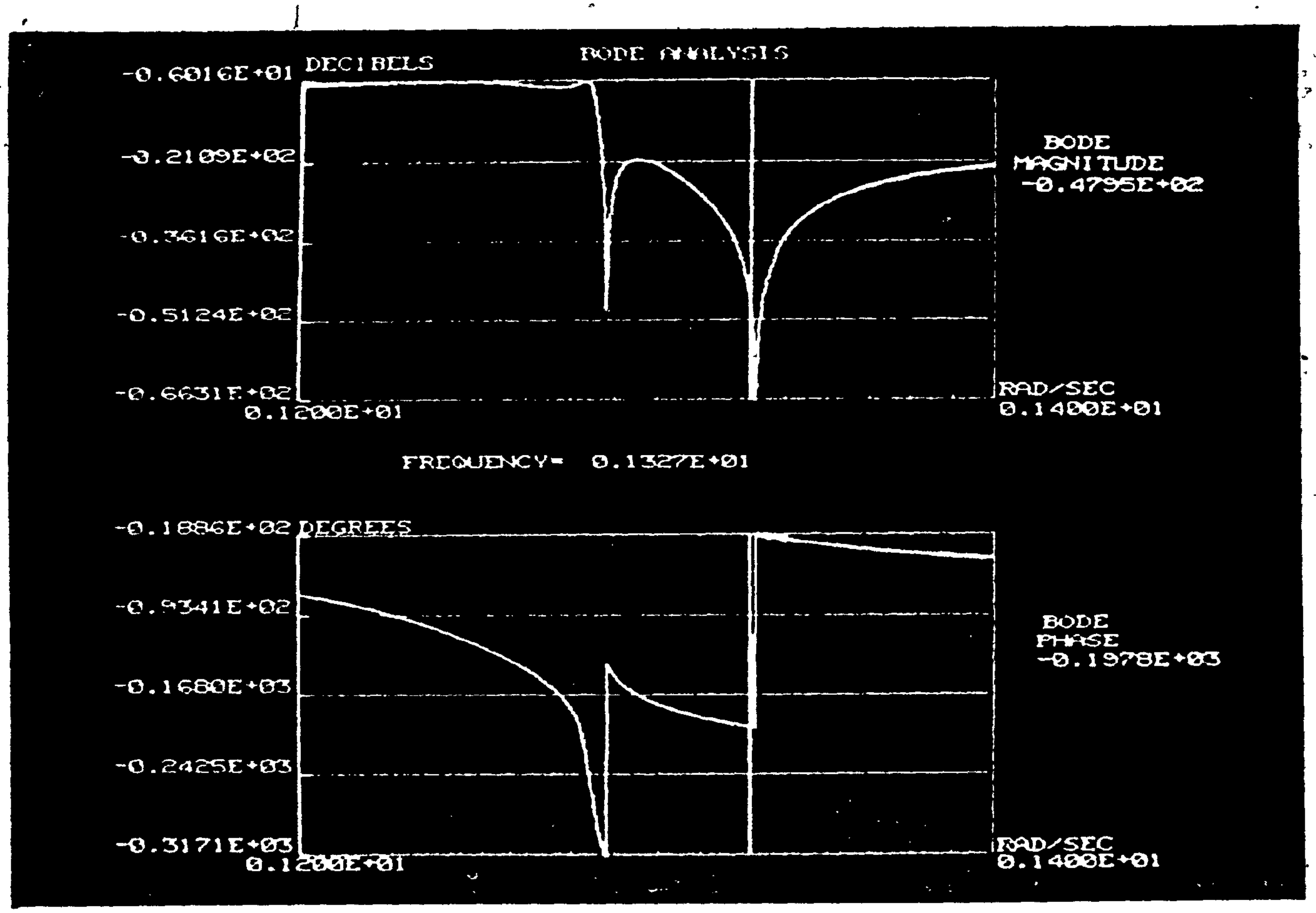


Fig. 4.35 Bode Plot between 1.2 and 1.4 rad/sec of 10th Order Elliptic Band-Pass Filter with 5% Variation in Inductor Values and -5% Variation in Capacitor Values Cursor at 1.327 rad/sec

The output of this entry is

```
DO YOU WISH TO ENTER YOUR OWN TRANSFER FUNCTION?
TYPE IN YES OR NO

YES
```

to which we enter a YES. This reply gives us

```
ENTER THE ORDER OF THE TRANSFER FUNCTION
ORDER=
```

We enter the order of the TF below

```
ENTER THE ORDER OF THE TRANSFER FUNCTION
ORDER=5
```

which results in the teletype to print

```
ENTER THE COEFFICIENTS OF THE TRANSFER FUNCTION
COEFFICIENTS BEING ENTERD FROM LOWEST TO HIGHEST ORDER
```

We begin to enter the coefficients of the TF and this is given below.

```
COEFFICIENT OF S** 0

NUMERATOR=1.

DENOMINATOR=0.

COEFFICIENT OF S** 1

NUMERATOR=2.4

DENOMINATOR=0.

COEFFICIENT OF S** 2

NUMERATOR=1.4

DENOMINATOR=0.
```

```
COEFFICIENT OF  S** 3
NUMERATOR=0.
DENOMINATOR=1.
COEFFICIENT OF  S** 4
NUMERATOR=0.
DENOMINATOR=.
COEFFICIENT OF  S** 5
NUMERATOR=0.
DENOMINATOR=.0324
```

At the last entry, the message below is given.

```
DO YOU WANT A PRINT OUT OF THE COEFFICIENTS JUST ENTERED?
TYPE IN YES OR NO
```

An answer of YES is given and the output is given below.

```
                   ***TRANSFER FUNCTION***
COEFFICIENTS              NUMERATOR                    DENOMINATOR
S** 0                     1.000000E+00                 0.000000E-01
S** 1                     2.400000E+00                 0.000000E-01
S** 2                     1.400000E+00                 0.000000E-01
S** 3                     0.000000E-01                 1.000000E+00
S** 4                     0.000000E-01                 3.600000E-01
S** 5                     0.000000E-01                 3.240000E-02
ARE YOU SATISFIED?
IF ANSWER IS YES BODE  PLOT BEGINS
IF THE ANSWER IS NO RE-ENTER COEFFICIENTS
TYPE IN YES OR NO
```

At the end of the print out, we type in YES which gives us

```
ENTER THE STARTING FREQUENCY(IN RAD/SEC)=
ENTER THE FINAL FREQUENCY(IN RAD/SEC)=
```

and we enter the following frequency limits.

```
ENTER THE STARTING FREQUENCY(IN RAD/SEC)=.1
ENTER THE FINAL FREQUENCY(IN RAD/SEC)=10.
```

The computer begins to calculate the Bode and Nyquist plots. At the end of the calculations, the teletype prints

```
WHICH DO YOU WANT?     BODE OR NYQT?
TYPE IN  BODE OR NYQT

NYQT
```

We enter NYQT and the results are shown in Fig. 4.36. As we can see, the response does not give us the necessary information to obtain the range of the gain K. Therefore, we place a cross marker on the plot whereby we can obtain a better plot for our analysis. This cross marker is shown in Fig. 4.37 and the information pertaining to its position is shown in the right hand corner.

Using the information obtained from Fig. 4.37, we enter the following frequency limits.

```
ENTER THE STARTING FREQUENCY(IN RAD/SEC)=1.3
ENTER THE FINAL FREQUENCY(IN RAD/SEC)=10.
```

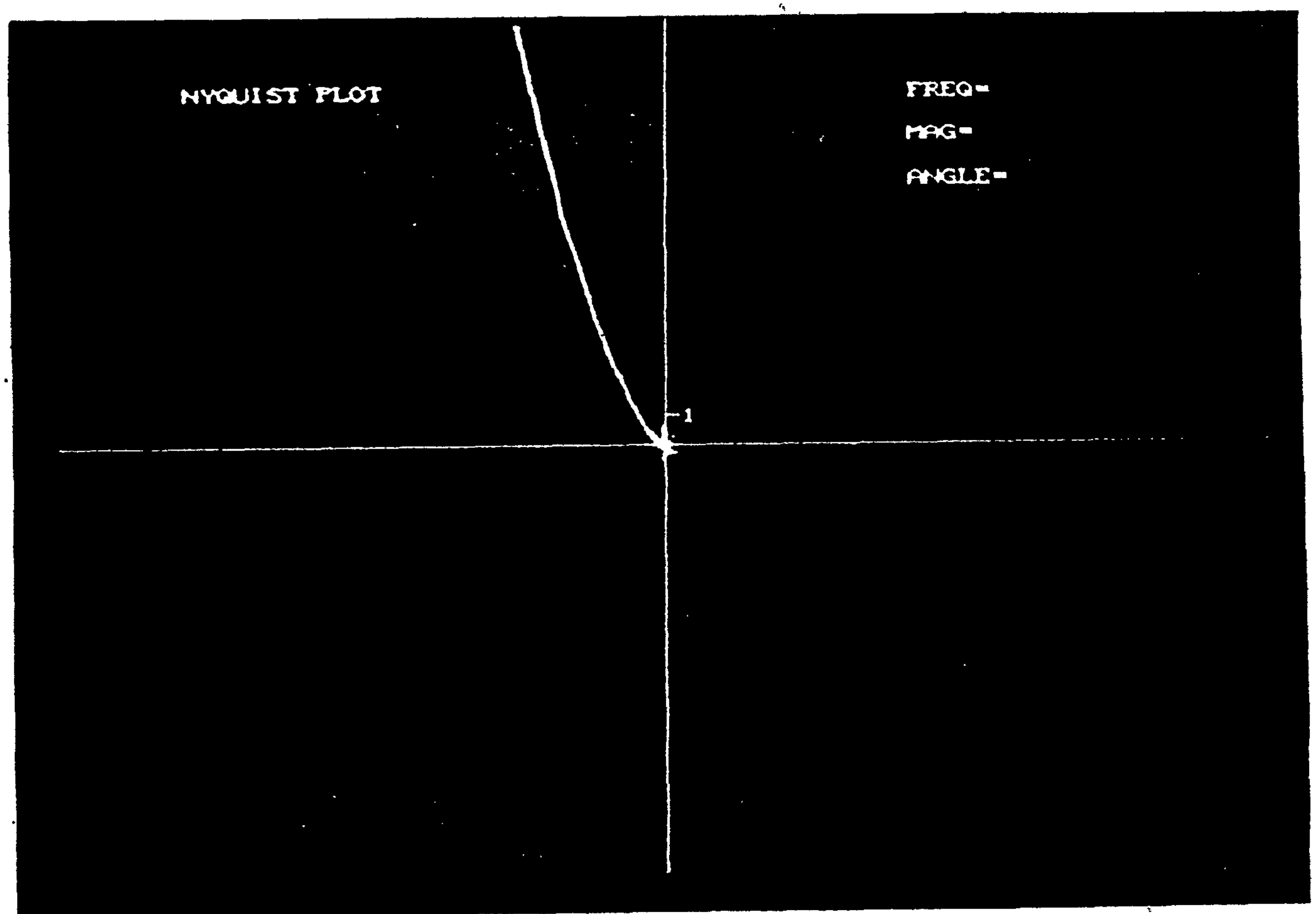


Fig. 4.36 Nyquist Plot between .1 and 10. rad/sec of Equation 4.1

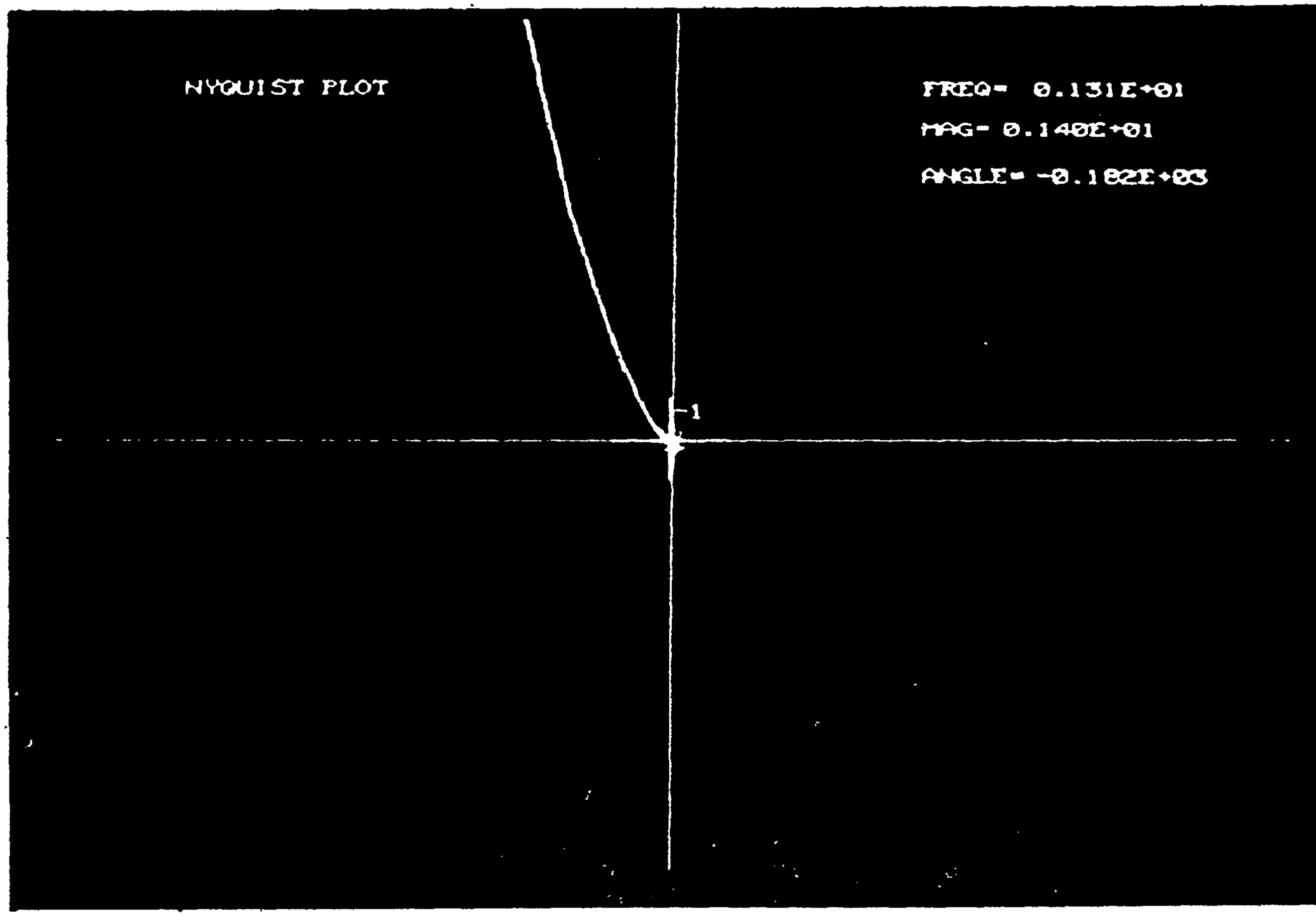


Fig. 4.37 Nyquist Plot between .1 and 10. rad/sec of Equation 4.1 with Cross Marker at 1.31 rad/sec

These limits give us the Nyquist plot of Fig. 4.38. This plot does help us in our analysis. To determine the conditional stability of the closed-loop transfer function, we determine the points where the plot of Fig. 4.38 crosses the axis.

We determine the first crossing in Fig. 4.39, whereby the information is in the right hand corner. The necessary information to determine the value of K is the magnitude at the crossing of the real axis. The magnitude in Fig. 4.39 is 1.24. We follow the same procedure to obtain the second crossing and this is shown in Fig. 4.40. The magnitude at that point is .358. Having both magnitudes, we determine the range of K as follows

(1) For the crossing in Fig. 4.39, the value of K is decreased from 1 to

$$\frac{1}{1.24} = .806$$

(2) For the point in Fig. 4.40, the value of K is increased from 1 to

$$\frac{1}{.358} = 2.79$$

Therefore, the closed-loop transfer function is conditionally stable in the range, $.806 < K < 2.79$.

The analysis studies that were performed, illustrated how powerful and versitile a tool the LNA package is. The visual displays

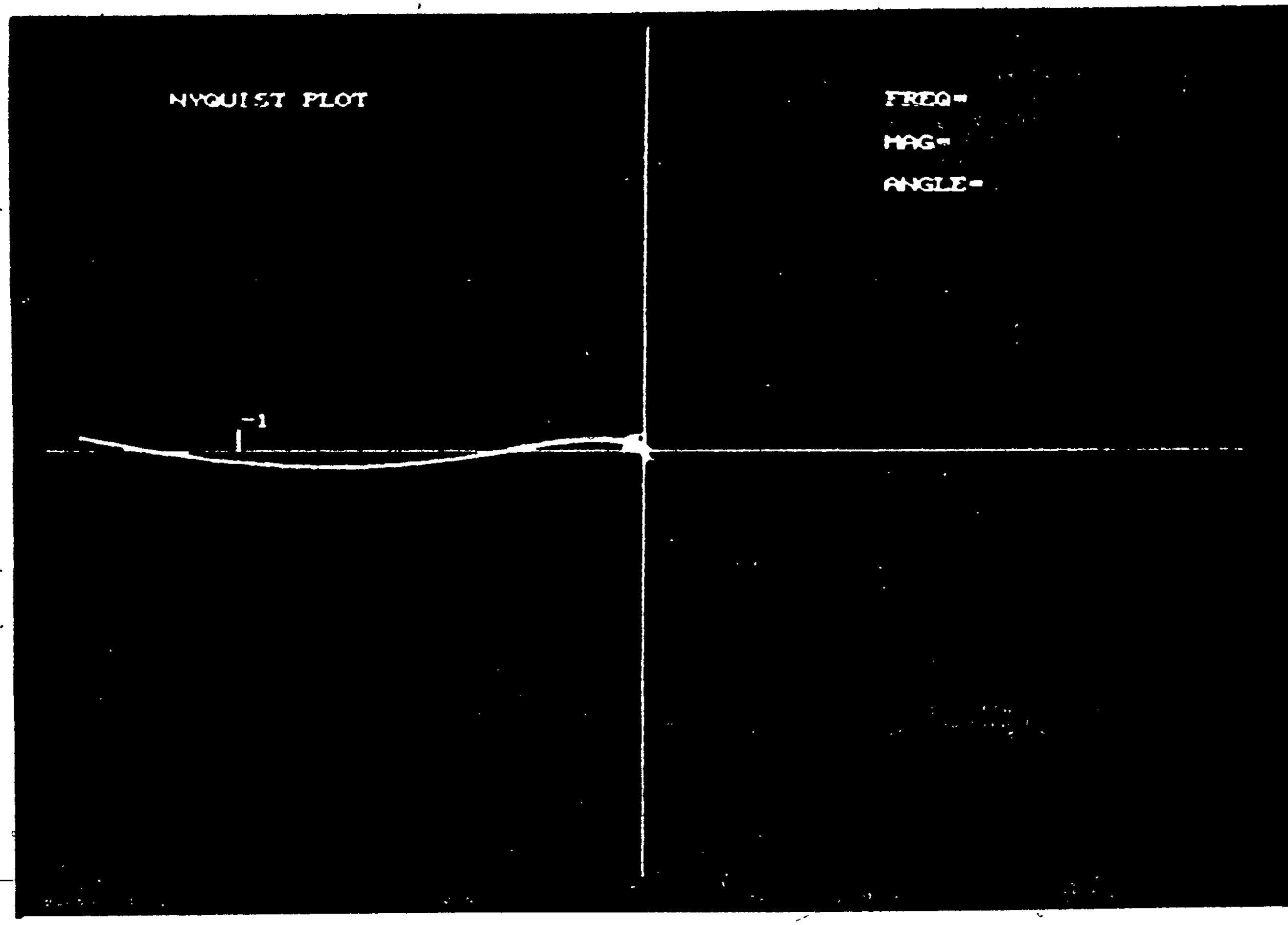


Fig. 4.38 Nyquist Plot between 1.3 and 10. rad/sec of Equation 4.1

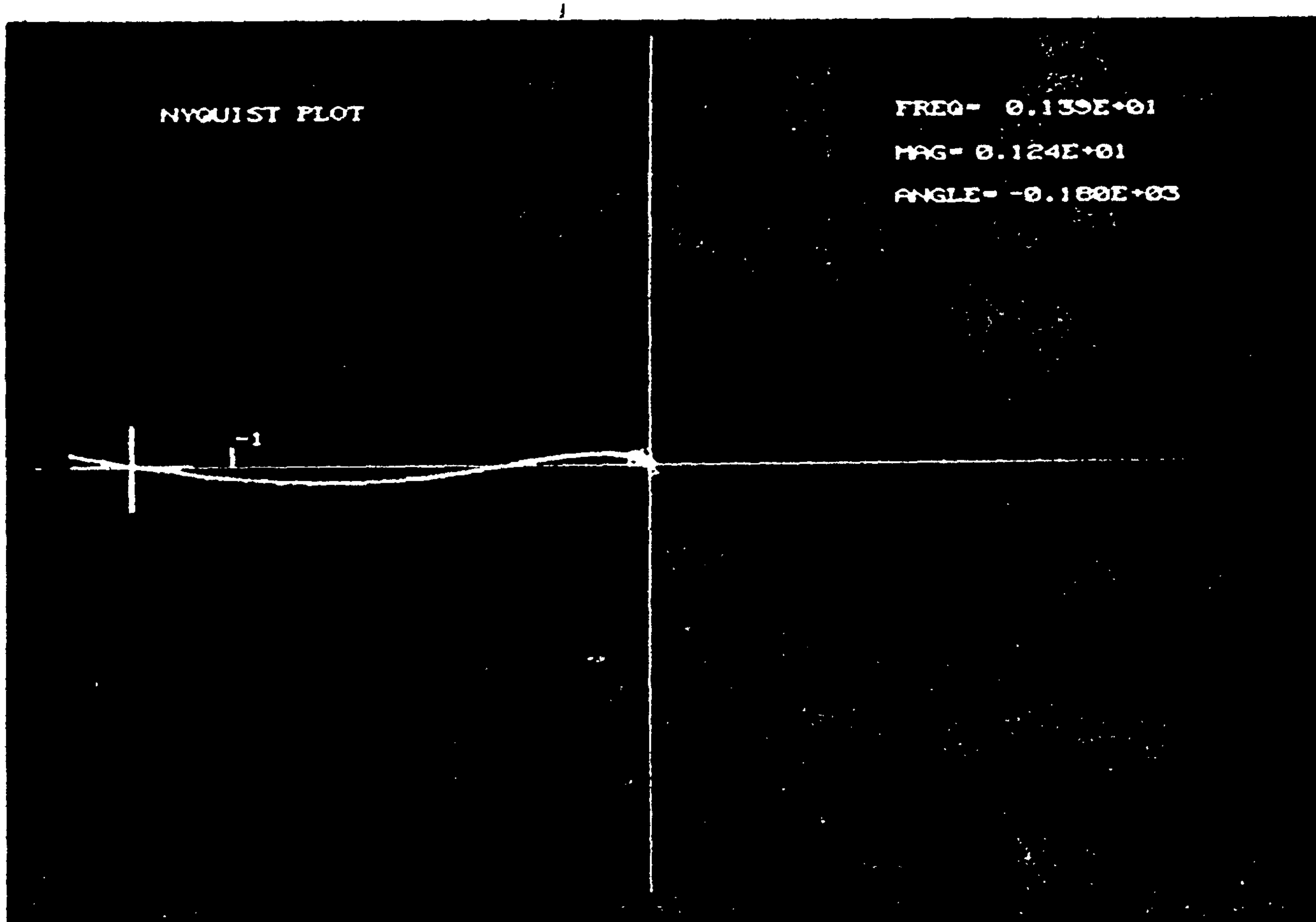


Fig. 4.39 Nyquist Plot between 1.3 and 10. rad/sec of Equation 4.1 with Cross Marker at 1.39 rad/sec

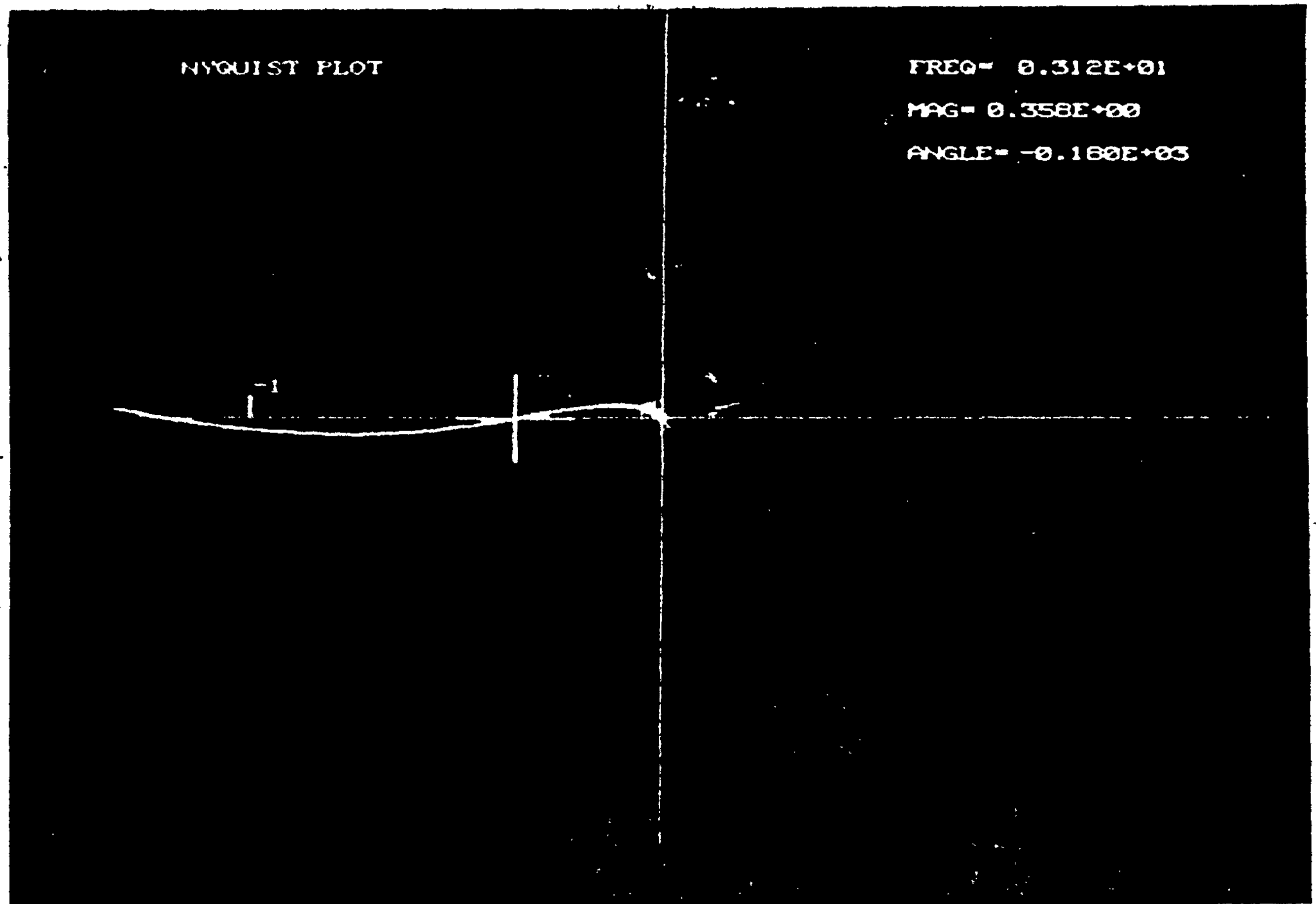


Fig. 4.40 Nyquist Plot between 1.3 and 10. rad/sec of Equation 4.1 with Cross Marker at 3.12 rad/sec

and computer interactions allowes us to perform a complete analysis in a short time by eliminating a substantial amount of manual calculations and operations.

CHAPTER 5

SUMMARY AND DISCUSSION

SUMMARY AND DISCUSSION

This thesis discusses the development and application of the CAD package LNA. This package incorporates the technique of interactive graphics in the construction of ladder networks. In addition, the response of ladder network Transfer Functions and system functions is obtained using this technique.

The LNA package consists of three programs which are as follows:

1. Program LADNET
2. Program TRANF
3. Program ANALY

The program LADNET introduces the operation of interactive graphics. This program allows the construction of ladder networks by a series of command instructions activated through a light pen. The set of commands that are contained in LADNET allows the user to perform the following operations

i) Enter and alter components anywhere on the ladder structure.

ii) Enter and alter component values individually or in a sequence.

iii) Allows the user to return to the original structure to make modifications.

iv) The ability to reset the display for constructing a new network.

The program TRANF calculates the TF and DPF of the ladder network established by the program LADNET. This program eliminates a great deal of tedious calculations involved in obtaining these functions. A scaling routine can be utilized in the program, if the ladder network to be studied is of a high order, or if unscaled component values are entered.

The program ANALY is used to study the response of ladder network TF calculated by TRANF, or the response of system functions entered by the user. The response is obtained by entering the frequency limits of interest. The user then has the option to study the response using either the Bode or Nyquist Plot. In additon, these plots can be studied in detail by a cursor or cross marker which gives the frequency, magnitude, and phase for each specific point. A printout is also available for either plot.

The LNA package is utilized in the analysis of a 10th Order Elliptic Band-Pass filter and of a system function. These examples made full use of the capabilities of the package. Starting with the Elliptic Band-Pass filter, the program LADNET has enabled us to build and enter the component values for the filter. The TF and DPF were calculated by the program TRANF. Various response curves of the filter have been obtained using the program ANALY.

Further analysis has been performed on the filter by the variation of inductor and capacitor values by 5% and -5% respectively. The new TF and DPF are obtained which then enables us to observe any changes in the response.

A system function has been studied for stability. The option of ANALY is used to enter the system function. Various Nyquist plots have been generated and these are studied in detail to obtain the stability range.

This package being quite comprehensive, can be further utilized or improved in the following ways:

1. Develop or utilize existing programs that can synthesize ladder networks and have the program LADNET display them on the CRT.

2. Using the techniques developed in LADNET and TRANF, develop programs to handle feedback components in a ladder network.

The LNA package is only a small part of what can be achieved using interactive graphics. Many more packages can be developed using this technique. Some of these packages may be as follows:

1. Develop a package to study Active Filters.

2. Develop a package to study simple electronic circuits.

3. Develop a package to construct and study Digital Filters.

This thesis has shown that interactive graphics is an invaluable tool for design or analysis of ladder networks and system functions.

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APPENDIX I

GT44 USER'S GUIDE

1.3.1 PDP-11/40 Computer

The PDP-11/40 is a 16-bit general purpose, parallel logic, microprogrammed computer using single and double operand instructions and 2's complement arithmetic. The PDP-11/40 contains a multiple word instruction processor, which can directly address up to 28K words of core memory. All communication among system components (including processor, core memory, and peripherals) is performed on a single high-speed bus, the Unibus. Because of the bus concept, all peripherals are compatible, and device-to-device transfers can be accomplished at the rate of 2.5 million words per second. All system components and peripherals are linked by the Unibus and power connectors, and all peripherals are in the basic system address space. Therefore, all instructions applied to data in memory can also be applied to data in peripheral device registers, enabling peripheral device registers to be manipulated by the processor as flexibly as memory.

Subsequent paragraphs present a brief functional description of the PDP-11/40.

1.3.1.1 Unibus – The Unibus provides high-speed communication between system components. With bidirectional data, address, and control lines, the Unibus allows data transfers to occur between all units on the bus, with control of the bus an important factor in these transfers. The fixed repertoire of bus operations is flexible enough for speed and design economy, yet provides a fixed specification for interfaces. The asynchronous nature of these operations also eases design and operation. The repertoire of bus operations is:

DATI, DATIP, DATO, DATOB – data operations
INTR, PTR (BR, NPR) – control operations

Full 16-bit words or 8-bit bytes of information can be transferred on the bus between the master and slave. The DATI, DATIP operations transfer data into the master; DATO, DATOB operations transfer data out of the master. When a device is capable of becoming bus master and requests use of the bus, it is for one of two purposes: to make a Direct Memory Access (DMA) transfer of data directly to or from another device or memory without processor intervention, or to INTeRrupt (INTR) program execution and force the processor to branch to a specific address where an interrupt service routine is located

Bus control is obtained under a Non-Processor Request (NPR) for the DMA or under a Bus Request (BR) for an INTR. A device can perform a DMA after acquiring bus control via a BR.

Requests for the bus can be made at any time on the BR and NPR lines. Transfer of bus control from one device to another is made by the processor priority arbitration logic which grants control of the bus to the device having the highest priority. NPRs are accorded higher priority than BRs. The NPRs are serviced before and immediately after Unibus data cycles, in addition to specific times during WAIT or TRAP sequences. The BRs are serviced upon completion of the current instruction if the requesting priority exceeds that of the processor.

The PDP-11/40 processor has a special role in bus control operations as it performs the priority arbitration to select the next bus master. The processor assumes bus control when no other device has control.

The Unibus originates in the processor with the M981 Internal Unibus and Terminator module, which carries the Unibus from the processor to the next system unit. All 56 Unibus signals and 17 grounds are carried in this one module. A 120-conductor Mylar cable is used to connect system units in different mounting boxes or to connect a peripheral device removed from the mounting box.

A complete description of the Unibus, including specifications, is presented in the *PDP-11 Peripherals Handbook.*

1.3.1.2 KD11-A Processor – The KD11-A Processor decodes instructions; accepts, modifies, and outputs data, performs arithmetic operations; and controls allocation of the Unibus among external devices. The processor contains sixteen hardware registers, eight of which are programmable. Two of the eight programmable registers are specifically used for processor operation: a program counter (PC) and a stack pointer (SP); the remaining six serve as arithmetic accumulators, index register, and autoincrement and autodecrement registers.

The eight non-programmable registers are used for storage of a variety of functions including intermediate address, source and destination data, a copy of the instruction register, the last interrupt vector address and console operation data.

Because of the flexibility of hardware registers, address modes, instruction set, and DMA, PDP-11/40 programs are written in directly relocatable codes. The processor also includes a full complement of instructions that manipulate byte operands and provisions for byte swapping. Either words or bytes may be displayed on the programmer's console.

Any of the eight programmable internal registers can be used to build last-in, first-out stacks. One register serves as a processor (or system) stack pointer for automatic stacking. This stack-handling capability permits save and restore of the program counter and status word in conjunction with subroutine calls and interrupts. This feature allows true reentrant codes and automatic nesting of subroutines.

The Unibus serves the processor and all peripheral devices; therefore, there must be a priority structure to determine which device becomes bus master. Generally, a device requests use of the bus for one of two reasons: to make a non-processor transfer of data directly to or from memory, or to interrupt program execution and force the processor to branch to an interrupt service routine. An NPR is granted by the processor at the end of bus cycles and allows device-to-device data transfers without processor intervention. A BR is granted by the processor at the end of an instruction and allows the device to interrupt the current processor task.

The processor recognizes four levels of hardware BRs, with each major level containing sublevels. Many devices can be attached on each major level, with the device that is electrically closest to the processor given priority over other devices on the same priority level. The priority level of the processor itself is programmable within the hardware levels; therefore, a running program can select the priority level of permissible interrupts.

Additional speed and power are added to the interrupt structure through the use of the PDP-11/40 fully vectored interrupt scheme. With vectored interrupts, the device identifies itself, and a unique interrupt service routine is automatically selected by the processor. This eliminates device polling and permits nesting of device service routines. The device interrupt priority and service routine priority are independent to allow dynamic adjustment of system behavior in response to real-time conditions.

The Unibus addresses generated by the KD11-A Processor are 18-bit direct byte addresses, even though the PDP-11/40 word length and operational logic is 16-bit word length. Thus, while the PDP-11/40 word can only contain address references up to 32K words (64K bytes), the KD11-A Processor can reference addresses up to 128K words (256K bytes).

In addition to the word length constraint on basic addressing space, the uppermost 4K words of address space are reserved for peripheral control, status, and data registers. In the basic PDP-11/40 configuration, all address references to the uppermost 4K words of 16-bit address space (160000–177777) are converted to full 18-bit references with bits 16 and 17 always set to 1. Thus, a 16-bit reference to address 173224_8 is automatically converted to a full 18-bit I/O device register address of 773224_8. Consequently, the basic PDP-11/40 configuration can address up to 28K words of core memory and 4K words of I/O device registers.

A detailed description of the KD11-A Processor is contained in the *KD11-A Processor Manual*, DEC-11-HKDAA-A-D.

1.3.1.3 KY11-D Programmer's Console – The KY11-D Programmer's Console provides the programmer with a direct system interface. The console allows the user to start, stop, load, modify, examine, step, or continue a program. Console displays indicate processor operation and the contents of the address and data registers. The console is mounted as the front panel of the processor mounting box and is connected to the processor by two cables.

The programmer's console interacts with the processor through a microprogram control located in the processor. The console contains only indicators (light-emitting diodes), switches, and the contact bounce filtering circuits for the control switches. Console operation does require certain Unibus operations through the processor: DATO for DEP and DATI for EXAM. For single-step operation, the processor responds to a Console Bus Request (CBR) whose priority supersedes all other BR priorities.

Console operation, including descriptions of all controls and indicators, is presented in Paragraph 2.1. Detailed descriptions of console logic circuits are contained in the *KD11-A Processor Manual*, DEC-11-HKDAA-A-D.

1.3.1.4 MF11-L Core Memory – The PDP-11/40 in the GT44 contains an MF11-L Core Memory with 16K word capacity. The MF11-L consists of 2 MM11-L memories mounted on a double system unit backplane. Each MM11-L is an 8K, 16-bit word memory consisting of three modules. The backplane has additional unused slots which can be used to accomodate a third optional MM11-L 8K memory.

The core memory uses the Unibus for data transfers to and from the processor and other devices. The core memory, however, is never bus master. Because of the Unibus structure, the memory can be directly addressed by the processor or any other master device. Because of double operand instructions, every location in core can function as a true arithmetic accumulator.

The memory does not enter the priority structure because it is always a slave device. The master device, however, can request use of the Unibus, and thus the memory, through either a BR or an NPR. Because the memory is completely independent of the processor, any master device can perform direct data transfers with memory without processor intervention.

1.3.1.4.1 MM11-L Core Memory – The following paragraphs briefly describe the MM11-L memories, which make up the MF11-L memory. For more detailed descriptions of the MM11-L and MF11-L memories, refer to the *MM11-S, MF11-L, and MF11-LP Core Memory Systems Manual,* DEC-11-HMFLA-B-D.

The MM11-L Core Memory is a read/write, random access, coincident current, magnetic core type memory with a cycle time of 900 ns and Unibus access time of 400 ns. The memory is organized in a 3D, 3-wire planar configuration. It provides 8192 (8K) 16-bit words that are both word and byte addressable.

The memory is organized into 16-bit words, each word containing two 8-bit bytes. The bytes are identified as the low-order byte (bits 07–00) and the high-order byte (bits 15–08). Each byte is addressable and has its own address location. Low bytes are always even numbered and high bytes are odd numbered. Full words are addressed at even-numbered locations only. When a full word is addressed, the high byte is automatically included. For example, the 8K memory has 8,192 words or 16,384 bytes; therefore, 16,384 locations are assigned. Address 000000 is the first low byte, address 000001 is the first high byte, 000002 is the second low byte, 000003 is the second high byte, etc.

The MM11-L consists of three modules: a G110 Hex module containing the memory control logic and data channels; a G231 Hex module containing the memory driver logic; and an H214 Quad module containing the memory core stack.

The memory control logic acknowledges the request of the master device, determines which of the four basic operations (DATI, DATIP, DATO, or DATOB) is to be performed, and sets up appropriate timing and control circuits to perform the desired read or write operation. It also contains the inhibit drivers and sense amplifiers as well as device selector logic to determine if the memory bank has been addressed from the Unibus. The control logic includes a 16-bit flip-flop storage register. During DATI operations, this register stores the contents of the memory location being read (destructive read) so that the data can be written back into memory (restored). The register is also used during DATO and DATOB cycles to store incoming data from the Unibus lines so that it can be written into core memory.

The memory driver logic includes: address selection logic that decodes the incoming address to determine the core specifically addressed; the switches and drivers that direct current flow through the magnetic cores to ensure the proper polarity for the desired function; and the X and Y current generators that provide the necessary current to change the state of the magnetic cores.

The ferrite core memory stack consists of 16 memory mats arranged in a planar configuration. Each mat contains 8192 ferrite cores arranged in a 128 X 64 matrix. Each mat represents a single bit position of a word. Each ferrite core can assume a stable magnetic state corresponding to either a binary 1 or binary 0. Even if power is removed from the core, the core retains its state until changed by appropriate control signals.

1.3.1.5 Power System – The PDP-11/40 power system consists of an 861 Power Controller, an H742 Power Supply, three H744 +5 V Regulators, two H745 −15 V Regulators, and interconnection and power distribution cabling.

The 861 Power Controller controls all ac power input to the processor cabinet. The controller is equipped with a circuit breaker for overload protection and a thermostat for excessive heat protection. The power controller provides switched ac outputs (uncontrolled) which provide power for the entire cabinet and related peripherals. (A second 861 Power Controller is located in the drives cabinet. The two controllers operate in parallel. The DECwriter and display monitor may be plugged into the switched output of either controller.)

The H742 Power Supply takes ac input power from the 861 Power Controller, generates and distributes dc power and control signals to the system, and provides ac power to the logic cooling fans and H744 and H745 regulators.

There are three control signals generated: a clock signal, a DC LO logic signal, and an AC LO logic signal. The clock signal is used by the VT11 Graphic Display Processor to synchronize the display. The AC LO and DC LO signals warn the processor of imminent power failure, allowing the processor time to perform a power-fail sequence.

The H744 and H745 regulators generate +5 V and −15 V outputs, respectively, which are distributed to the KD11-A Processor and MF11 L Memory backplanes and the KY11-D console. H744 +5 V also goes to the VT11 Graphic Display Processor backplane.

1.3.2 VT11 Graphic Display Processor

The VT11 Graphic Display Processor is the "heart" of the GT44 Graphics System. It is the VT11 that generates the displays and drives the CRT.

The VT11 processor consists of three hex-height modules that are mounted on a 4-slot systems unit backplane. The unit is mounted inside the PDP-11/40 cabinet.

The VT11 interfaces with the system by way of the Unibus. It obtains ±22 V power from the VR17 CRT and +5 V power from the PDP-11/40 power supply.

The VT11 is a high performance display processing unit that operates as a peripheral of the PDP-11/40. The VT11 is started by the central processor when a valid address is placed in the Display Processor Program Counter (DPC). The VT11 responds by issuing NPRs and fetching its display program from memory locations specified by the DPC. Once the display processor is granted control of the Unibus it can fetch its display program, and execute it independently.

The VT11 also issues interrupts to the central processor when it encounters an illegal character code or unresponsive memory. If enabled by program, it will issue an interrupt when instructed to stop, or when a light pen hit is sensed.

The VT11 is a stable device that requires only minimum adjustments because it employs a combination of digital and analog techniques as opposed to analog circuits alone. The vector function operates efficiently, providing a good compromise of speed and accuracy and assuring a precise vector calculation. The presentation and accumulation of vectors means that every point of a vector is available in digital form.

All beam position calculations are done digitally. After plotting each vector, the end-point position is automatically updated to the digitally calculated values, preventing accumulated errors or drift. Four different vector types — solid, long dash, short dash, and dot dash — are possible through standard hardware.

The VT11 character generator has both upper and lower case capability with a large repertoire of displayable characters. The display is the automatically refreshing type rather than the storage type so that a bright, continuous image, with excellent contrast ratio, is provided during motion or while changes are being made in the elements of the picture. A hardware blink feature is applicable to any characters or graphics drawn on the screen. A separate line clock input to the display processor permits the VT11 to be synchronized to line frequency.

The VT11 includes logic for descender characters such as *p* and *g*, positioning them correctly with respect to the text line. In addition to the 96 ASCII printing characters, 31 special characters are included which are addressed through the shift-in/shift-out control codes (Appendix A). These special characters include some Greek letters, architectural symbols, and math symbols. Characters can be drawn in italics simply by selecting the feature through the status instruction bit. Eight intensity levels permit the brightness and contrast to be varied so that the scope can be viewed in a normally lighted room

The instruction set consists of five control instructions and six data formats. The control instructions set the mode of data interpretation, set the parameters of the displayed image, and allow branching of the instruction flow. Data can be interpreted in any of six different formats, allowing multiple tasks to be accomplished efficiently from both a core usage and time standpoint. The graph/plot feature of the VT11 automatically plots the X or Y axis according to preset distances as values for the opposite axis are recorded.

For a detailed description of the VT11 Graphic Display Processor see the *VT11 Graphic Display Processor Manual*, DEC-11-HVTGA-A-D.

1.3.3 VR17 Cathode Ray Tube Monitor

The VR17 is a completely self-contained CRT display that provides a 9.25 inch by 9.25 inch viewing area in a compact package. The VR17 requires only analog X and Y position information and intensity signals to generate sharp, bright displays. Except for the CRT itself, the unit is composed of all solid state circuits, utilizing high-speed magnetic deflection to enhance brightness and resolution.

In addition, the VR17 construction is modular for easy maintenance. Any subassembly or major component can be replaced in minutes, using only a screwdriver.

For a detailed description of the VR17 CRT monitor see *VR14 and VR17 CRT Display User's Manual*, DEC-12-HVCRT-D-D.

1.3.4 375 Light Pen

The 375 Light Pen is a pencil-shaped light detector for use by the operator in a wide range of interactive applications.

The 375 uses a photosensitive transistor for high gain and fast response. In addition, an infrared doped phosphor and matching spectral response in the photo-detector used in the 375 yields very good light pen capability, without the normally attendant visual flicker of the fast phosphor component.

The 375 is connected to the VR17 by a flexible cable attached to the front panel of the CRT monitor, it is easily removed by simply unplugging it from the CRT panel. The G840 Light Pen Amplifier is situated inside the VR17 cabinet. The output of the light pen amplifier is fed to the VT11 by way of the scope cable.

1.3.5 LA30-S DECwriter and DL11 Asynchronous Line Interface

The LA30-S DECwriter is a dot-matrix impact printer and keyboard for use as a hard copy I/O terminal. It is capable of printing a set of 64 ASCII characters at speeds up to 30 characters per second on a sprocket-fed 9-7/8 inch continuous form. Data entry is from a keyboard capable of generating 128 characters.

The LA30-S is a serial asynchronous device, and therefore uses the DL11-A Asynchronous Line Interface to interface it with the Unibus. Serial information read or written by the LA30 DECwriter is assembled or disassembled by the DL11 for parallel transfer to or from the Unibus. The DL11 also formats the data from the Unibus so that it is in the format required by the LA30. The interface provides the flags that initiate these data transfers and causes a priority interrupt to indicate the availability of the LA30 DECwriter.

The DL11 transfers data via processor DATI and DATOB bus cycles. Although a DATO can be used, normal operation consists of a DATOB transfer because the LA30 DECwriter and the interface handle byte rather than word data. The interface can acquire bus control through a BR and is normally set at the BR4 priority level. Because the DL11 interface operates through an interrupt, no NPR hardware exists.

The DL11 consists of a single quad module which is installed in the processor in a Small Peripheral Controller (SPC) slot. This module contains address selection logic for decoding the incoming bus address, an interrupt control for generating the interrupt, and receiver/transmitter logic that performs the conversion and formatting functions.

The LA30 DECwriter controls and indicators are covered in Paragraph 2.1.3. A detailed description of the DECwriter is contained in the *LA30 DECwriter Maintenance Manual*, DEC-00-LA30-DD. A detailed description of the DL11 interface is presented in the *DL11 Asynchronous Line Interface Manual*, DEC-11-HDLAA-A-D.

1.3.6 RK05 Disk Drives and RK11-D Disk Drive Control

The GT44 Graphics System contains two RK05 Disk Drives. Each RK05 is a self-contained, random-access, data storage device that is especially well suited for use in small or medium size computer systems, data acquisition systems terminals, and other storage applications. Power to the disk drives is controlled by an 861 Power Controller mounted at the bottom of the drives Cabinet. Each RK05 Disk Drive has its own internal power supply.

The RK05 is a moving-head disk drive that uses RK03-KA disk cartridges for data storage. Data is stored on both sides of the disk by a pair of movable heads, which are always positioned over opposing surfaces of the same cylinder simultaneously. Each side of the disk contains 203_{10} tracks, each of which contains 12_{10} sectors capable of storing 400_8 or 256_{10} data words.

The sector format consists of 15_8 words of preamble terminating in a sync bit, followed by a one-word header, 400_8 data words, a one-word checksum, and one word of postamble. Sector pulses signal the beginning of each sector, and an index pulse indicates the last sector, that the sector following is sector 0.

The RK11 Controller and the RK05 Disk Drives form the disk drive system, which interfaces with the PDP-11/40 processor via the Unibus. One RK11 can control up to eight RK05 Disk Drives.

The RK11 contains seven 16-bit programmable hardware registers, addressed from the Unibus, that provide the software interface between the RK11 and the Unibus. Table 1 lists these registers and their addresses. (A more detailed discussion of RK11 registers is provided in Paragraph 4.2).

Table 1
RK11 Registers

Name	Abbreviation	Address
RK11 Drive Status Register	RKDS	777400
RK11 Error Register	RKER	777402
RK11 Control Status Register	RKCS	777404
RK11 Word Count Register	RKWC	777406
RK11 Bus Address Register (Current Memory Address)	RKBA	777410
RK11 Disk Address Register	RKDA	777412
RK11 Data Buffer Register	RKDB	777416

APPENDIX II

Fig.II A - Program LADNET General Organization

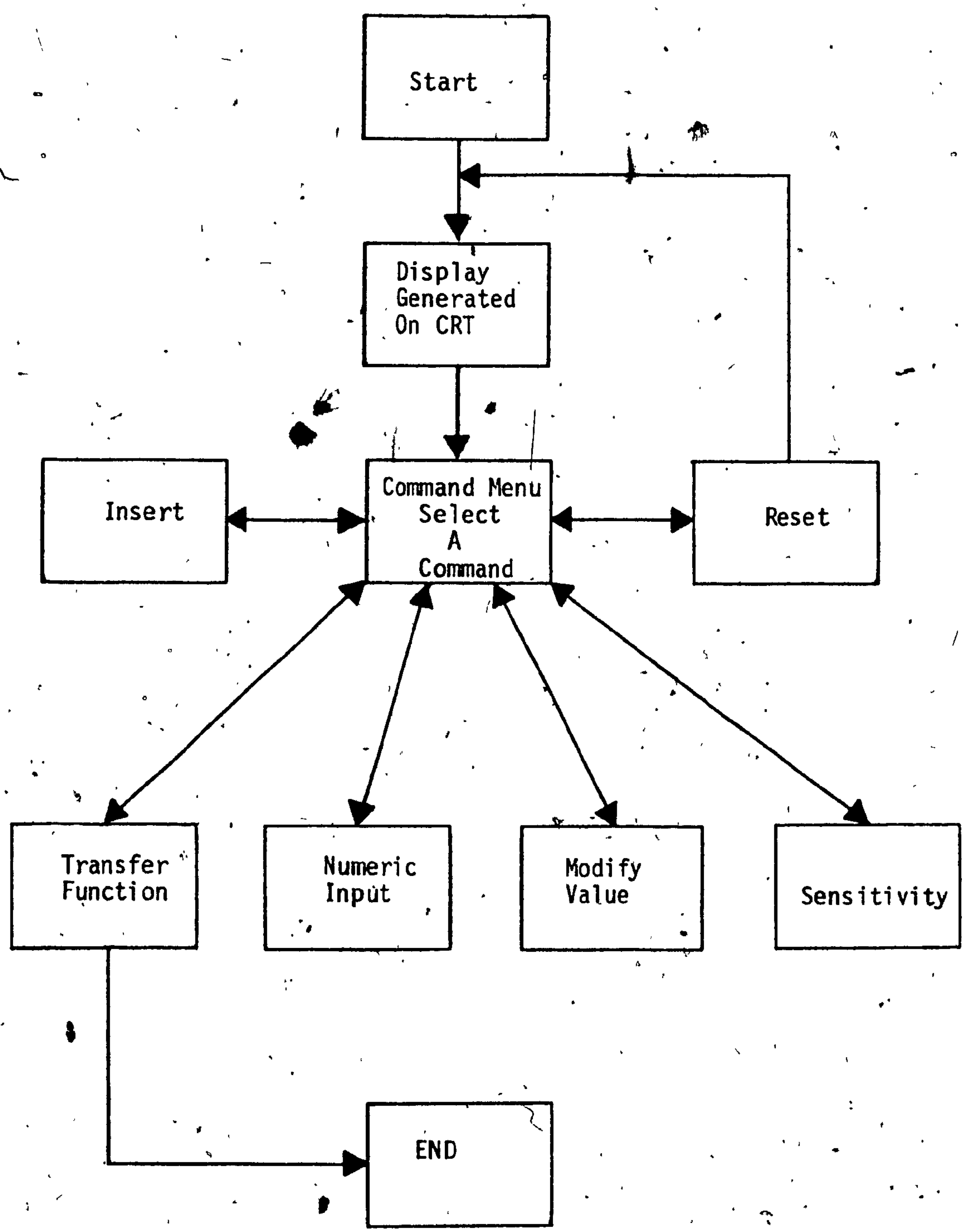


Fig. II B -Insert Command Sequence

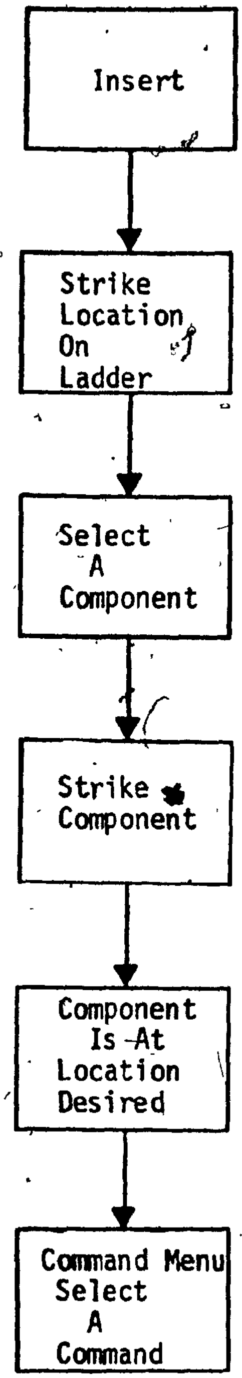


Fig. II C - Numeric Input Command Sequence

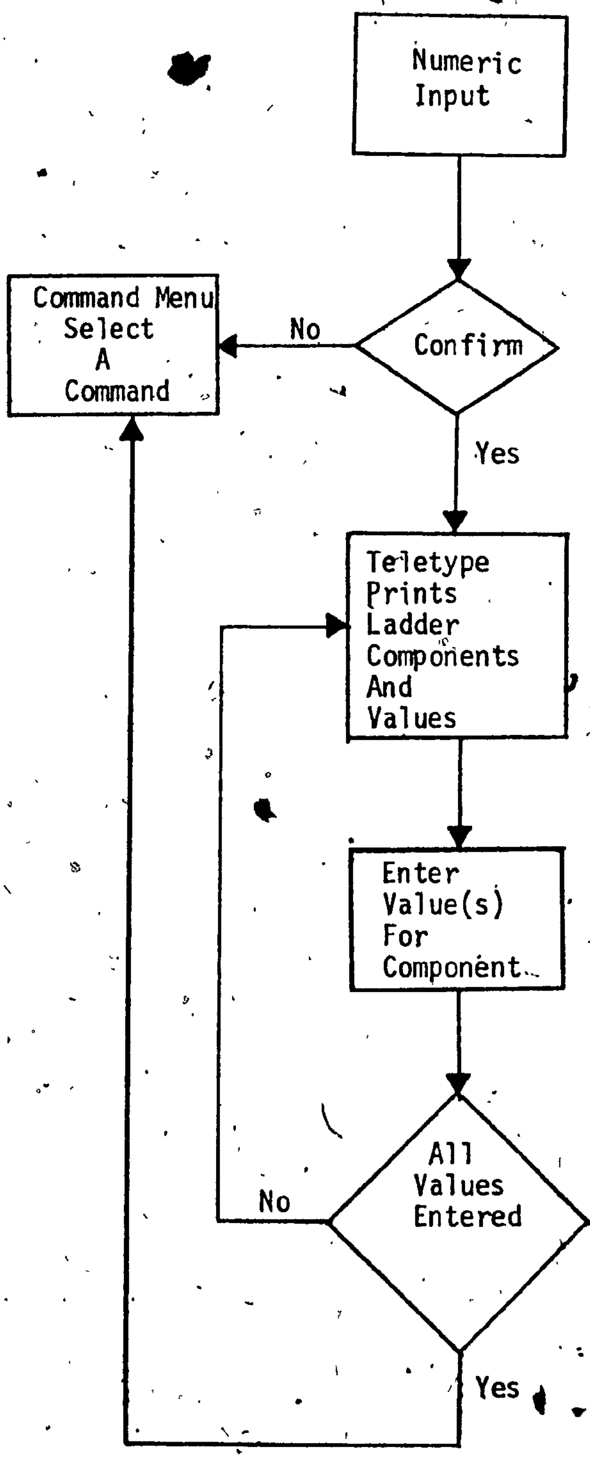


Fig. II D Transfer Function Command Sequence

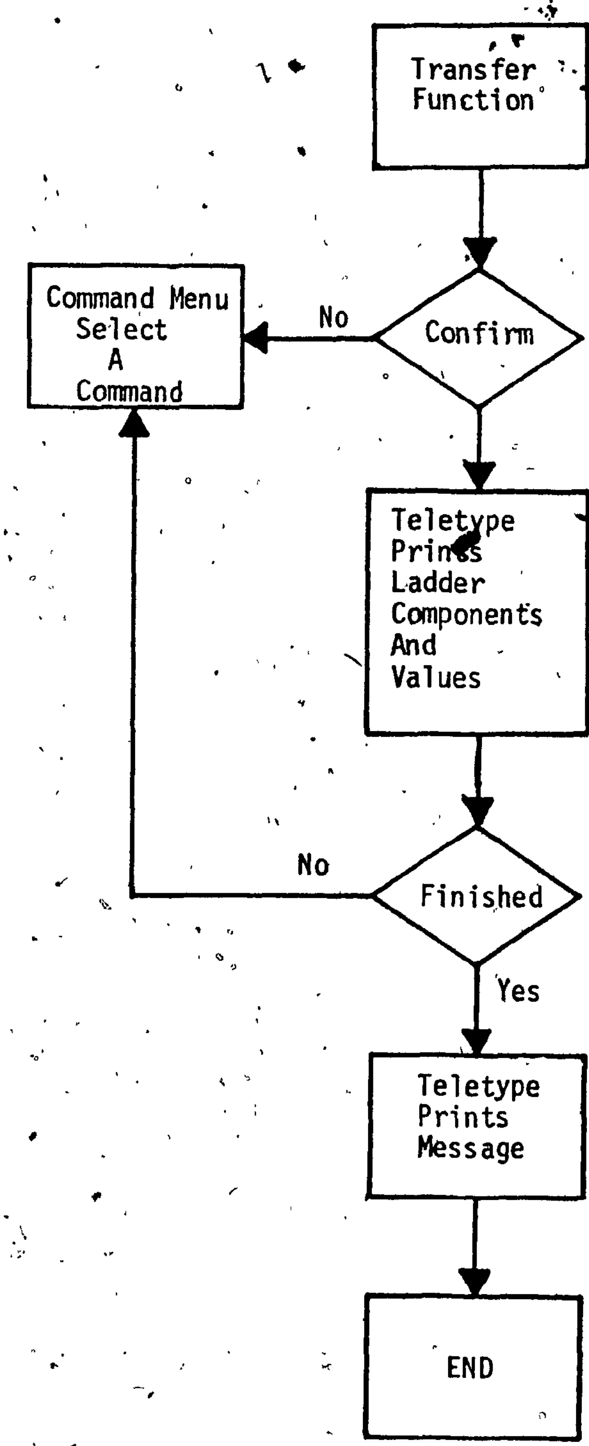


Fig. II E- Modify Value Command Sequence

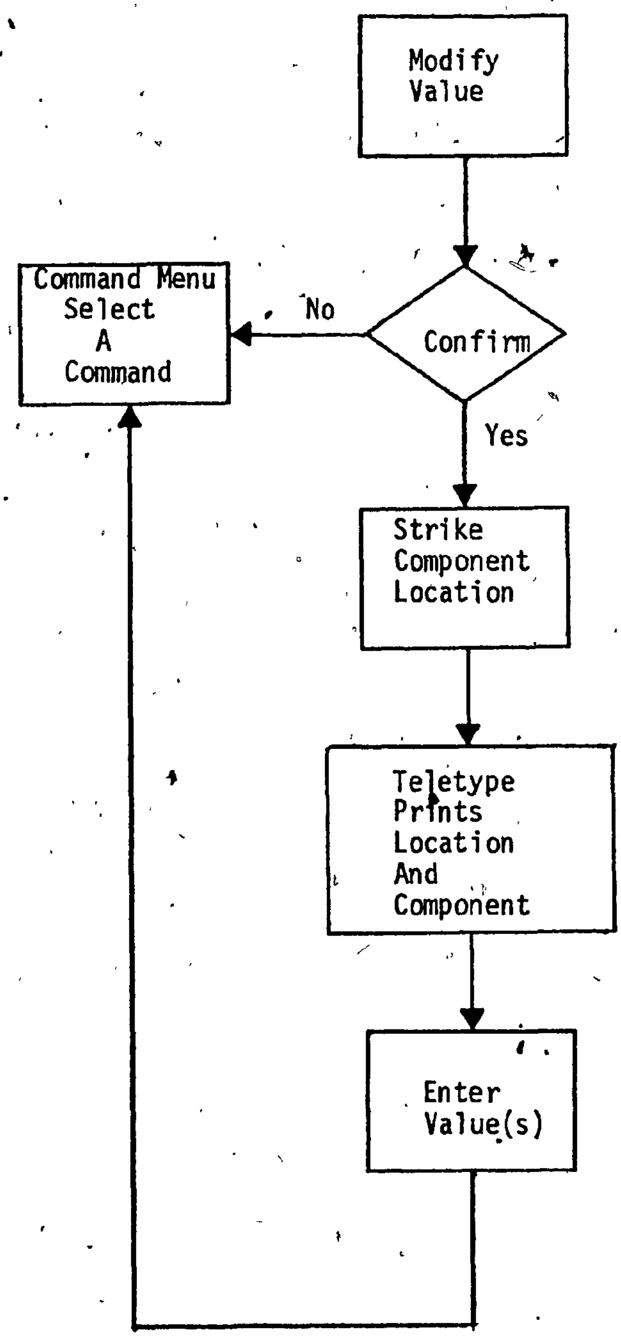


Fig. II F - Reset Command Sequence

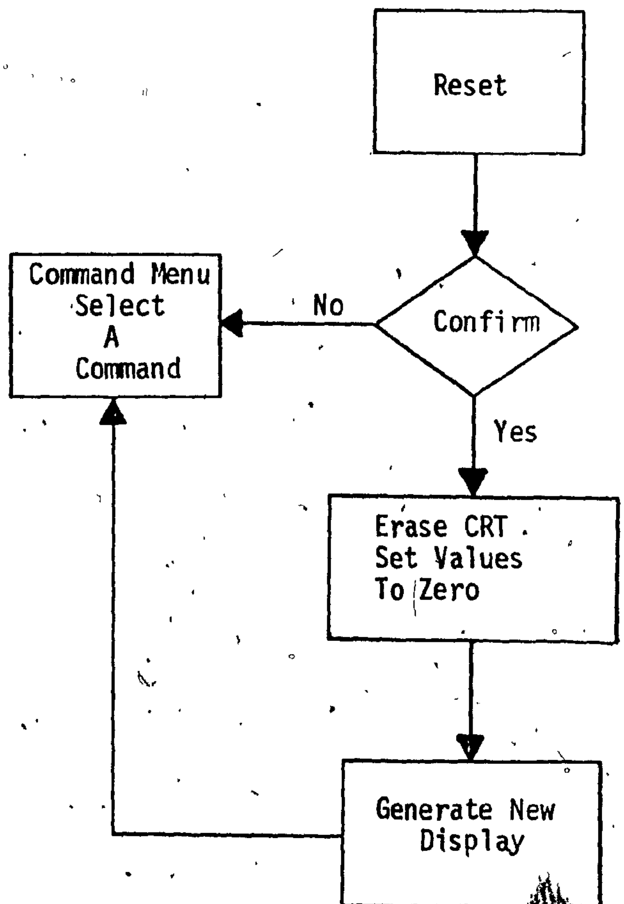
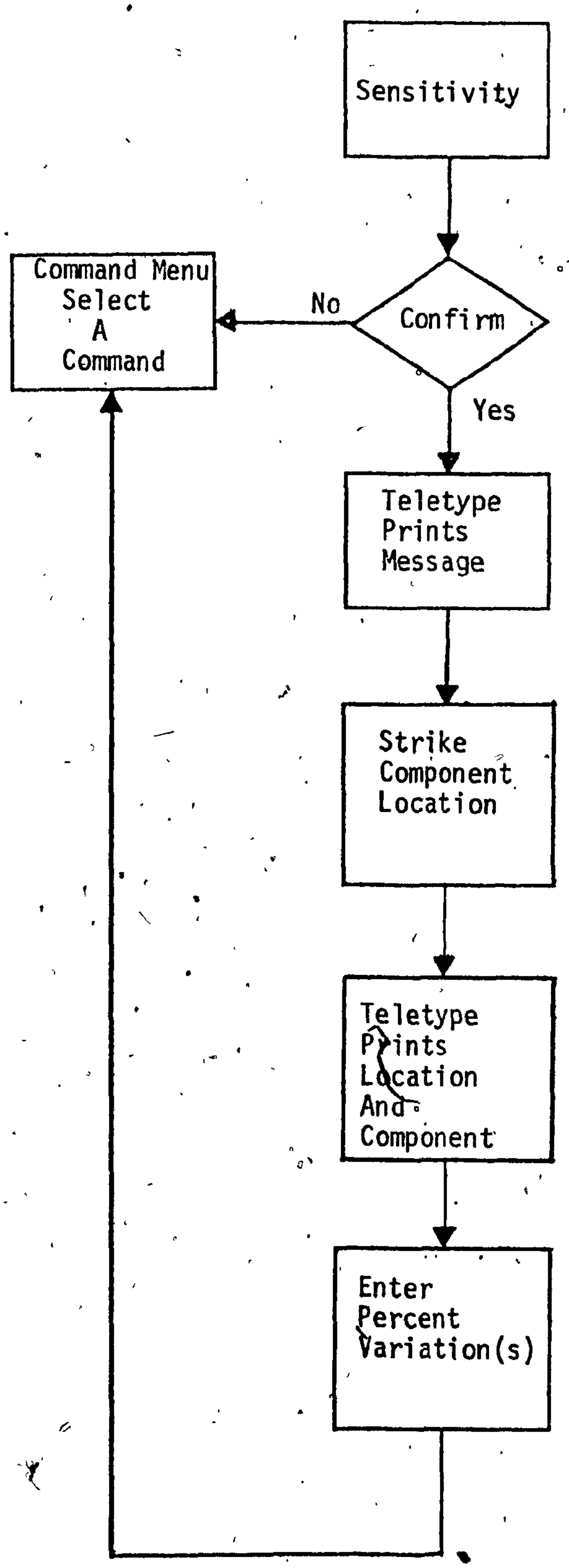


Fig. II G - Sensitivity Command Sequence



```
C     THIS IS A PROGRAM TO DEVELOPE LADDER FILTERS ON THE COMPUTER
      DIMENSION IBUF(3000),XLAD(16,3)
      CALL ASSIGN (1,'RF.1:XLAD.JM ')
      REWIND 1
      CALL ASSIGN (6,'TT.')
      DATA YES/4HYES /,NO/4HNO  /
      REAL YES,NO
1     CALL INIT (IBUF,3000)
      CALL APNT (350.,950.,0,-8)
      CALL TEXT ('LADDER NETWORK DEVELOPEMENT')
      CALL APNT(700.,500.,1,-8)
      CALL SUBP (901)
      CALL TEXT ('INSERT')
      CALL ESUB
      CALL OFF (901)
      CALL SUBP (1,901)
      CALL APNT (700.,450.,1,-8)
      CALL SUBP (902)
      CALL TEXT ('TRANSFER FUNCTION')
      CALL ESUB
      CALL OFF (902)
      CALL SUBP (2,902)
      CALL APNT (700.,400.,1,-8)
      CALL SUBP (903)
      CALL TEXT ('NUMERIC INPUT')
      CALL ESUB
      CALL OFF (903)
      CALL SUBP (3,903)
      CALL APNT (700.,350.,1,-8)
      CALL SUBP (905)
      CALL TEXT ('MODIFY VALUE')
      CALL ESUB
      CALL OFF (905)
      CALL SUBP (5,905)
      CALL APNT(700.,300.,1,-8)
      CALL SUBP(906)
      CALL TEXT('SENSITIVITY')
      CALL ESUB
      CALL OFF(906)
      CALL SUBP(6,906)
      CALL APNT(700.,250.,1,-8)
      CALL SUBP(904)
      CALL TEXT('RESET')
      CALL ESUB
      CALL OFF(904)
      CALL SUBP(4,904)
      CALL APNT (700.,200.,1,-8,1)
      CALL SUBP (1500)
      CALL TEXT ('SELECT A COMMAND')
      CALL ESUB
      CALL APNT(700.,150.,0,-8,1)
      CALL SUBP(1515)
      CALL TEXT('CONFIRM')
      CALL ESUB
      CALL OFF(1515)
      CALL APNT(825.,150.,1,-8,1)
      CALL SUBP(1516)
      CALL TEXT('YES ')
      CALL ESUB
      CALL OFF(1516)
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```
      CALL APNT(890.,150 ,1,-8,1)
      CALL SUBP(1517)
      CALL TEXT('NO')
      CALL ESUB
      CALL OFF(1517)
      CALL APNT (100.,850.,1,5,-1)
      DO 10 J=1,16,2
      LIN=J
      K=J+1
      M=(J+3)/2
      X=50.*(J+1)
      Y=100*M
      CALL APNT(X+43.,875.,0,-5)
      CALL NMBR(400+LIN,J,'I2')
      CALL APNT (X,850.,1,5,-1,1)
      CALL SUBP (J+200)
      CALL VECT (100.,0.,1,5,-1,1)
      CALL ESUB
      CALL APNT (Y,850.,1,5,-1,1)
      CALL SUBP (K+200)
      CALL VECT (0.,-200.,1,5,-1,1)
      CALL ESUB
      CALL APNT(Y+10.,670.,0,-5)
      CALL NMBR(500+K,K,'I2')
10    CONTINUE
      CALL APNT (100.,650.)
      DO 11 J=1,8
      CALL SUBP (J+922)
      CALL VECT (100.,0.,0,5)
      CALL ESUB
11    CONTINUE
      CALL APNT (900.,850.,0,5)
      CALL SUBP (931)
      CALL VECT (50.,0.,0,5)
      CALL ESUB
      CALL OFF (931)
      CALL SUBP (525,931)
      CALL APNT (900.,650.,0,5)
      CALL SUBP (932)
      CALL VECT (50.,0.,0,5)
      CALL ESUB
      CALL OFF (932)
      CALL SUBP (526,932)
      CALL APNT (100.,500.,1,-5)
      CALL SUBP (933)
      CALL HRES
      CALL ESUB
      CALL OFF (933)
      CALL SUBP (101,933)
      CALL APNT (250.,500.,1,-5)
      CALL SUBP (934)
      CALL HCAPAC
      CALL ESUB
      CALL OFF (934)
      CALL SUBP (102,934)
      CALL APNT (400.,500.,1,-5)
      CALL SUBP (935)
      CALL HINDUC
      CALL ESUB
      CALL OFF (935)
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CALL SUBP (103,935)
CALL APNT (100.,400.,1,-5)
CALL SUBP (937)
CALL HPLC
CALL ESUB
CALL OFF (937)
CALL SUBP (105,937)
CALL APNT (250.,400.,1,-5)
CALL SUBP (938)
CALL HSLC
CALL ESUB
CALL OFF (938)
CALL SUBP (106,938)
CALL APNT (400.,400.,1,-5)
CALL SUBP (939)
CALL HIMCAP
CALL ESUB
CALL OFF (939)
CALL SUBP (107,939)
CALL APNT (100.,300.,1,-5)
CALL SUBP (940)
CALL HIMIND
CALL ESUB
CALL OFF (940)
CALL SUBP (108,940)
CALL APNT (250.,300.,1,-5)
CALL SUBP (941)
CALL HOCIR
CALL ESUB
CALL OFF (941)
CALL SUBP (109,941)
CALL APNT (400.,300.,1,-5)
CALL SUBP (936)
CALL VECT (100.,0.,1,5,0,1)
CALL ESUB
CALL OFF (936)
CALL SUBP (104,936)
CALL APNT (100.,200.,1,-5)
CALL SUBP (951)
CALL HSRC
CALL ESUB
CALL OFF (951)
CALL SUBP (110,951)
CALL APNT (250.,200.,1,-5)
CALL SUBP (952)
CALL HPRL
CALL ESUB
CALL OFF (952)
CALL SUBP (111,952)
CALL APNT (100.,500.,1,-5)
CALL SUBP (942)
CALL VRES
CALL ESUB
CALL OFF (942)
CALL SUBP (112,942)
CALL OFF (112)
CALL APNT (250.,500.,1,-5)
CALL SUBP (943)
CALL VCAPAC
CALL ESUB
```

```
CALL OFF (943)
CALL SUBP (113,943)
CALL OFF (113)
CALL APNT (400.,500.,1,-5)
CALL SUBP (944)
CALL VIND
CALL ESUB
CALL OFF (944)
CALL SUBP (114,944)
CALL OFF (114)
CALL APNT (100.,450.,1,-5)
CALL SUBP (946)
CALL VPLC
CALL ESUB
CALL OFF (946)
CALL SUBP (116,946)
CALL OFF (116)
CALL APNT (250.,450.,1,-5)
CALL SUBP (947)
CALL VSLC
CALL ESUB
CALL OFF (947)
CALL SUBP (117,947)
CALL OFF (117)
CALL APNT (400.,450.,1,-5)
CALL SUBP (948)
CALL VIMIND
CALL ESUB
CALL OFF (948)
CALL SUBP (119,948)
CALL OFF (119)
CALL APNT (100.,400.,1,-5)
CALL SUBP (949)
CALL VIMCAP
CALL ESUB
CALL OFF (949)
CALL SUBP (118,949)
CALL OFF (118)
CALL APNT (250.,400.,1,-5)
CALL SUBP (950)
CALL VOPCIR
CALL ESUB
CALL OFF (950)
CALL SUBP (120,950)
CALL OFF (120)
CALL APNT (400.,400.,1,-5)
CALL SUBP (945)
CALL VECT (0.,200.,1,5,0,1)
CALL ESUB
CALL OFF (945)
CALL SUBP (115,945)
CALL OFF (115)
CALL APNT (100.,200.,1,-5)
CALL SUBP (953)
CALL VSRC
CALL ESUB
CALL OFF (953)
CALL SUBP (121,953)
CALL OFF (121)
CALL APNT (250.,200.,1,-5)
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      CALL SUBP (954)
      CALL VPRL
      CALL ESUB
      CALL OFF (954)
      CALL SUBP (122,954)
      CALL OFF (122)
      CALL APNT (700.,200.,1,-8,1)
      CALL SUBP (1501)
      CALL TEXT ('LOCATION')
      CALL ESUB
      CALL OFF(1501)
      CALL APNT (700.,200.,1,-8,1)
      CALL SUBP (1502)
      CALL TEXT ('WHICH COMPONENT')
      CALL ESUB
      CALL OFF (1502)
      DO 18 J=1,3
      DO 18 J1=1,16
      READ(1,16,END=21)XLAD(J1,J)
16    FORMAT(E16.8)
18    CONTINUE
21    REWIND 1
      DO 50 J=1,16
      IF(XLAD(J,1)-100.LE.0.)GO TO 120
      IF((J/2)*2.EQ.J)GO TO 35
      X=50*(J+1)
      N=J+200
      L=XLAD(J,1)
      CALL APNT(X,850.,1,-8,-1)
      CALL ERAS(J+200)
      CALL SUBP(N,L)
      GO TO 50
35    LL=XLAD(J,1)+11
      K=J
      N=K+200
      M=(J+3)/2
      Y=100.*M
      CALL APNT(Y,650.,1,-8,-1)
      CALL ERAS(K+200)
      CALL SUBP(N,LL)
50    CONTINUE
120   CALL LPEN (M,N,X,Y)
      IF (M.EQ.0)GO TO 120
      IF (N.LT.100.AND.N.GT.0) GO TO 135
      GO TO 120
135   GO TO (140,1200,475,400,790,1800)'N
140   CALL ERAS (N)
      X=700.
      CALL APNT (X,Y,1,-8,1)
      CALL SUBP (1,901)
      CALL APNT (700.,200.,1,-8,1)
      CALL OFF (1500)
      CALL ON (1501)
150   CALL LPEN (M,N,X,Y)
      IF (M.EQ.0)GO TO 150
      IF (N.LE.200.OR.N.GT.300)GO TO 150
      IF(N/2*2.EQ.N)GO TO 160
      Y=850
      LL=(N-200)/2
      X=100+LL*100
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      GO TO 180
160   Y=650.
      X=100+(N-200)*50
180   J=N
      J1=J-200
      CALL ERAS (N)
      CALL APNT (700. , 200. , 1, -8, 1)
      CALL OFF (1501)
      CALL ON (1502)
200   CALL LPEN (M, N)
      IF (M. EQ. 0) GO TO 200
      IF (N. GT. 125. OR. N. LE. 100) GO TO 200
      IF (J/2*2. EQ. J)GO TO 250
      CALL APNT (X, Y, 1, -5, -8, 0)
      CALL SUBP (J, N)
      XLAD(J1, 1)=N
      GO TO 290
250   CALL APNT (X, Y, 1, -5, -8, 0)
      CALL SUBP (J, N+11)
      XLAD(J1, 1)=N
290   CALL APNT (700. , 500. , 1, -8, -5)
      CALL ERAS (1)
      CALL SUBP (1, 901)
      CALL APNT (700. , 200. , 1, -8, 1)
      CALL OFF (1502)
      CALL ON (1500)
      GO TO 120
400   CALL ERAS(N)
      CALL APNT(700. , 250. , 0, -8, 1)
      CALL SUBP(4, 904)
      CALL APNT (800. , 250. , -1, -8, 1)
      CALL SUBP (1505)
      CALL TEXT ('CONFIRM')
      CALL ESUB
      CALL APNT (925. , 250. , 1, -8, 1)
      CALL SUBP (1506)
      CALL TEXT ('YES')
      CALL ESUB
      CALL APNT (990. , 250. , 1, -8, 1)
      CALL SUBP (1507)
      CALL TEXT ('NO')
      CALL ESUB
      CALL APNT(700. , 200. , 0, -8)
      CALL OFF(1500)
455   CALL LPEN (M, N)
      IF (M. EQ. 0)GO TO 455
      IF (N. EQ. 1506. OR. N. EQ. 1507)GO TO 460
      GO TO 455
460   CALL ERAS (1505)
      CALL ERAS (1506)
      CALL ERAS (1507)
      IF(N. EQ. 1507)GO TO 470
      IF(N. EQ. 1506)GO TO 1050
470   CALL APNT(700. , 250. , 1, -8, -1)
      CALL ERAS(4)
      CALL SUBP(4, 904)
      CALL APNT(700. , 200. , 0, -8, 1)
      CALL ON(1500)
      GO TO 120
475   CALL APNT (700. , 400. , 0, -8, 1)
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      CALL ERAS(N)
      CALL SUBP(3,903)
      CALL APNT(700.,200.,0,-8)
      CALL OFF(1500)
      CALL APNT(700.,150.,-1,-8,1)
      CALL ON(1515)
      CALL APNT(825.,150.,1,-8,1)
      CALL ON(1516)
      CALL APNT(890.,150.,1,-8,1)
      CALL ON(1517)
500   CALL LPEN(M,N)
      IF(M.EQ.0)GO TO 500
      IF(N.EQ.1516.OR.N.EQ.1517)GO TO 502
      GO TO 500
502   CALL OFF(1515)
      CALL OFF(1516)
      CALL OFF(1517)
      IF(N.EQ.1517)GO TO 760
      IF(N.EQ.1516)GO TO 508
508   DO 750 J=1,16
      IF(J/2*2.EQ.J) GO TO 515
      WRITE (6,510) J
510   FORMAT (2X,'LOCATION',1X,I2,1X,' IS A SERIES ARM ',/)
      GO TO 535
515   WRITE (6,520) J
520   FORMAT (2X,'LOCATION',1X,I2,1X,' IS A SHUNT ARM ',/)
530   FORMAT (F25.10)
535   KK=XLAD(J,1)-100
      IF(KK.GT.0)GO TO 575
      WRITE(6,565)
565   FORMAT(2X,'*****WARNING NO ELEMENT WAS INSERTED*****',//)
      GO TO 760
575   GO TO (610,620,630,640,650,660,670,680,690,700,710)KK
610   WRITE (6,611)
611   FORMAT (2X,'ELEMENT IS A RESISTOR ',/,2X,'ENTER THE VALUE YOU
     1 WANT IN KILO-OHMS ',/,2X,'VALUE(KILO-OHMS)= ',$)
      READ (6,530) XLAD(J,2)
      GO TO 750
620   WRITE(6,621)
621   FORMAT(2X,' ELEMENT IS A CAPACITOR ',/,2X,'ENTER THE VALUE YOU
     1 WANT IN MICRO-FARADS ',/,2X,'VALUE(MICRO-FARADS)= ',$)
      READ (6,530)XLAD(J,2)
      GO TO 750
630   WRITE (6,631)
631   FORMAT (2X,'ELEMENT IS AN INDUCTOR ',/,2X,'ENTER THE VALUE YOU
     1 WANT IN MILLI-HENRIES ',/,2X,'VALUE(MILLI-HENRIES)= ',$)
      READ (6,530) XLAD(J,2)
      GO TO 750
640   WRITE (6,641)
641   FORMAT (2X,'THIS IS A SHORT CIRCUIT WHOSE IMPEDANCE IS = 0.0 ',/)
      XLAD(J,2)=0.0
      GO TO 750
650   WRITE (6,651)
651   FORMAT (2X,'ELEMENTS COMBINATION PARALLEL INDUCTOR AND CAPACITOR'
     1 ,/,2X,'ENTER VALUE FOR INDUCTOR',/,2X,'VALUE(MILLI-HENRIES)= ',$)
      READ(6,530)XLAD(J,2)
      WRITE (6,652)
652   FORMAT(2X,'ENTER VALUE FOR CAPACITOR',/,2X,'VALUE(MICRO-FARADS)=
     1 ',$)
      READ (6,530)XLAD(J,3)
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```
      GO TO 750
660   WRITE(6,661)
661   FORMAT(2X,'ELEMENTS COMBINATION SERIES INDUCTOR AND CAPACITOR',/,
     1 2X,'ENTER VALUE FOR INDUCTOR',/,2X,'VALUE(MILLI-HENRIES)= ',$)
      READ (6,530)XLAD(J,2)
      WRITE(6,662)
662   FORMAT (2X,'ENTER VALUE FOR CAPACITOR',/,2X,'VALUE(MICRO-FARADS)=
     1 ',$)
      READ (6,530)XLAD(J,3)
      GO TO 750
670   WRITE(6,671)
671   FORMAT(2X,'ELEMENTS COMBINATION PARALLEL RESISTOR AND CAPACITOR',
     1 /,2X,'ENTER VALUE FOR RESISTOR',/,2X,'VALUE(KILO-OHMS)= ',$)
      READ(6,530)XLAD(J,2)
      WRITE(6,672)
672   FORMAT(2X,'ENTER VALUE FOR CAPACITOR',/,2X,'VALUE(MICRO-FARADS)=
     1 ',$)
      READ(6,530)XLAD(J,3)
      GO TO 750
680   WRITE(6,681)
681   FORMAT(2X,'ELEMENTS COMBINATION SERIES RESISTOR AND INDUCTOR',/,
     1 2X,'ENTER VALUE FOR RESISTOR',/,2X,'VALUE(KILO-OHMS)= ',$)
      READ(6,530)XLAD(J,2)
      WRITE(6,682)
682   FORMAT(2X,'ENTER VALUE FOR INDUCTOR',/,2X,'VALUE(MILLI-HENRIES)=
     1 ',$)
      READ(6,530)XLAD(J,3)
      GO TO 750
690   WRITE(6,691)
691   FORMAT(2X,'THIS IS AN OPEN CIRCUIT WHOSE ADMITTANCE IS= 0.0',/)
      XLAD(J,2)=0
      GO TO 750
700   WRITE(6,701)
701   FORMAT(2X,'ELEMENTS COMBINATION SERIES RESISTOR AND CAPACITOR',/,
     1 2X,'ENTER VALUE FOR RESISTOR',/,2X,'VALUE(KILO-OHMS)= ',$)
      READ(6,530)XLAD(J,2)
      WRITE(6,702)
702   FORMAT(2X,'ENTER VALUE FOR CAPACITOR',/,2X,'VAULE(MICRO-FARADS)=
     1 ',$)
      READ(6,530)XLAD(J,3)
      GO TO 750
710   WRITE(6,711)
711   FORMAT(2X,'ELEMENTS COMBINATION PARALLEL RESISTOR AND INDUCTOR',/
     1 ,2X,'VALUE(KILO-OHMS)= ',$)
      READ(6,530)XLAD(J,2)
      WRITE(6,712)
712   FORMAT(2X,'ENTER VAULE FOR INDUCTOR',/,2X,'VALUE(MILLI-HENRIES)=
     1 ',$)
      READ(6,530)XLAD(J,3)
750   CONTINUE
760   CALL APNT(700.,200.,0,-8,1)
      CALL ON (1500)
      CALL APNT(700.,400.,1,-8,-5)
      CALL ERAS(3)
      CALL SUBP(3,903)
      GO TO 120
790   CALL ERAS(N)
      CALL APNT(700.,350.,-8,-8,1)
      CALL SUBP(5,905)
      CALL APNT(700.,200.,0,-8,1)
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      CALL OFF (1500)
      CALL APNT(700 ,150. ,0,-8,1)
      CALL ON (1515)
      CALL APNT(825. ,150. ,1,-8,1)
      CALL ON (1516)
      CALL APNT(850 ,150. ,1,-8,1)
      CALL ON (1517)
791   CALL LPEN(M,N)
      IF(M EQ. 0)GO TO 791
      IF(N EQ 1516 OR N EQ. 1517)GO TO 792
      GO TO 791
792   CALL OFF(1515)
      CALL OFF(1516)
      CALL OFF(1517)
      IF(N EQ 1517)GO TO 795
      GO TO 800
795   CALL APNT(700 ,200. ,0,-8,1)
      CALL ON (1500)
      CALL APNT(700 ,350. ,1,-8,-5)
      CALL ERAS(5)
      CALL SUBP(5,905)
      GO TO 120
800   CALL ON(1501)
801   CALL LPEN(M,N)
      IF(M EQ. 0)GO TO 801
      IF(N. LE, 200 OR. N. GT. 300)GO TO 801
      JOJ=N-200
      IF((JOJ/2)*2. EQ. JOJ)GO TO 820
      WRITE(6,510)JOJ
      GO TO 850
820   WRITE(6,520)JOJ
830   FORMAT(F25. 10)
850   KIK=XLAD(JOJ,1)-100.
      IF(KIK. GT. 0)GO TO 875
      WRITE(6,565)
      GO TO 1020
875   GO TO (910,920,930,940,950,960,970,980,990,1000,1010)KIK
910   WRITE(6,611)
      READ(6,830)XLAD(JOJ,2)
      GO TO 1020
920   WRITE(6,621)
      READ(6,830)XLAD(JOJ,2)
      GO TO 1020
930   WRITE(6,631)
      READ(6,830)XLAD(JOJ,2)
      GO TO 1020
940   WRITE(6,641)
      XLAD(JOJ,2)=0.0
      GO TO 1020
950   WRITE(6,651)
      READ(6,830)XLAD(JOJ,2)
      WRITE(6,652)
      READ(6,830)XLAD(JOJ,3)
      GO TO 1020
960   WRITE(6,661)
      READ(6,830)XLAD(JOJ,2)
      WRITE(6,662)
      READ(6,830)XLAD(JOJ,3)
      GO TO 1020
970   WRITE(6,671)
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      READ(6,830)XLAD(JOJ,2)
      WRITE(6,672)
      READ(6,830)XLAD(JOJ,3)
      GO TO 1020
980   WRITE(6,681)
      READ(6,830)XLAD(JOJ,2)
      WRITE(6,682)
      READ(6,830)XLAD(JOJ,3)
      GO TO 1020
990   WRITE(6,691)
      XLAD(JOJ,2)=0.0
      GO TO 1020
1000  WRITE(6,701)
      READ(6,830)XLAD(JOJ,2)
      WRITE(6,702)
      READ(6,830)XLAD(JOJ,3)
      GO TO 1020
1010  WRITE(6,711)
      READ(6,830)XLAD(JOJ,2)
      WRITE(6,712)
      READ(6,830)XLAD(JOJ,3)
1020  CALL APNT(700.,350.,0,-8)
      CALL ERAS(5)
      CALL APNT(700.,350.,1,-8,-5,0)
      CALL SUBP(5,905)
      CALL APNT(700.,200.,0,-8,1)
      CALL OFF (1501)
      CALL ON (1500)
      GO TO 120
1050  DO 1100 KILL=1,3000
      CALL ERAS(KILL)
1100  CONTINUE
      DO 1110 J=1,3
      DO 1110 J1=1,16
      XLAD(J1,J)=0.0
      WRITE(1,1105)XLAD(J1,J)
1105  FORMAT(E16.8)
1110  CONTINUE
      REWIND 1
      GO TO 1
1200  CALL APNT(700.,450.,0,-8,1)
      CALL ERAS(N)
      CALL SUBP(2,902)
      CALL APNT(700.,200.,0,-8)
      CALL OFF(1500)
      CALL APNT(700.,150.,-1,-8,1)
      CALL ON(1515)
      CALL APNT(825.,150.,1,-8,1)
      CALL ON(1516)
      CALL APNT(890.,150.,1,-8,1)
      CALL ON(1517)
1201  CALL LBEN(M,N)
      IF(M.EQ.0)GO TO 1201
      IF(N.EQ.1516.OR.N.EQ.1517)GO TO 1202
      GO TO 1201
1202  CALL OFF(1515)
      CALL OFF(1516)
      CALL OFF(1517)
      IF(N.EQ.1517)GO TO 1210
      IF(N.EQ.1516)GO TO 1215
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1210      CALL APNI(700 ,450 ,1,-8,-1)
          CALL ERAS(2)
          CALL SUBP(2,902)
          CALL APNI(700.,200 ,0,-8,1)
          CALL ON (1500)
          GO TO 120
1215      WRITE(6,1205)
1205      FORMAT(30X,'*****LADDER ELEMENTS AND VALUES*****'//)
          DO 1450 J=1,16
          IF(XLAD(J,1)-100 .LE. 0. )GO TO 1425
          IF((J/2)*2.EQ.J)GO TO 1270
          WRITE(6,1265)J
1265      FORMAT(2X,'LOCATION',1X,I2,1X,'IS A SERIES ARM')
          GO TO 1290
1270      WRITE(6,1280)J
1280      FORMAT(2X,'LOCATION',1X,I2,1X,'IS A SHUNT ARM')
1290      KLK=XLAD(J,1)-100
          IF(KLK .GT. 0)GO TO 1295
          GO TO 1425
1295      GO TO (1310,1320,1330,1340,1350,1360,1370,1380,1390,1400,1410)KLK
1310      WRITE(6,1311)XLAD(J,2)
1311      FORMAT(2X,'ELEMENT IS A RESISTOR',/,2X,'VALUE(KILO-OHMS)=',
     1    1PE16.8,/)
          GO TO 1450
1320      WRITE(6,1321)XLAD(J,2)
1321      FORMAT(2X,'ELEMENT IS A CAPACITOR',/,2X,'VALUE(MICRO-FARADS)=',
     1    1PE16.8,/)
          GO TO 1450
1330      WRITE(6,1331)XLAD(J,2)
1331      FORMAT(2X,'ELEMENT IS AN INDUCTOR',/,2X,'VALUE(MILLI-HENERIES)=',
     1    1PE16.8,/)
          GO TO 1450
1340      XLAD(J,2)=0.0
          WRITE(6,1341)
1341      FORMAT(2X,'THIS IS A SHORT CIRCUIT WHOSE IMPEDANCE IS =0.0',/)
          GO TO 1450
1350      WRITE(6,1351)XLAD(J,2)
1351      FORMAT(2X,'ELEMENTS COMBINATION PARALLEL INDUCTOR AND CAPACITOR',
     1    /,2X,'VALUE(MILLI-HENERIES)=',1PE16.8)
          WRITE(6,1352)XLAD(J,3)
1352      FORMAT(2X,'VALUE(MICRO-FARADS)=',1PE16.8,/)
          GO TO 1450
1360      WRITE(6,1361)XLAD(J,2)
1361      FORMAT(2X,'ELEMENTS COMBINATION SERIES INDUCTOR AND CAPACITOR',/,
     1    2X,'VALUE(MILLI-HENERIES)=',1PE16.8)
          WRITE(6,1362)XLAD(J,3)
1362      FORMAT(2X,'VALUE(MICRO-FARADS)=',1PE16.8,/)
          GO TO 1450
1370      WRITE(6,1371)XLAD(J,2)
1371      FORMAT(2X,'ELEMENTS COMBINATION PARALLEL RESISTOR AND CAPACITOR'/
     1    ,2X,'VALUE(KILO-OHMS)=',1PE16.8)
          WRITE(6,1372)XLAD(J,3)
1372      FORMAT(2X,'VALUE(MICRO-FARADS)=',1PE16.8,/)
          GO TO 1450
1380      WRITE(6,1381)XLAD(J,2)
1381      FORMAT(2X,'ELEMENTS COMBINATION SERIES RESISTOR AND INDUCTOR',/,
     1    2X,'VALUE(KILO-OHMS)=',1PE16.8)
          WRITE(6,1382)XLAD(J,3)
1382      FORMAT(2X,'VALUE(MILLI-HENERIES)=',1PE16.8,/)
          GO TO 1450
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1390     XLAD(J,2)=0.0
         WRITE(6,1391)
1391     FORMAT(2X,'THIS IS AN OPEN CIRCUIT WHOSE ADMITTANCE IS =0.0',/)
         GO TO 1450
1400     WRITE(6,1401)XLAD(J,2)
1401     FORMAT(2X,'ELEMENTS SERIES RESISTOR AND CAPACITOR',/,2X,
       1 'VALUE(KILO-OHMS)=',1PE16.8)
         WRITE(6,1402)XLAD(J,3)
1402     FORMAT(2X,'VALUE(MICRO-FARADS)=',1PE16.8,/)
         GO TO 1450
1410     WRITE(6,1411)XLAD(J,2)
1411     FORMAT(2X,'ELEMENTS COMBINATION PARALLEL RESISTOR AND INDUCTOR',/
       1 ,2X,'VALUE(KILO-OHMS)=',1PE16.8)
         WRITE(6,1412)XLAD(J,3)
1412     FORMAT(2X,'VALUE(MILLI-HENERIES)=',1PE16.8,/)
         GO TO 1450
1425     XLAD(J,2)=0.0
         XLAD(J,3)=0.0
1450     CONTINUE
         DO 1460 J=1,3
         DO 1460 J1=1,16
         WRITE(1,1455)XLAD(J1,J)
1455     FORMAT(E16.8)
1460     CONTINUE
         REWIND 1
         CALL APNT(700.,450.,1,-8,-1)
         CALL ERAS(2)
         CALL SUBP(2,902)
         WRITE(6,1475)
1475     FORMAT(2X,'ARE YOU FINISHED?',/,2X,'TYPE IN YES OR NO',/)
1477     READ(6,1480)COM
1480     FORMAT(A4)
         IF(COM.EQ.YES)GO TO 3000
         IF(COM.EQ.NO)GO TO 1490
         WRITE(6,1485)
1485     FORMAT(2X,'*******ILLEGAL COMMAND ENTRY*******',/)
         GO TO 1477
1490     CALL APNT(700.,200.,0,-8,1)
         CALL ON (1500)
         GO TO 120
1800     CALL APNT(700.,300.,0,-8,1)
         CALL ERAS(6)
         CALL SUBP(6,906)
         CALL APNT(700.,200.,0,-8)
         CALL OFF(1500)
         CALL APNT(700.,150.,0,-8,1)
         CALL ON(1515)
         CALL APNT(825.,150.,1,-8,1)
         CALL ON(1516)
         CALL APNT(890.,150.,1,-8,1)
         CALL ON(1517)
1810     CALL LPEN(M,N)
         IF(M.EQ.0)GO TO 1810
         IF(N.EQ.1516.OR.N.EQ.1517)GO TO 1820
         GO TO 1810
1820     CALL OFF(1515)
         CALL OFF(1516)
         CALL OFF(1517)
         IF(N.EQ.1516)GO TO 1850
         CALL APNT(700.,300.,1,-8,-1)
```

```
      CALL ERAS(6)
      CALL SUBP(6,906)
      CALL APNT(700.,200.,0,-8,1)
      CALL ON (1500)
      GO TO 120
1850  WRITE(6,1851)
1851  FORMAT(2X,'SENSITIVITY STUDIES ARE MADE BY INSERTING A
     1 FLOATING NUMBER BETWEEN + OR - 100 FOR EACH ELEMENT(S) LOCATION'
     1 ,/)
      CALL APNT(700.,200.,0,-8,1)
      CALL ON (1501)
1860  CALL LPEN(M,N)
      IF(M.EQ.0)GO TO 1860
      IF(N.LE.200 OR.N.GT.300)GO TO 1860
      LOG=N-200
      IF((LOG/2)*2 EQ.LOG)GO TO 1900
      WRITE(6,510)LOG
      GO TO 1910
1900  WRITE(6,520)LOG
1910  NES=XLAD(LOG,1)-100.
      IF(NES.GT.0)GO TO 1920
      WRITE(6,565)
      CALL APNT(700.,300.,1,-8,-1)
      CALL ERAS(6)
      CALL SUBP(6,906)
      CALL APNT(700.,200.,0,-8,1)
      CALL OFF(1501)
      CALL ON(1500)
      GO TO 120
1920  GO TO (2010,2020,2030,2040,2050,2050,2070,2080,2090,2070,2080)NES
1965  FORMAT(F10.4)
2010  WRITE(6,2011)
2011  FORMAT(2X,'% VARIATION FOR RESISTOR=',$)
      READ(6,1965)CHNG
2015  XLAD(LOG,2)=XLAD(LOG,2)*(1.+CHNG/100.)
      GO TO 2200
2020  WRITE(6,2021)
2021  FORMAT(2X,'% VARIATION FOR CAPACITOR=',$)
      READ(6,1965)CHNG
2025  XLAD(LOG,2)=XLAD(LOG,2)*(1.+CHNG/100.)
      GO TO 2200
2030  WRITE(6,2031)
2031  FORMAT(2X,'% VARAITION FOR INDUCTOR=',$)
      READ(6,1965)CHNG
2035  XLAD(LOG,2)=XLAD(LOG,2)*(1.+CHNG/100.)
      GO TO 2200
2040  WRITE(6,641)
      GO TO 2200
2050  WRITE(6,2031)
      READ(6,1965)CHNG
2053  XLAD(LOG,2)=XLAD(LOG,2)*(1.+CHNG/100.)
2054  WRITE(6,2021)
      READ(6,1965)CHNG
2057  XLAD(LOG,3)=XLAD(LOG,3)*(1.+CHNG/100.)
      GO TO 2200
2070  WRITE(6,2011)
      READ(6,1965)CHNG
2073  XLAD(LOG,2)=XLAD(LOG,2)*(1.+CHNG/100.)
2074  WRITE(6,2021)
      READ(6,1965)CHNG
```

```
2077    XLAD(LOG,3)=XLAD(LOG,3)*(1.+CHNG/100.)
        GO TO 2200
2080    WRITE(6,2011)
        READ(6,1965)CHNG
2083    XLAD(LOG,2)=XLAD(LOG,2)*(1.+CHNG/100.)
2084    WRITE(6,2031)
        READ(6,1965)CHNG
2087    XLAD(LOG,3)=XLAD(LOG,3)*(1.+CHNG/100.)
        GO TO 2200
2090    WRITE(6,691)
2200    CALL APNT (700.,200.,1,-8,1)
        CALL OFF (1501)
        CALL ON (1500)
        CALL APNT(700.,300.,1,-8,-8)
        CALL ERAS(6)
        CALL SUBP(6,906)
        GO TO 120
3000    WRITE(6,3001)
3001    FORMAT(2X,'TO CONTINUE THE LADDER ANALYSIS AND OBTAIN THE
      1 TRANSFER FUNCTION TYPE IN RUN RK1:TRANF')
        STOP
        END
C       THIS IS A PROGRAM TO DEVELOPE LADDER FILTERS ON THE COMPUTER
        DIMENSION IBUF(3000),XLAD(16,3)
        CALL ASSIGN (1,'RK1:XLAD.JM')
        REWIND 1
        CALL ASSIGN (6,'TT:')
        DATA YES/4HYES /,NO/4HNO  /
        REAL YES,NO
```

```
      SUBROUTINE HRES
      CALL VECT (25.,0.,1,5,0,1)
      CALL VECT (2.5,5.)
      DO 1 I=1,4
      CALL VECT (5.,-10.)
1     CALL VECT (5.,10.)
      CALL VECT (5.,-10.)
      CALL VECT (2.5,5.)
      CALL VECT (25.,0.)
      RETURN
      END

      SUBROUTINE HCAPAC
      CALL VECT (47.,0.,1,5,0)
      CALL VECT (0.,12.,1,5,0)
      CALL VECT (0.,-24.,1,-5,0)
      CALL VECT (0.,12.,1,5,0)
      CALL VECT (6.,0.,1,-8)
      CALL VECT (0.,12.,1,5,0)
      CALL VECT (0.,-24.,1,-5)
      CALL VECT (0.,12.,1,5,0)
      CALL VECT (47.,0.,1,5,0)
      RETURN
      END

      SUBROUTINE HINDUC
      CALL VECT (28.,0.,1,5,0)
      DO 20 J=1,4
      CALL VECT (2.,5.)
      CALL VECT (4.,1.5)
      CALL VECT (4.,-1.5)
      CALL VECT (2.,-5.)
      CALL VECT (-2.,-5.)
      CALL VECT (-2.,5.)
20    CONTINUE
      CALL VECT (2.,5.)
      CALL VECT (4.,1.5)
      CALL VECT (4.,-1.5)
      CALL VECT (2.,-5.)
      CALL VECT (28.,0.)
      RETURN
      END

      SUBROUTINE HSLC
      CALL VECT (14.,0.,1,5)
      DO 20  J=1,2
      CALL VECT (2.,5.)
      CALL VECT (4.,1.5)
      CALL VECT (4.,-1.5)
      CALL VECT (2.,-5.)
      CALL VECT (-2.,-5.)
      CALL VECT (-2.,5.)
20    CONTINUE
      CALL VECT (2.,5.)
      CALL VECT (4.,1.5)
      CALL VECT (4.,-1.5)
      CALL VECT (2.,-5.)
      CALL VECT (26.,0.,1,5)
```

```
      CALL VECT (0.,12.)
      CALL VECT (0.,-24.,1,-5)
      CALL VECT (0.,12.,1,5)
      CALL VECT (6.,0.,1,-8)
      CALL VECT (0.,12.,1,5)
      CALL VECT (0.,-24.,1,-8)
      CALL VECT (0.,12.,1,5)
      CALL VECT (26.,0.)
      RETURN
      END

      SUBROUTINE HPLC
      CALL VECT (28.,0.,1,5,0,1)
      CALL VECT (0.,15.)
      DO 20 J=1,4
      CALL VECT (2.,5.)
      CALL VECT (4.,1.5)
      CALL VECT (4.,-1.5)
      CALL VECT (2.,-5.)
      CALL VECT (-2.,-5.)
      CALL VECT (-2.,5.)
20    CONTINUE
      CALL VECT (2.,5.)
      CALL VECT (4.,1.5)
      CALL VECT (4.,-1.5)
      CALL VECT (2.,-5.)
      CALL VECT (0.,-15.)
      CALL VECT (28.,0.)
      CALL VECT (-72.,0.,1,-8)
      CALL VECT (0.,-15.,1,5)
      CALL VECT (19.,0.)
      CALL VECT (0.,12.)
      CALL VECT (0.,-24.,1,-8)
      CALL VECT (0.,12.,1,5)
      CALL VECT (6.,0.,1,-5)
      CALL VECT (0.,12.,1,5)
      CALL VECT (0.,-24.,1,-5)
      CALL VECT (0.,12.,1,5)
      CALL VECT (19.,0.)
      CALL VECT (0.,15.)
      RETURN
      END

      SUBROUTINE HIMCAP
      CALL VECT (25.,0.,1,5,0,1)
      CALL VECT (0.,15.)
      CALL VECT (22.,0.)
      CALL VECT (0.,12.)
      CALL VECT (0.,-24.,1,-5)
      CALL VECT (0.,12.,1,5)
      CALL VECT (6.,0.,1,-8)
      CALL VECT (0.,12.,1,5)
      CALL VECT (0.,-24.,1,-8)
      CALL VECT (0.,12.,1,5)
      CALL VECT (22.,0.,1,5)
      CALL VECT (0.,-15.)
      CALL VECT (25.,0.)
      CALL VECT (-75.,0.,1,-8)
      CALL VECT (0.,-15.,1,5)
      CALL VECT (10.,0.)
```

```
      CALL VECT (2.5,5.)
      DO 20 J=1,2
      CALL VECT (5.,-10.)
20    CALL VECT (5.,10.)
      CALL VECT (5.,-10.)
      CALL VECT (2.5,5.)
      CALL VECT (10.,0.)
      CALL VECT (0.,15.)
      RETURN
      END

      SUBROUTINE VPLC
      CALL VECT (0.,66.,1,5,0,1)
      CALL VECT (-15.,0.)
      DO 20 J=1,7
      CALL VECT (-5.,2.)
      CALL VECT (-1.5,4.)
      CALL VECT (1.5,4.)
      CALL VECT (5.,2.)
      CALL VECT (5.,-2.)
      CALL VECT (-5.,-2.)
20    CONTINUE
      CALL VECT (-5.,2.)
      CALL VECT (-1.5,4.)
      CALL VECT (1.5,4.)
      CALL VECT (5.,2.)
      CALL VECT (15.,0.)
      CALL VECT (0.,66.)
      CALL VECT (0.,-134.,1,-5)
      CALL VECT (15.,0.,1,5)
      CALL VECT (0.,31.)
      CALL VECT (12.,0.)
      CALL VECT (-24.,0.,1,-5)
      CALL VECT (12.,0.,1,5)
      CALL VECT (0.,6.,1,-5)
      CALL VECT (12.,0.,1,5)
      CALL VECT (-24.,0.,1,-5)
      CALL VECT (12.,0.,1,5)
      CALL VECT (0.,31.)
      CALL VECT (-15.,0.)
      RETURN
      END

      SUBROUTINE VSLC
      CALL VECT (0.,48.,1,5)
      DO 20 J=1,5
      CALL VECT (5.,2.)
      CALL VECT (1.5,4.)
      CALL VECT (-1.5,4.)
      CALL VECT (-5.,2.)
      CALL VECT (-5.,-2.)
      CALL VECT (5.,-2.)
20    CONTINUE
      CALL VECT (5.,2.)
      CALL VECT (1.5,4.)
      CALL VECT (-1.5,4.)
      CALL VECT (-5.,2.)
      CALL VECT (0.,47.)
      CALL VECT (12.,0.)
      CALL VECT (-24.,0.,1,-5)
```

```
      CALL VECT (12.,0.,1,5)
      CALL VECT (0.,6.,1,-5)
      CALL VECT (12.,0.,1,5)
      CALL VECT (-24.,0.,1,-5)
      CALL VECT (12.,0.,1,5)
      CALL VECT (0.,47.)
      RETURN
      END

      SUBROUTINE VIMCAP
      CALL VECT (0.,65.,1,5)
      CALL VECT (-15.,0.)
      CALL VECT (0.,32.)
      CALL VECT (12.,0.)
      CALL VECT (-24.,0.,1,-5)
      CALL VECT (12.,0.,1,5)
      CALL VECT (0.,6.,1,-5)
      CALL VECT (12.,0.,1,5)
      CALL VECT (-24.,0.,1,-5)
      CALL VECT (12.,0.,1,5)
      CALL VECT (0.,32.)
      CALL VECT (15.,0.)
      CALL VECT (0.,65.)
      CALL VECT (0.,-135.,1,-5)
      CALL VECT (15.,0.,1,5)
      CALL VECT (0.,10.)
      CALL VECT (5.,2.5)
      DO 1 J=1,4
      CALL VECT (-10.,5.)
 1    CALL VECT (10.,5.)
      CALL VECT (-10.,5.)
      CALL VECT (5.,2.5)
      CALL VECT (0.,10.)
      CALL VECT (-15.,0.)
      RETURN
      END

      SUBROUTINE HIMIND
      CALL VECT (14.,0.,1,5)
      DO 20 J=1,3
      CALL VECT (2.,5.)
      CALL VECT (4.,1.5)
      CALL VECT (4.,-1.5)
      CALL VECT (2.,-5.)
      CALL VECT (-2.,-5.)
      CALL VECT (-2.,5.)
 20   CONTINUE
      CALL VECT (2.,5.)
      CALL VECT (4.,1.5)
      CALL VECT (4.,-1.5)
      CALL VECT (2.,-5.)
      CALL VECT (10.,0.)
      CALL VECT (2.5,5.)
      DO 30 J=1,2
      CALL VECT (5.,-10.)
 30   CALL VECT (5.,10.)
      CALL VECT (5.,-10.)
      CALL VECT (2.5,5.)
      CALL VECT (10.,0.)
      RETURN
```

```
C        PROGRAM TRANF
C        TRANF COMPUTES THE TRANSFER AND DRIVING-POINT FUNCTIONS
         DIMENSION XLAD(16,3),Z(384)
         CALL ASSIGN (6,'TT:')
         CALL ASSIGN (2,'RK1:XLAD.JM')
         DOUBLE PRECISION Z
         COMMON Z,MIG
         DATA YES/4HYES /,NO/4HNO  /
         REAL YES,NO
         REWIND 2
         DO 5 J=1,3
         DO 5 I=1,16
         READ(2,4)XLAD(I,J)
4        FORMAT(E16.8)
5        CONTINUE
         WRITE(6,12)
12       FORMAT(2X,'DO YOU WANT TO ENGAGE SCALING ROUTINE?',/,
     1   2X,'TYPE IN YES OR NO',/)
7        READ(6,10)COM
10       FORMAT(A4)
         IF(COM.EQ.YES)GO TO 20
         IF(COM.EQ.NO)GO TO 15
         WRITE(6,25)
25       FORMAT(10X,'******ILLEGAL COMMAND ENTRY TRY AGAIN ******')
         GO TO 7
15       MIG=10
         GO TO 35
20       MIG=0
35       CALL TFS(XLAD)
         STOP
         END

         SUBROUTINE TFS (XLAD)
         DIMENSION XLAD(16,3),Z(384)
         DIMENSION RN1(50),RD1(50)
         DOUBLE PRECISION Z,RN1,RD1
         COMMON Z,MIG,M,M2,M3,M5
         DO 2000 J=1,384
         Z(J)=0.
2000     CONTINUE
         DO 2200 J=1,16
         L=XLAD(J,1)-100.
         IF(L.LT.0)GO TO 2250
         K=J*24-23
         Z(K+2)=1.
         Z(K+5)=1.
         Z(K+20)=1.
         Z(K+23)=1.
         IF(J/2*2.EQ.J)GO TO 2100
         GO TO (2010,2020,2030,2200,2040,2050,2060,2070,2200,2080,2090),L
2010     Z(K+8)=XLAD(J,2)*1000.
         Z(K+11)=1.
         GO TO 2200
2020     Z(K+8)=1.
         Z(K+10)=XLAD(J,2)/1000000.
         GO TO 2200
2030     Z(K+7)=XLAD(J,2)/1000.
         Z(K+11)=1.
         GO TO 2200
2040     Z(K+7)=XLAD(J,2)/1000.
```

```
      Z(K+9)=XLAD(J,2)/1000.*XLAD(J,3)/1000000.
      Z(K+11)=1.
      GO TO 2200
2050  Z(K+6)=XLAD(J,2)/1000.*XLAD(J,3)/1000000.
      Z(K+8)=1
      Z(K+10)=XLAD(J,3)/1000000.
      GO TO 2200
2060  Z(K+8)=XLAD(J,2)*1000.
      Z(K+10)=XLAD(J,2)*XLAD(J,3)/1000.
      Z(K+11)=1.
      GO TO 2200
2070  Z(K+7)=XLAD(J,3)/1000.
      Z(K+8)=XLAD(J,2)*1000.
      Z(K+11)=1.
      GO TO 2200
2080  Z(K+7)=XLAD(J,2)*XLAD(J,3)/1000.
      Z(K+8)=1.
      Z(K+10)=XLAD(J,3)/1000000.
      GO TO 2200
2090  Z(K+7)=XLAD(J,2)*XLAD(J,3)
      Z(K+10)=XLAD(J,3)/1000.
      Z(K+11)=XLAD(J,2)*1000.
      GO TO 2200
2100  GO TO (2110,2120,2130,2200,2140,2150,2160,2170,2200,2180,2190),L
2110  Z(K+14)=1.
      Z(K+17)=XLAD(J,2)*1000.
      GO TO 2200
2120  Z(K+13)=XLAD(J,2)/1000000.
      Z(K+17)=1.
      GO TO 2200
2130  Z(K+14)=1.
      Z(K+16)=XLAD(J,2)/1000.
      GO TO 2200
2140  Z(K+12)=XLAD(J,2)*XLAD(J,3)/1000./1000000.
      Z(K+14)=1.
      Z(K+16)=XLAD(J,2)/1000.
      GO TO 2200
2150  Z(K+13)=XLAD(J,3)/1000000.
      Z(K+15)=XLAD(J,2)*XLAD(J,3)/1000./1000000.
      Z(K+17)=1.
      GO TO 2200
2160  Z(K+14)=XLAD(J,2)*1000.
      Z(K+16)=XLAD(J,2)*XLAD(J,3)/1000.
      Z(K+17)=1.
      GO TO 2200
2170  Z(K+14)=1.
      Z(K+16)=XLAD(J,3)/1000.
      Z(K+17)=XLAD(J,2)*1000.
      GO TO 2200
2180  Z(K+13)=XLAD(J,3)/1000000.
      Z(K+16)=XLAD(J,2)*XLAD(J,3)/1000.
      Z(K+17)=1.
      GO TO 2200
2190  Z(K+13)=XLAD(J,3)/1000.
      Z(K+14)=XLAD(J,2)*1000.
      Z(K+16)=XLAD(J,2)*XLAD(J,3)
2200  CONTINUE
2250  M=(J-1)*24
      CALL TRANS3(RN1,RD1,XLAD)
      RETURN
```

```
      END
      SUBROUTINE TRANS3(RN1,RD1,XLAD)
      DIMENSION Z(384),RN1(50),RD1(50),RN2(50),RD2(50),RN3(50),
     1 RD3(50),RN4(50),RD4(50),X1(3),X2(3),X3(50),X4(50),
     1 X5(3),X6(3),X7(50),X8(50),RTN(50),RTD(50),RTN1(50),
     1 RTD1(50),RTN2(50),RTD2(50),XLAD(16,3)
      DOUBLE PRECISION Z,RN1,RD1,RN2,RD2,RN3,RD3,RN4,RD4,X1,X2,X3,
     1 X4,X5,X6,X7,X8,RTN,RTD,RTN1,RTD1,RTN2,RTD2
      COMMON Z,MIG,M,M2,M3,M5,X1,X2,X3,X4,X5,X6,X7,X8
      M2=1
      DO 10 J=1,3
      X1(J)=0.
      X2(J)=0.
      X5(J)=0.
      X6(J)=0.
 10   CONTINUE
      DO 30 J=1,50
      X3(J)=0.
      X4(J)=0.
      X7(J)=0.
      X8(J)=0.
 30   CONTINUE
      CALL TRANS2(X3,X4,RN1,3)
 35   M6=M/24
      M5=M
      IF(XLAD(M6,1).NE.104.AND.XLAD(M6,1).NE.109)GO TO 38
      M=M-24
      GO TO 35
 38   X8(1)=Z(M-6)
      X8(2)=Z(M-7)
      X8(3)=Z(M-8)
      X7(1)=Z(M-18)
      X7(2)=Z(M-19)
      X7(3)=Z(M-20)
      X6(1)=Z(M-36)
      X6(2)=Z(M-37)
      X6(3)=Z(M-38)
      X5(1)=Z(M-42)
      X5(2)=Z(M-43)
      X5(3)=Z(M-44)
      X4(1)=Z(M-9)
      X4(2)=Z(M-10)
      X4(3)=Z(M-11)
      X3(1)=Z(M-21)
      X3(2)=Z(M-22)
      X3(3)=Z(M-23)
      X2(1)=Z(M-39)
      X2(2)=Z(M-40)
      X2(3)=Z(M-41)
      X1(1)=Z(M-45)
      X1(2)=Z(M-46)
      X1(3)=Z(M-47)
      M3=1
      IF(XLAD(M6-1,1).NE.104.AND.XLAD(M6-1,1).NE.109)GO TO 42
      DO 40 J=1,50
      RN1(J)=X3(J)
      RD1(J)=X7(J)
      RN3(J)=X4(J)
      RD3(J)=X8(J)
```

```
40      CONTINUE
        GO TO 44
42      CALL TRANS1(RN1,RD1)
44      X3(1)=Z(M-15)
        X3(2)=Z(M-16)
        X3(3)=Z(M-17)
        X4(1)=Z(M-3)
        X4(2)=Z(M-4)
        X4(3)=Z(M-5)
        X7(1)=Z(M-12)
        X7(2)=Z(M-13)
        X7(3)=Z(M-14)
        X8(1)=Z(M)
        X8(2)=Z(M-1)
        X8(3)=Z(M-2)
        M3=2
        IF(XLAD(M6-1,1).NE.104.AND.XLAD(M6-1,1).NE.109)GO TO 48
        DO 46 J=1,50
        RN2(J)=X3(J)
        RD2(J)=X7(J)
        RN4(J)=X4(J)
        RD4(J)=X8(J)
46      CONTINUE
        GO TO 50
48      CALL TRANS1(RN2,RD2)
        X8(1)=Z(M-6)
        X8(2)=Z(M-7)
        X8(3)=Z(M-8)
        X7(1)=Z(M-18)
        X7(2)=Z(M-19)
        X7(3)=Z(M-20)
        X6(1)=Z(M-24)
        X6(2)=Z(M-25)
        X6(3)=Z(M-26)
        X5(1)=Z(M-30)
        X5(2)=Z(M-31)
        X5(3)=Z(M-32)
        X4(1)=Z(M-9)
        X4(2)=Z(M-10)
        X4(3)=Z(M-11)
        X3(1)=Z(M-21)
        X3(2)=Z(M-22)
        X3(3)=Z(M-23)
        X2(1)=Z(M-27)
        X2(2)=Z(M-28)
        X2(3)=Z(M-29)
        X1(1)=Z(M-33)
        X1(2)=Z(M-34)
        X1(3)=Z(M-35)
        M3=3
        CALL TRANS1(RN3,RD3)
        X3(1)=Z(M-15)
        X3(2)=Z(M-16)
        X3(3)=Z(M-17)
        X4(1)=Z(M-3)
        X4(2)=Z(M-4)
        X4(3)=Z(M-5)
        X7(1)=Z(M-12)
        X7(2)=Z(M-13)
        X7(3)=Z(M-14)
```

```
      X8(1)=Z(M)
      X8(2)=Z(M-1)
      X8(3)=Z(M-2)
      M3=4
      CALL TRANS1(RN4,RD4)
50    M4=M-24
      IF(M4.LT.35)GO TO 1070
      M2=10
      DO 500 JJ=25,M4,24
      K=M4+25-JJ
      M6=K/24
      IF(XLAD(M6-1,1).EQ.104.OR.XLAD(M6-1,1).EQ.109)GO TO 500
      M5=K-24
      X6(1)=Z(K-36)
      X6(2)=Z(K-37)
      X6(3)=Z(K-38)
      X5(1)=Z(K-42)
      X5(2)=Z(K-43)
      X5(3)=Z(K-44)
      X2(1)=Z(K-39)
      X2(2)=Z(K-40)
      X2(3)=Z(K-41)
      X1(1)=Z(K-45)
      X1(2)=Z(K-46)
      X1(3)=Z(K-47)
      M3=1
      DO 55 J=1,50
      X3(J)=RN1(J)
      X4(J)=RN3(J)
      X7(J)=RD1(J)
      X8(J)=RD3(J)
55    CONTINUE
      CALL TRANS1(RTN,RTD)
      M3=2
      DO 60 J=1,50
      X3(J)=RN2(J)
      X4(J)=RN4(J)
      X7(J)=RD2(J)
      X8(J)=RD4(J)
60    CONTINUE
      CALL TRANS1(RTN1,RTD1)
      X1(1)=Z(K-33)
      X1(2)=Z(K-34)
      X1(3)=Z(K-35)
      X2(1)=Z(K-27)
      X2(2)=Z(K-28)
      X2(3)=Z(K-29)
      X5(1)=Z(K-30)
      X5(2)=Z(K-31)
      X5(3)=Z(K-32)
      X6(1)=Z(K-24)
      X6(2)=Z(K-25)
      X6(3)=Z(K-26)
      M3=3
      DO 80 J=1,50
      X3(J)=RN1(J)
      X4(J)=RN3(J)
      X7(J)=RD1(J)
      X8(J)=RD3(J)
80    CONTINUE
```

```
      CALL TRANS1(RTN2,RTD2)
      DO 100 J=1,50
      RN1(J)=RTN(J)
      RD1(J)=RTD(J)
      RN3(J)=RTN2(J)
      RD3(J)=RTD2(J)
100   CONTINUE
      M3=4
      DO 150 J=1,50
      X4(J)=RN4(J)
      X3(J)=RN2(J)
      X7(J)=RD2(J)
      X8(J)=RD4(J)
150   CONTINUE
      CALL TRANS1(RTN,RTD)
      DO 200 J=1,50
      RN2(J)=RTN1(J)
      RD2(J)=RTD1(J)
      RN4(J)=RTN(J)
      RD4(J)=RTD(J)
200   CONTINUE
      CALL SHIFT(RN1,RD1)
      CALL SHIFT(RN2,RD2)
      CALL SHIFT(RN3,RD3)
      CALL SHIFT(RN4,RD4)
500   CONTINUE
550   CALL DIVI(RN1,RD1)
      CALL ASSIGN (1,'RK1:JOKE.JM')
      DO 700 JJJ=1,50
      WRITE(1,600)RD1(JJJ),RN1(JJJ)
600   FORMAT(3X,2E20.10)
700   CONTINUE
      ENDFILE 1
      WRITE(6,750)
750   FORMAT(20X,'***TRANSFER FUNCTION***',///)
      WRITE(6,800)
800   FORMAT(2X,'COEFFICIENTS',6X,'NUMERATOR'16X,'DENOMINATOR')
      DO 900 J=1,50
      IF(RN1(J).EQ.0..AND.RD1(J).EQ.0.)GO TO 900
      KIF=J-1
      WRITE(6,850)KIF,RD1(J),RN1(J)
850   FORMAT(2X,'S**',I2,10X,1PE15.6,10X,1PE15.6)
900   CONTINUE
      CALL DIVI(RN3,RD3)
      CALL TRANS2(RN1,RD3,RN2,25)
      CALL TRANS2(RD1,RN3,RD2,25)
      CALL SHIFT(RN2,RD2)
      WRITE(6,1000)
1000  FORMAT(///,10X,'***DRIVING-POINT IMPEDANCE***',///)
      WRITE(6,800)
      DO 1100 J=1,50
      IF(RN2(J).EQ.0..AND.RD2(J).EQ.0.)GO TO 1100
      KIJ=J-1
      WRITE(6,850)KIJ,RN2(J),RD2(J)
1100  CONTINUE
      GO TO 1200
1070  CALL SHIFT(RN1,RD1)
      CALL SHIFT(RN2,RD2)
      CALL SHIFT(RN3,RD3)
      CALL SHIFT(RN4,RD4)
```

```
      GO TO 550
1200  WRITE(6,1175)
1175  FORMAT(///,2X,'TO CONTINUE THE LADDER NETWORK ANALYSIS PACKAGE',/
     1 2X,'TYPE IN RUN RK1:ANALY TO PERFORM BODE AND NYQUIST PLOTS')
      RETURN
      END

      SUBROUTINE TRANS1(RN,R)
      DIMENSION X1(3),X2(3),X3(50),X4(50),X5(3),X6(3),
     1 X7(50),X8(50),RN(50),R(50),R1(50),Z(384)
      DOUBLE PRECISION Z,X1,X2,X3,X4,X5,X6,X7,X8,RN,R,R1
      COMMON Z,MIG,M,M2,M3,M5,X1,X2,X3,X4,X5,X6,X7,X8
      L=M5/24
      IF(L/2*2.EQ.L)GO TO 100
      IF(M2.NE.1)GO TO 50
      GO TO (2010,2010,2010,900),M3
150   GO TO (2010,2010,900,900),M3
100   IF(M2.NE.1)GO TO 150
      GO TO (900,2020,2020,2020),M3
50    GO TO (900,900,2020,2020),M3
900   I1=3
      CALL TRANS2(X5,X7,R,I1)
      I1=25
      CALL TRANS2(X4,R,R1,I1)
      I1=3
      CALL TRANS2(X2,R1,R,I1)
      DO 1000 J=1,50
      RN(J)=R(J)
1000  CONTINUE
      I1=3
      CALL TRANS2(X6,X8,R,I1)
      I1=25
      CALL TRANS2(X3,R,R1,I1)
      I1=3
      CALL TRANS2(X1,R1,R,I1)
      DO 2000 J=1,50
      RN(J)=RN(J)+R(J)
2000  CONTINUE
      I1=3
      CALL TRANS2(X6,X8,R,I1)
      I1=25
      CALL TRANS2(X7,R,R1,I1)
      I1=3
      CALL TRANS2(X5,R1,R,I1)
      GO TO 9000
2010  I1=3
      CALL TRANS2(X1,X3,RN,I1)
      CALL TRANS2(X5,X7,R,I1)
      GO TO 9000
2020  I1=3
      CALL TRANS2(X2,X4,RN,I1)
      CALL TRANS2(X6,X8,R,I1)
9000  RETURN
      END

      SUBROUTINE TRANS2(X11,X22,R6,I1)
      DIMENSION X11(50),X22(50),R6(50)
      DOUBLE PRECISION X11,X22,R6
```

```
      DO 10 J=1,50
      R6(J)=0.0
10    CONTINUE
      DO 1000 J=1,25
      DO 500 K=1,I1
      IF(X11(K).EQ.0.OR.X22(J).EQ.0.)GO TO 300
      IF(X22(J).GT.1.)GO TO 200
      P=.2E-35/X22(J)
      IF(X11(K).GE.1.)GO TO 300
      IF(X11(K).LE.1..AND.X11(K).GT.P)GO TO 300
      GO TO 2000
200   P=.1E+36/X22(J)
      IF(X11(K).LE.1.)GO TO 300
      IF(X11(K).GT.P)GO TO 2000
300   R6(J+K)=R6(J+K)+X11(K)*X22(J)
500   CONTINUE
1000  CONTINUE
      GO TO 5000
2000  WRITE(6,1990)
1990  FORMAT(2X,'FURTHER COMPUTATION WIIL EXCEED THE LIMITS OF',/
     1 ,'THIS MACHINE PLEASE RESCALE OR USE CDC6600')
      STOP
      GO TO 6000
5000  RETURN
6000  END

      SUBROUTINE SHIFT(XRN1,XRD1)
      DIMENSION SDN(384),XRN1(50),XRD1(50),Q(50),XL1(3),
     1 QD(50)
      DOUBLE PRECISION SDN,XRN1,XRD1,Q,XL1,QD,DIF,FAC,R1,R2,R3,ER
      COMMON SDN,MIG
      DO 3700 J10=1,50
      IF(XRN1(J10).GT.0.)GO TO 3800
      IF(XRD1(J10).GT.0.)GO TO 3800
3700  CONTINUE
3800  L10=51-J10
      XMAXRD=.2E-38
      XMINRD=.1E+38
      XMAXRN=.2E-38
      XMINRN=.1E+38
      IF(MIG.GT.5)GO TO 4300
      DO 2000 J=1,50
      IF(XRN1(J).LE.0.0)GO TO 1500
      IF(XRN1(J).GT.XMAXRN)XMAXRN=XRN1(J)
      IF(XRN1(J).LT.XMINRN)XMINRN=XRN1(J)
1500  IF(XRD1(J).LE.0.0)GO TO 2000
      IF(XRD1(J).GT.XMAXRD)XMAXRD=XRD1(J)
      IF(XRD1(J).LT.XMINRD)XMINRD=XRD1(J)
2000  CONTINUE
      XMAXRN=ALOG10(XMAXRN)
      XMINRN=ALOG10(XMINRN)
      XMAXRD=ALOG10(XMAXRD)
      XMINRD=ALOG10(XMINRD)
      XMAX=XMAXRN
      IF(XMAX.LT.XMAXRD)XMAX=XMAXRD
      XMIN=XMINRN
      IF(XMIN.GT.XMINRD)XMIN=XMINRD
      DIF=(XMAX+XMIN)/2.+.5
      FAC=10.**DIF
```

```
      DO 4000 J=1,L10
      L12=J+J10-1
      XRN1(J)=XRN1(L12)/FAC
      XRD1(J)=XRD1(L12)/FAC
4000  CONTINUE
      GO TO 4400
4300  DO 4200 J=1,L10
      L12=J+J10-1
      XRN1(J)=XRN1(L12)
      XRD1(J)=XRD1(L12)
4200  CONTINUE
4400  ER=1.E-06
      L13=L10+1
      DO 4500 J=L13,50
      XRN1(J)=0.
      XRD1(J)=0.
4500  CONTINUE
      DO 5 J=1,50
      Q(J)=0.0
      QD(J)=0.0
5     CONTINUE
      J=51
10    J=J-1
      IF(J.LT.1)GO TO 4600
      IF(XRN1(J).EQ.0.)GO TO 10
      J1=J
      K=385
20    K=K-1
      IF(SDN(K).EQ.0.)GO TO 20
      K=((K+2)/3*3)-2
25    DO 600 L=1,K,3
      XL1(3)=SDN(L)
      XL1(2)=SDN(L+1)
      XL1(1)=SDN(L+2)
      MM=0
      IF(XL1(1).GT.0.)MM=MM+1
      IF(XL1(2).GT.0.)MM=MM+1
      IF(XL1(3).GT.0.)MM=MM+1
      IF(MM.LT.2)GO TO 600
      L1=4
30    L1=L1-1
      IF(XL1(L1).EQ.0.)GO TO 30
      IF(L1.GT.J1)GO TO 600
      J11=J1-L1+1
      J12=J1
      GO TO (600,50,200),L1
50    R1=XRN1(J12)
      R2=XRN1(J12-1)
60    Q(J11)=R1/XL1(L1)
      IF(Q(J11).LT.0.)GO TO 500
      R2=R2-Q(J11)*XL1(L1-1)
      J11=J11-1
      IF(J11-0)500,90,70
70    J12=J12-1
      R1=R2
      R2=XRN1(J12-1)
      GO TO 60
90    IF(ABS(R2).GT.ER)GO TO 500
      I=51
140   I=I-1
```

```
      IF(L1.GT.I)GO TO 600
      IF(XRD1(I).EQ.0.)GO TO 140
      J11=I-L1+1
      R1=XRD1(I)
      R2=XRD1(I-1)
150   QD(J11)=R1/XL1(L1)
      R2=R2-QD(J11)*XL1(L1-1)
      J11=J11-1
      IF(J11-0)180,180,160
160   I=I-1
      R1=R2
      R2=XRD1(I-1)
      GO TO 150
180   IF(ABS(R2).GT.ER)GO TO 500
      GO TO 390
200   R1=XRN1(J12)
      R2=XRN1(J12-1)
      R3=XRN1(J12-2)
210   Q(J11)=R1/XL1(L1)
      IF(Q(J11).LT.0.0)GO TO 500
      R2=R2-Q(J11)*XL1(L1-1)
      R3=R3-Q(J11)*XL1(L1-2)
      J11=J11-1
      IF(J11-0)500,300,230
230   J12=J12-1
      R1=R2
      R2=R3
      R3=XRN1(J12-2)
      GO TO 210
300   IF(ABS(R2).GT.ER)GO TO 500
      IF(ABS(R3).GT.ER)GO TO 500
      I=51
340   I=I-1
      IF(XRD1(I).EQ.0)GO TO 340
      J11=I-L1+1
      R1=XRD1(I)
      R2=XRD1(I-1)
      R3=XRD1(I-2)
350   QD(J11)=R1/XL1(L1)
      R2=R2-QD(J11)*XL1(L1-1)
      R3=R3-QD(J11)*XL1(L1-2)
      J11=J11-1
      IF(J11-0)370,370,360
360   I=I-1
      R1=R2
      R2=R3
      R3=XRD1(I-2)
      GO TO 350
370   IF(ABS(R2).GT.ER)GO TO 500
      IF(ABS(R3).GT.ER)GO TO 500
390   DO 420 N7=1,50
      XRD1(N7)=QD(N7)
      XRN1(N7)=Q(N7)
      QD(N7)=0.
      Q(N7)=0.
420   CONTINUE
      GO TO 5[illegible]
500   DO 520 [illegible],50
      Q(N7)=[illegible]
      QD(N7)=0.
```

```
520     CONTINUE
530     R1=0.
        R2=0.
        R3=0.
600     CONTINUE
4600    RETURN
        END

        SUBROUTINE DIVI(F11,F22)
        DIMENSION F11(50),F22(50),N(46)
        DATA N/2,3,5,7,11,13,17,19,23,29,31,37,41,43,47,53,59,61,67,
      1 71,73,79,83,89,97,101,103,107,109,113,127,131,137,139,149,
      1 151,157,163,167,173,179,181,191,193,197,199/
        M=1
5       DO 100 J=M,46
        Z=F11(1)/N(J)
        IF(Z.GT.32767.)GO TO 125
        L=Z
        IF(L.NE.Z)GO TO 90
        Z=F22(1)/N(J)
        IF(Z.GT.32767.)GO TO 125
        L=Z
        IF(L.NE.Z)GO TO 90
        DO 10 K=1,50
        F11(K)=F11(K)/N(J)
        F22(K)=F22(K)/N(J)
10      CONTINUE
        GO TO 5
90      M=M+1
100     CONTINUE
        IF(M.LT.46)GO TO 5
125     RETURN
        END
```

APPENDIX IV

Fig. IV A- Program ANALY Operation Sequence

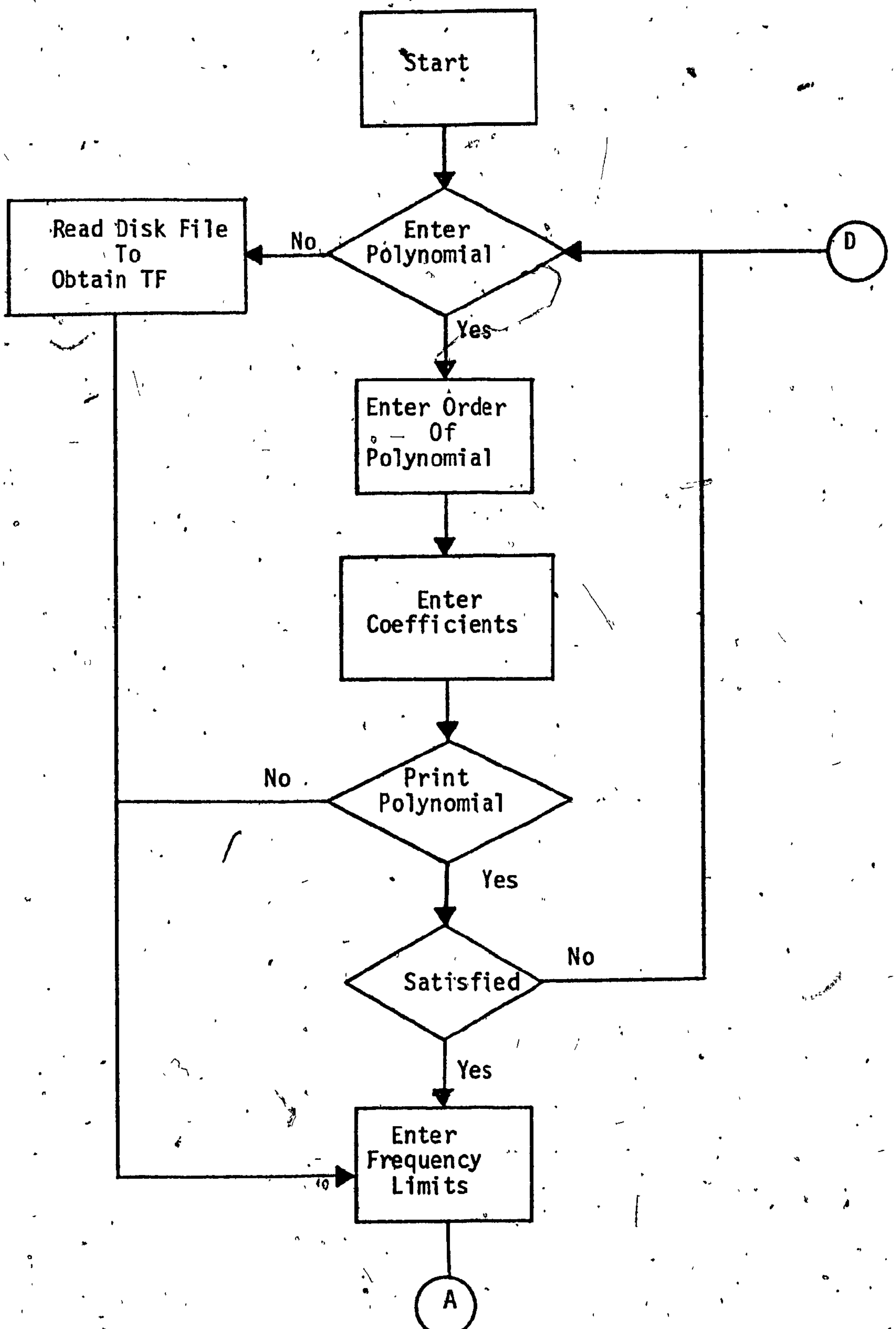


Fig. IV A (Cont'd)

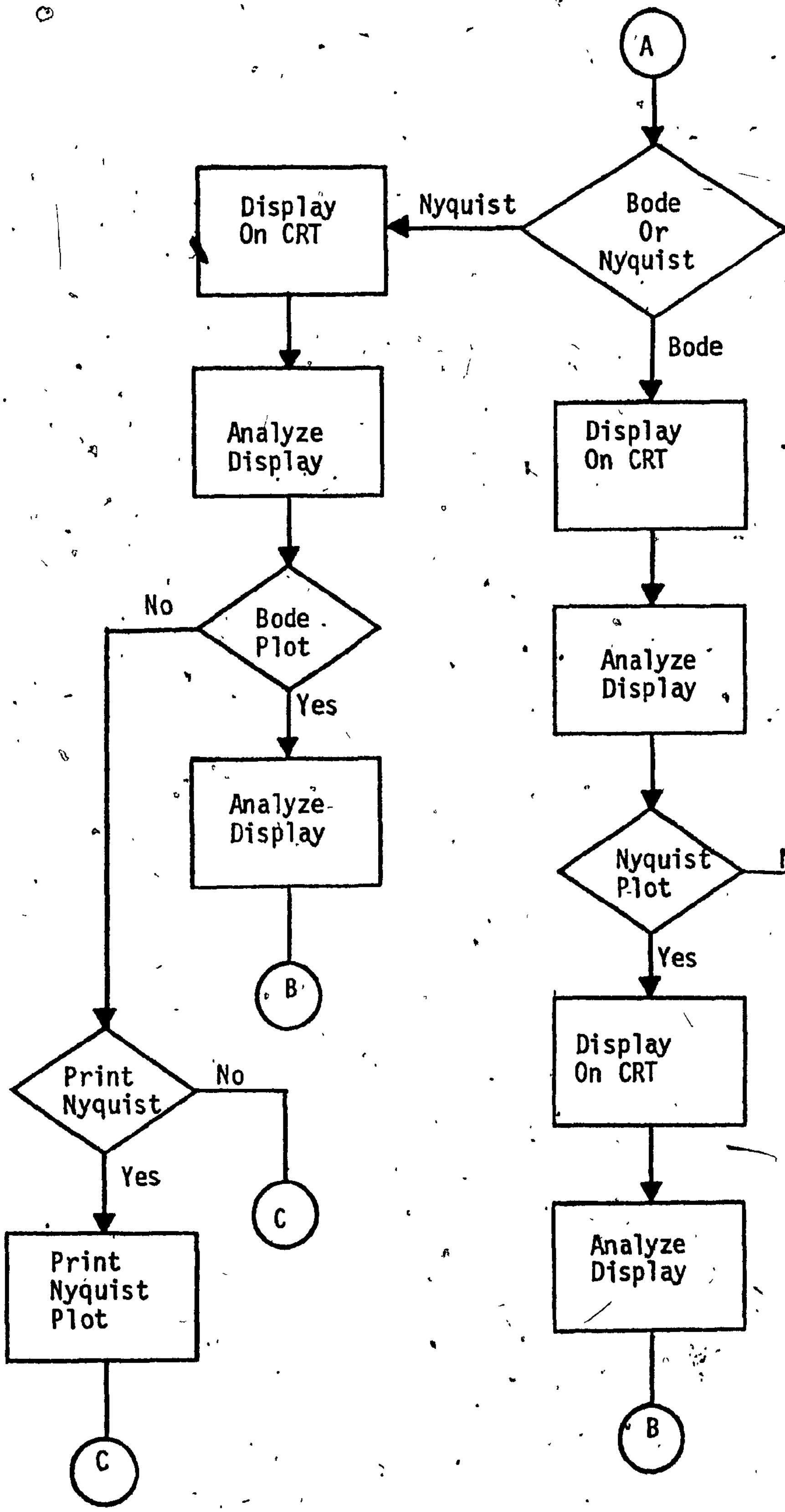
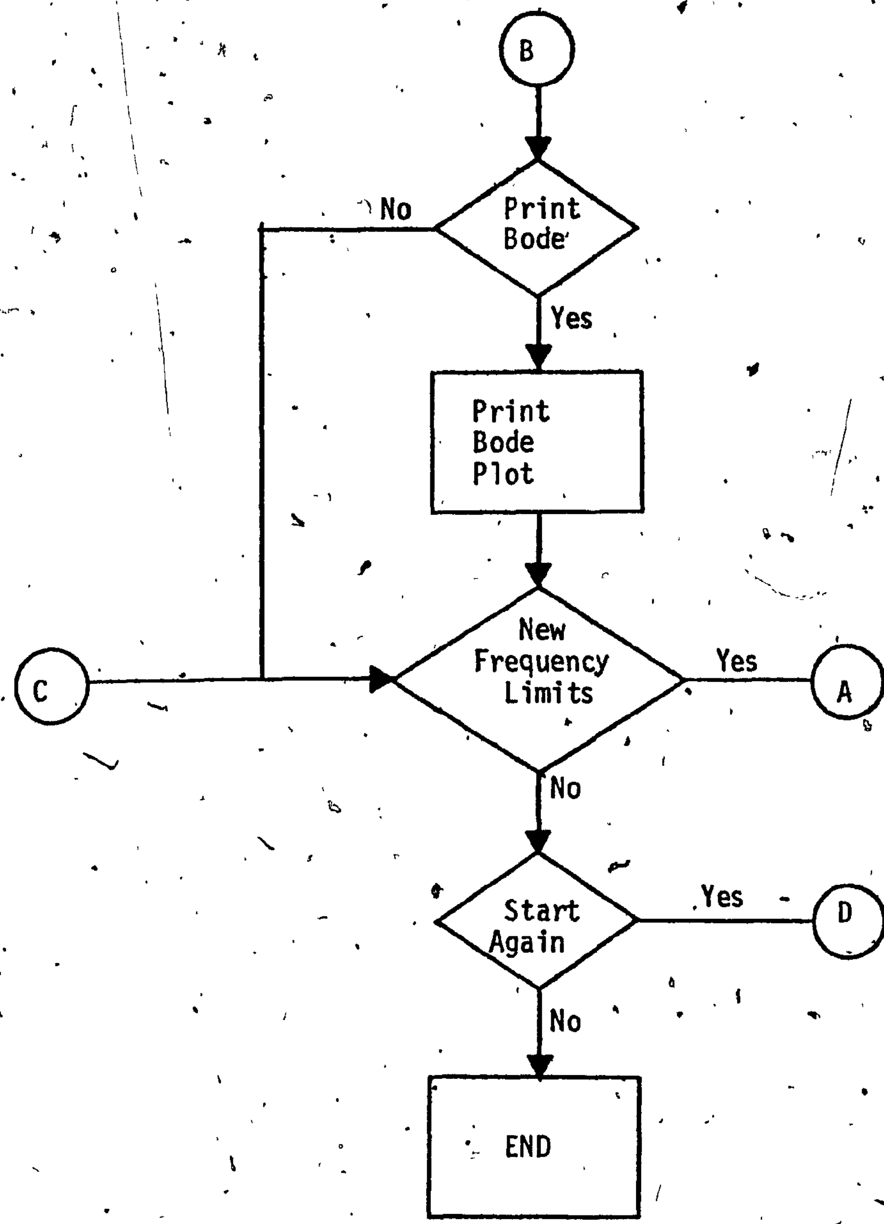


Fig. IV A (Cont'd)



```
C         PROGRAM ANALY COMPUTES THE BODE, PHASE, AND NYQUIST PLOTS
          DIMENSION RN(80),RD(80),DBPLT(401),PHIBLT(401)
          COMMON DBPLT,PHIBLT,SF,EF,DBMIN,DBMAX,PHIMIN,PHIMAX,DIVI,NBRAN
          COMPLEX BODEN,BODED,S,BODEN1,BODED1
          DATA YES/4HYES /,NO/4HNO  /,BODE/4HBODE/,NYQT/4HNYQT/
          REAL YES,NO,BODE,NYQT
          CALL ASSIGN (1,'RK1:JOKE.JM')
          CALL ASSIGN (6,'TT:')
          CALL ASSIGN (7,'LP:')
1         REWIND 1
          KOUNT=0
          DO 2 J=1,80
          RN(J)=0.
          RD(J)=0.
2         CONTINUE
3         DBMAX=-1000.
          DBMIN=1000.
          PHIMIN=-3000.
          PHIMAX=3000.
          PHID=0.
          PHINT=0.
          PHIT=0.
          TOPHI=0.
          PHIDT=0.
          PHI2=0.
          BNR=0.
          BNI=0.
          BOR=0.
          BOI=0.
          BDR=0.
          BDI=0.
          BODR=0.
          BODI=0.
          N=0
          NN=0
          LL=0
          ML=0
          DBT=0.
          EVED=0.
          EVEN=0.
          VOR=0.
          VIR=0.
          IF(KOUNT.EQ.1)GO TO 101
          IF(KOUNT1.EQ.2)GO TO 90
          WRITE(6,4)
4         FORMAT(2X,'DO YOU WISH TO ENTER YOUR OWN TRANSFER FUNCTION?',/,
     1    2X,'TYPE IN YES OR NO',/)
5         READ(6,7)COM
7         FORMAT(A4)
          IF(COM.EQ.YES)GO TO 9
          IF(COM.EQ.NO)GO TO 90
          WRITE(6,8)
8         FORMAT(10X,'*****ILLEGAL COMMAND ENTRY TRY AGAIN*****')
          GO TO 5
9         KOUNT=1
          WRITE(6,10)
10        FORMAT(2X,'ENTER THE ORDER OF THE TRANSFER FUNCTION',/,
     1    2X,'ORDER='$)
          READ(6,11)FORD
11        FORMAT(F7.0)
```

```
      NORD=FORD+1
      WRITE(6,30)
30    FORMAT(2X,'ENTER THE COEFFICIENTS OF THE TRANSFER FUNCTION',/,
     1 2X,'COEFFICIENTS BEING ENTERD FROM LOWEST TO HIGHEST ORDER')
      DO 50 NIF=1,NORD
      NORT=NIF-1
      WRITE(6,41)NORT
41    FORMAT(2X,'COEFFICIENT OF S**',I2,/)
      WRITE(6,42)
42    FORMAT(2X,'NUMERATOR=',$)
      READ(6,43)RD(NIF)
43    FORMAT(F20.10)
      WRITE(6,44)
44    FORMAT(2X,'DENOMINATOR=',$)
      READ(6,43)RN(NIF)
50    CONTINUE
      WRITE(6,51)
51    FORMAT(2X,'DO YOU WANT A PRINT OUT OF THE COEFFICIENTS JUST
     1 ENTERED?',/,2X,'TYPE IN YES OR NO',/)
52    READ(6,7)COM
      IF(COM.EQ.YES)GO TO 55
      IF(COM.EQ.NO)GO TO 100
      WRITE(6,8)
      GO TO 52
55    WRITE(6,59)
59    FORMAT(20X,'***TRANSFER FUNCTION***')
      WRITE(6,60)
60    FORMAT(2X,'COEFFICIENTS',11X,'NUMERATOR',21X,'DENOMINATOR')
      DO 71 NIF=1,NORD
      NORT=NIF-1
      WRITE(6,62)NORT,RD(NIF),RN(NIF)
62    FORMAT(2X,'S**',I2,15X,1PE15.6,15X,1PE15.6)
71    CONTINUE
      WRITE(6,72)
72    FORMAT(2X,'ARE YOU SATISFIED?',/,2X,'IF ANSWER IS YES BODE
     1 PLOT BEGINS',/,2X,'IF THE ANSWER IS NO RE-ENTER COEFFICIENTS',/,
     1 2X,'TYPE IN YES OR NO',/)
74    READ(6,7)COM
      IF(COM.EQ.YES)GO TO 80
      IF(COM.EQ.NO)GO TO 1
      WRITE(6,8)
      GO TO 74
80    JIJ=NORD+1
      DO 81 MOL=JIJ,80
      RN(MOL)=0.0
      RD(MOL)=0.0
81    CONTINUE
      GO TO 100
90    KOUNT=2
      DO 95 LLL=1,80
      READ(1,96,END=100) RD(LLL),RN(LLL)
96    FORMAT(3X,2E20.10)
95    CONTINUE
100   REWIND 1
101   WRITE(6,120)
120   FORMAT(5X,'ENTER THE STARTING FREQUENCY(IN RAD/SEC)=',$)
      READ(6,130)SF
130   FORMAT(F20.7)
      WRITE(6,140)
140   FORMAT(5X,'ENTER THE FINAL FREQUENCY(IN RAD/SEC)=',$)
```

```
      READ(6,130)EF
      IF(EF.LT.SF)GO TO 150
      GO TO 180
150   WRITE(6,170)
170   FORMAT(2X,'ERROR YOU HAVE SPECIFIED ILLEGAL FREQUENCY LIMITS',/
     1 ,2X,'PLEASE TYPE IN CORRECT LIMITS'/,)
      GO TO 100
180   DIVI=(EF-SF)/400.
      FF=SF
      FS=SF-101*DIVI
      J=81
200   J=J-1
      IF(RN(J).EQ.0.)GO TO 200
      JJ=0
250   JJ=JJ+1
      IF(RN(JJ).EQ.0.)GO TO 250
      I=81
300   I=I-1
      IF(RD(I).EQ.0.)GO TO 300
      II=0
350   II=II+1
      IF(RD(II).EQ.0.)GO TO 350
      JOL=JJ
      DO 400 LEV=JOL,J,1
      LEV=LEV+1
      IF(RN(LEV).NE.0.)GO TO 450
400   CONTINUE
      EVEN=10.
450   IOI=II
      DO 475 LED=IOI,I,1
      LED=LED+1
      IF(RD(LED).NE.0.)GO TO 500
475   CONTINUE
      EVED=10.
500   PIHD=0.
      PHIN=0.
      S=CMPLX(0.,0.)
      DO 1150 KLM=1,502
      FRS=FS+(DIVI*KLM)
      S=CMPLX(0.,FRS)
      IF(AIMAG(S).LE.0.)GO TO 1150
      BODEN=(0.,0.)
      BODEN1=(0.,0.)
      DO 600 KJ=1,J
      KI=KJ-1
      BODEN=BODEN+RN(KJ)*(S**KI)
      BODEN1=BODEN1+RN(KJ)*(S**(KJ-JJ))
600   CONTINUE
      BODMAN=ABS(REAL(BODEN)*REAL(BODEN)+AIMAG(BODEN)*AIMAG(BODEN))
      IF(JJ-J.EQ.0)GO TO 780
      IF(EVEN.NE.10.)GO TO 610
      NL=0
      IF(REAL(BODEN1).LE.0..AND.VIR.GT.0.)NL=1
      IF(VIR.LT.0..AND.REAL(BODEN1).GE.0.)NL=1
      IF(NL.NE.0)PHINUT=180.
      IF(NL.EQ.0)PHINUT=0.
      PHID=PHID-PHINUT
      VIR=REAL(BODEN1)
      GO TO 780
610   QUIT=REAL(BODEN1)
```

```
      IF(ABS(QUIT).LT..1E-35)GO TO 630
      PHI2=ATAN(AIMAG(BODEN1)/REAL(BODEN1))*180/3.14
630   BNR=REAL(BODEN1)
      BNI=AIMAG(BODEN1)
      IF(BNR.GE.0..AND.BOR.LT.0.)LL=LL+1
      IF(BNR.LT.0..AND.BOR.GE.0.)LL=LL+1
      IF(BNI.GE.0..AND.BOI.LT.0.)LL=LL+1
      IF(BNI.LT.0..AND.BOI.GE.0.)LL=LL+1
      BOR=BNR
      BOI=BNI
      IF(LL.LT.4)GO TO 750
      NN=NN+360
      LL=0
750   IF(REAL(BODEN1).GE.0..AND.AIMAG(BODEN1).GE.0.)PHID=-(NN+PHI2)
      IF(REAL(BODEN1).LT.0..AND.AIMAG(BODEN1).GE.0.)PHID=-(NN+180.+PHI2
     1 )
      IF(REAL(BODEN1).LT.0..AND.AIMAG(BODEN1).LT.0.)PHID=-(NN+180.+PHI2
     1 )
      IF(REAL(BODEN1).GT.0..AND.AIMAG(BODEN1).LT.0.)PHID=-(NN+360.+PHI2
     1 )
780   PHIDS=(1-JJ)*90.
      PHIDT=PHID+PHIDS
      BODED=(0.,0.)
      BODED1=(0.,0.)
      DO 800 M=1,I
      MM=M-1
      BODED=BODED+RD(M)*(S**MM)
      BODED1=BODED1+RD(M)*(S**(M-II))
800   CONTINUE
      BODMAD=ABS(REAL(BODED)*REAL(BODED)+AIMAG(BODED)*AIMAG(BODED))
      DBT=20.*ALOG10(SQRT(BODMAD/BODMAN))
      IF(II-I.EQ.0)GO TO 920
      IF(EVED.NE.10.)GO TO 810
      NOL=0
      IF(REAL(BODED1).LE.0..AND.VOR.GT.0.)NOL=1
      IF(VOR.LT.0..AND.REAL(BODED1).GE.0.)NOL=1
      IF(NOL.NE.0)PHINLT=180.
      IF(NOL.EQ.0)PHINLT=0.
      PHIN=PHIN+PHINLT
      VOR=REAL(BODED1)
      GO TO 920
810   QUIT=REAL(BODED1)
      IF(ABS(QUIT).LT..1E-35)GO TO 820
      PHI=ATAN(AIMAG(BODED1)/REAL(BODED1))*(180./3.14)
820   BDR=REAL(BODED1)
      BDI=AIMAG(BODED1)
      IF(BDR.GE.0..AND.BODR.LT.0.)ML=ML+1
      IF(BDR.LT.0..AND.BODR.GE.0.)ML=ML+1
      IF(BDI.GE.0..AND.BODI.LT.0.)ML=ML+1
      IF(BDI.LT.0 .AND.BODI.GE.0.)ML=ML+1
      BODR=BDR
      BODI=BDI
      IF(ML.LT.4)GO TO 850
      N=N+360
      ML=0
850   IF(REAL(BODED1).GE.0..AND.AIMAG(BODED1).GE.0.)PHIN=N+PHI
      IF(REAL(BODED1).LT.0..AND.AIMAG(BODED1).GE.0.)PHIN=(N+180.+PHI)
      IF(REAL(BODED1).LT.0..AND.AIMAG(BODED1).LT.0.)PHIN=(N+180.+PHI)
      IF(REAL(BODED1).GT.0..AND.AIMAG(BODED1).LT.0.)PHIN=(N+360.+PHI)
920   PHINS=(II-1)*90.
```

```
      PHINT=PHIN+PHINS
      TOPHI=PHINT+PHIDT
      IF(FRS.LT.SF)GO TO 1150
      IF(DBMAX.LT.DBT)DBMAX=DBT
      IF(DBMIN.GT.DBT)DBMIN=DBT
      IF(PHIMAX.GT.TOPHI)PHIMAX=TOPHI
      IF(PHIMIN.LT.TOPHI)PHIMIN=TOPHI
      DBPLT(KLM-101)=DBT
      PHIBLT(KLM-101)=TOPHI
 1150 CONTINUE
      WRITE(6,1170)
 1170 FORMAT(2X,'WHICH DO YOU WANT?',5X,'BODE.OR NYQT?',/,2X,'TYPE IN
     1 BODE OR NYQT',/)
 1175 READ(6,7)COMM
      IF(COMM.EQ.BODE)GO TO 1180
      IF(COMM.EQ.NYQT)GO TO 1190
      WRITE(6,8)
      GO TO 1175
 1180 NBRAN=1
      CALL GRAPH
      GO TO 1195
 1190 NBRAN=2
      CALL GRAPH
      IF(NBRAN.EQ.1)GO TO 1195
      GO TO 1295
 1195 WRITE(6,1200)
 1200 FORMAT(2X,'DO YOU WANT A PRINT OUT OF THE BODE PLOT?',/,
     1 2X,'TYPE IN YES OR NO',/)
 1201 READ(6,7)CIM
      IF (CIM.EQ.YES)GO TO 1202
      IF(CIM.EQ.NO)GO TO 1225
      WRITE(6,8)
      GO TO 1201
 1202 IF(KOUNT.EQ.1)GO TO 1203
      GO TO 1206
 1203 WRITE(7,59)
      WRITE(7,60)
      DO 1205 NIF=1,NORD
      NORT=NIF-1
      WRITE(7,62)NORT,RD(NIF),RN(NIF)
 1205 CONTINUE
      GO TO 1210
 1206 WRITE(7,59)
      WRITE(7,60)
      DO 1208 JJ=1,80
      IF(RD(JJ).EQ.0..AND.RN(JJ).EQ.0.)GO TO 1208
      KROL=JJ-1
      WRITE(7,62)KROL,RD(JJ),RN(JJ)
 1208 CONTINUE
 1210 WRITE(7,1211)
 1211 FORMAT(50X,'****BODE PLOT****')
      WRITE(7,1213)FF
 1213 FORMAT(40X,'STARTING FREQUENCY=',1PE15.7,2X,'RAD/SEC')
      WRITE(7,1215)EF
 1215 FORMAT(40X,'FINAL FREQUENCY=',1PE15.7,2X,'RAD/SEC')
      WRITE(7,1214)
 1214 FORMAT(20X,'FREQUENCY',33X,'MAGNITUDE',34X,'PHASE')
      DO 1221 JOJ=1,401,2
      SF=FF+(JOJ-1)*DIVI
      WRITE(7,1216)SF,DBPLT(JOJ),PHIBLT(JOJ)
```

```
1216      FORMAT(18X,1PE11.4,32X,1PE11.4,32X,1PE11.4)
1221      CONTINUE
1225      WRITE(6,1230)
1230      FORMAT(2X,'DO YOU WANT TO ENTER NEW FREQUENCY LIMITS?',/,
     1    2X,'TYPE IN YES OR NO',/)
1235      READ(6,7)COM
          IF(COM.EQ.YES)GO TO 1239
          IF(COM.EQ.NO)GO TO 1240
          WRITE(6,8)
          GO TO 1235
1239      IF(KOUNT.EQ.1)GO TO 3
          IF(KOUNT.EQ.2)GO TO 1241
1241      KOUNT1=KOUNT
          GO TO 1
1240      WRITE(6,1245)
1245      FORMAT(2X,'DO YOU WANT TO START OVER AGAIN?',/,2X,'TYPE IN YES OR
     1    NO',/)
1250      READ(6,7)CEM
          IF(CEM.EQ.YES)GO TO 1260
          IF(CEM.EQ.NO)GO TO 1500
          WRITE(6,8)
          GO TO 1250
1260      KOUNT1=0
          GO TO 1
1295      WRITE(6,1300)
1300      FORMAT(2X,'DO YOU WANT A PRINT OUT OF THE NYQUIST PLOT?',/,2X,
     1    'TYPE IN YES OR NO',/)
1301      READ(6,7)COM
          IF(COM.EQ.YES)GO TO 1302
          IF(COM.EQ.NO)GO TO 1225
          WRITE(6,8)
          GO TO 1301
1302      IF(KOUNT.EQ.1)GO TO 1303
          GO TO 1306
1303      WRITE(7,59)
          WRITE(7,60)
          DO 1305 NIF=1,NORD
          NORT=NIF-1
          WRITE(7,62)NORT,RD(NIF),RN(NIF)
1305      CONTINUE
          GO TO 1310
1306      WRITE(7,59)
          WRITE(7,60)
          DO 1308 JJ=1,80
          IF(RD(JJ).EQ.0..AND.RN(JJ).EQ.0.)GO TO 1308
          KROL=JJ-1
          WRITE(7,62)KROL,RD(JJ),RN(JJ)
1308      CONTINUE
1310      WRITE(7,1311)
1311      FORMAT(50X,'****NYQUIST PLOT****')
          WRITE(7,1213)FF
          WRITE(7,1215)EF
          WRITE(7,1214)
          DO 1350 JOG=1,401,2
          SF=FF+(JOG-1)*DIVI
          CONY=10.**(DBPLT(JOG)/20.)
          WRITE(7,1216)SF,CONY,PHIBLT(JOG)
1350      CONTINUE
          GO TO 1225
1500      STOP
```

```
      END

      SUBROUTINE GRAPH
      DIMENSION IBUF(6000),DBPLT(401),PHIBLT(401)
      COMMON DBPLT,PHIBLT,SF,EF,DBMIN,DBMAX,PHIMIN,PHIMAX,DIVI,NBRAN
      DATA YES/4HYES /,NO/4HNO  /
      REAL YES,NO
      FOF=SF
      NGRAPH=0
1     CALL INIT(IBUF,6000)
      IF(NBRAN.EQ.1)GO TO 5
      GO TO 106
5     CALL APNT(160.,590.,1,-5)
      CALL SUBP(999)
      CALL VECT(0.,400.,0,5)
      CALL ESUB
      CALL OFF(999)
      CALL SUBP(1000,999)
      CALL APNT(160.,22.,0,-8)
      CALL VECT(10.,0.,0,5)
      CALL VECT(590.,0.,0,1)
      CALL VECT(0.,400.,0,1)
      CALL VECT(-590.,0.,0,1)
      CALL VECT(-10.,0.,0,5)
      CALL VECT(0.,-400.,0,5)
      Y=22.
      DO 10 J=1,4
      Y=Y+100.
      CALL APNT (160.,Y,0,-8)
      CALL VECT(10.,0.,0,5)
      CALL VECT(590.,0.,0,1)
10    CONTINUE
      CALL APNT(160.,590.,0,-5)
      CALL VECT(0.,400.,0,5)
      CALL VECT(10.,0.,0,5)
      CALL VECT(590.,0.,0,1)
      CALL VECT(0.,-400.,0,1)
      CALL VECT(-590.,0.,0,1)
      CALL VECT(-10.,0.,0,5)
      Y=590.
      DO 15 J=1,4
      Y=Y+100.
      CALL APNT(160.,Y,0,-8)
      CALL VECT(10.,0.,0,5)
      CALL VECT(590.,0.,0,1)
15    CONTINUE
      CALL APNT(763.,590.,0,-8)
      CALL TEXT('RAD/SEC')
      CALL APNT(763.,20.,0,-8)
      CALL TEXT('RAD/SEC')
      CALL APNT(400.,1010.,0,-8)
      CALL TEXT('BODE ANALYSIS')
      CALL APNT(160.,1000.,0,-8)
      CALL TEXT('DECIBELS')
      CALL APNT(160.,422.,0,-8)
      CALL TEXT('DEGREES')
      CALL APNT(800.,900.,0,-8)
      CALL TEXT('BODE')
      CALL APNT(775.,875.,0,-8)
```

```
      CALL TEXT('MAGNITUDE')
      CALL APNT(250.,500.,0,-8)
      CALL TEXT('FREQUENCY=')
      CALL APNT(800.,300.,0,-8)
      CALL TEXT('BODE')
      CALL APNT(795.,275.,0,-8)
      CALL TEXT('PHASE')
      CALL APNT(100.,0.,0,-8)
      CALL NMBR(100,SF,'E11.4')
      CALL APNT(750.,0.,0,-8)
      CALL NMBR(101,EF,'E11.4')
      CALL APNT(100.,565.,0,-8)
      CALL NMBR(102,SF,'E11.4')
      CALL APNT(750.,565.,0,-8)
      CALL NMBR(103,EF,'E11.4')
      SCALE=(DBMIN-DBMAX)/4.
      Y=1090.
      DO 30 JJ=1,5
      Y=Y-100.
      PSCALE=DBMAX+SCALE*(JJ-1)
      CALL APNT(0.,Y,0,-8)
      CALL NMBR(150+JJ,PSCALE,'E11.4')
30    CONTINUE
      SCALE=(PHIMIN-PHIMAX)/4.
      Y=522.
      DO 40 JJ=1,5
      Y=Y-100.
      PSCALE=PHIMIN-SCALE*(JJ-1)
      CALL APNT(0.,Y,0,-8)
      CALL NMBR(200+JJ,PSCALE,'E11.4')
40    CONTINUE
      FF=SF
      GDIVX=ABS((ALOG10(EF)-ALOG10(SF))/600.)
      GMAGY=(DBMIN-DBMAX)/400.
      GPHIY=ABS(PHIMAX-PHIMIN)/400.
      WFP=160
      WMY=990.
      WPY=422.
      DO 50 J=26,401,25
      SF=FF+(J-1)*DIVI
      RFPT=(ALOG10(SF)-ALOG10(FF))/GDIVX
      RNFPT=WFP+RFPT
      CALL APNT(RNFPT,590.,0,-8)
      CALL VECT(0.,15.,0,1)
      CALL APNT(RNFPT,990.,0,-8)
      CALL VECT(0.,-15.,0,1)
      CALL APNT(RNFPT,422.,0,-8)
      CALL VECT(0.,-15.,0,1)
      CALL APNT(RNFPT,22.,0,-8)
      CALL VECT(0.,15.,0,1)
50    CONTINUE
      DO 75 J=1,400
      SF=FF+(J-1)*DIVI
      RFPT=(ALOG10(SF)-ALOG10(FF))/GDIVX
      RNFPT=WFP+RFPT
      RMPT=ABS((DBMAX-DBPLT(J))/GMAGY)
      RMPLT=WMY-RMPT
      SF=FF+(J)*DIVI
      RFPT1=(ALOG10(SF)-ALOG10(FF))/GDIVX
      RNFPT1=WFP+RFPT1
```

```
      RMPT1=ABS((DBMAX-DBPLT(J+1))/GMAGY)
      RMPLT1=WMY-RMPT1
      CALL APNT(RNFPT, RMPLT, 0, 5)
      CALL VECT(RNFPT1-RNFPT, RMPLT1-RMPLT, 0, 5)
      PMPT=ABS((PHIMIN-PHIBLT(J)))/GPHIY
      PMPLT=WPY-PMPT
      PMPT1=ABS((PHIMIN-PHIBLT(J+1)))/GPHIY
      PMPLT1=WPY-PMPT1
      CALL APNT(RNFPT, PMPLT, 0, 5)
      CALL VECT(RNFPT1-RNFPT, PMPLT1-PMPLT, 0, 5)
75    CONTINUE
      LN=0
      WRITE(6, 80)
80    FORMAT(2X, 'DETAILED EXAMINATION OF THE PLOT IS OBTAINED', /, 2X, 'BY
     1 TYPING IN AN INTERGER NUMBER FROM 1 TO 401', /, 2X, 'TO EXIT FROM
     1 THIS MODE TYPE IN INTERGER >401', /, 2X, 'TYPE IN INTEGER', /)
95    READ(6, 90)JIJ
90    FORMAT(I20)
      IF(JIJ. LT. 1)GO TO 95
      IF(JIJ. GT. 401)GO TO 100
      CALL APNT(RNFPT, 590., 0, -4)
      CALL ERAS(LN+1001)
      CALL ERAS(LN+2001)
      SF=FF+(JIJ-1)*DIVI
      RFPT=(ALOG10(SF)-ALOG10(FF))/GDIVX
      RNFPT=WFP+RFPT
      CALL APNT(RNFPT, 590., 0, -8)
      CALL SUBP(1001+JIJ, 999)
      CALL APNT(RNFPT, 22., 0, -8)
      CALL SUBP(2001+JIJ, 999)
      CALL APNT(780., 850., 0, -8)
      CALL NMBR(200., DBPLT(JIJ), 'E11. 4')
      CALL APNT(400., 500., 0, -8)
      CALL NMBR(301, SF, 'E11. 4')
      CALL APNT(795., 250., 0, -8)
      CALL NMBR(402, PHIBLT(JIJ), 'E11. 4')
      LN=JIJ
      GO TO 95
100   IF(NGRAPH. EQ. 1)GO TO 200
      WRITE(6, 101)
101   FORMAT(2X, 'DO YOU WANT NYQUIST PLOT?', /, 2X, 'TYPE IN YES OR NO', /)
102   READ(6, 103)COM
103   FORMAT(A4)
      IF(COM. EQ. YES)GO TO 105
      IF(COM. EQ. NO)GO TO 175
      WRITE(6, 104)
104   FORMAT(10X, '*****ILLEGAL COMMAND ENTRY*****')
      GO TO 102
105   CALL FREE
      CALL INIT(IBUF, 3000)
106   RCON=10. **((DBMAX)/20. )
      CALL SCAL(-RCON, -RCON, RCON, RCON)
      IF(RCON. GE. 1. )GO TO 110
      GO TO 120
110   CALL APNT(-1., 0., 0, -5)
      CALL SUBP(1001)
      CALL VECT(0., . 05*RCON)
      CALL TEXT('-1')
      CALL ESUB
120   CALL APNT(0., -RCON, 0, -8)
```

```
      CALL VECT(0.,2*RCON,0,1)
      CALL APNT(-RCON,0.,0,-8)
      CALL VECT(2*RCON,0.,0,1)
      CALL APNT(0.,RCON,0,-1)
      CALL TEXT('IMAG')
      CALL APNT((.85*RCON),0.,0,-1)
      CALL TEXT('REAL')
      CALL APNT(-.8*RCON,.8*RCON,0,-5)
      CALL TEXT('NYQUIST PLOT')
      RAD=3.14159/180.
      DO 130 JJ=1,400
      CON=10.**(DBPLT(JJ)/20.)
      CON1=10.**((DBPLT(JJ+1))/20.)
      XR=CON*(COS((PHIBLT(JJ)*(RAD))))
      YR=CON*(SIN((PHIBLT(JJ)*(RAD))))
      XR1=CON1*COS(PHIBLT(JJ+1)*RAD)
      YR1=CON1*SIN(PHIBLT(JJ+1)*RAD)
      CALL APNT(XR,YR,0,5)
      CALL VECT(XR1-XR,YR1-YR,0,5)
130   CONTINUE
      CALL APNT(.4*RCON,.8*RCON,0,-5)
      CALL TEXT('FREQ=')
      CALL APNT(.4*RCON,.7*RCON,0,-5)
      CALL TEXT('MAG=')
      CALL APNT(.4*RCON,.6*RCON,0,-5)
      CALL TEXT('ANGLE=')
      LOP=678
      WRITE(6,80)
135   READ(6,140)NUM
140   FORMAT(I4)
      CALL ERAS(LOP)
      IF(NUM.LT.1)GO TO 135
      IF(NUM.GT.401)GO TO 175
      FREQ=FOF+(NUM-1)*DIVI
      VER=10.**(DBPLT(NUM)/20.)
      XRR=VER*(COS((PHIBLT(NUM)*(RAD))))
      YRR=VER*(SIN((PHIBLT(NUM)*(RAD))))
      PKI=PHIBLT(NUM)
      CALL SUBP(900)
      CALL VECT(0.,.1*RCON,0,5)
      CALL VECT(0.,-.1*RCON,0,-8)
      CALL VECT(0.,-.1*RCON,0,5)
      CALL VECT(0.,.1*RCON,0,5)
      CALL VECT(-.1*RCON,0.,0,5)
      CALL VECT(.1*RCON,0.,0,-8)
      CALL VECT(.1*RCON,0.,0,5)
      CALL ESUB
      CALL OFF(900)
      CALL APNT(XRR,YRR,0,-8)
      CALL SUBP(NUM,900)
      CALL ERAS(900)
      CALL APNT(.55*RCON,.8*RCON,0,-5)
      CALL NMBR(777,FREQ,'E10.3')
      CALL APNT(.5*RCON,.7*RCON,0,-5)
      CALL NMBR(888,VER,'E10.3')
      CALL APNT(.58*RCON,.6*RCON,0,-5)
      CALL NMBR(999,PKI,'E10.3')
      LOP=NUM
      GO TO 135
175   IF (NBRAN.EQ.1)GO TO 200
```

```
      WRITE(6,180)
180   FORMAT(2X,'DO YOU WANT BODE PLOT?',/,2X,'TYPE IN YES OR NO',/)
185   READ(6,103)COM
      IF(COM.EQ.YES)GO TO 190
      IF(COM.EQ.NO)GO TO 200
      WRITE(6,104)
      GO TO 185
190   NBRAN=1
      NGRAPH=1
      CALL FREE
      GO TO 1
200   RETURN
      END
```

APPENDIX V

TRANSFER FUNCTION

COEFFICIENTS	NUMERATOR	DENOMINATOR
S** 0	0.000000E-01	2.304034E-01
S** 1	2.649790E-02	1.094303E-01
S** 2	0.000000E-01	1.271931E+00
S** 3	1.214919E-01	4.828747E-01
S** 4	0.000000E-01	2.679184E+00
S** 5	1.922179E-01	7.513314E-01
S** 6	0.000000E-01	2.678997E+00
S** 7	1.214919E-01	4.828435E-01
S** 8	0.000000E-01	1.271670E+00
S** 9	2.649790E-02	1.094163E-01
S**10	0.000000E-01	2.303268E-01

****BODE PLOT****

STARTING FREQUENCY= 5.4170001E-01 RAD/SEC

FINAL FREQUENCY= 1.9000000E+00 RAD/SEC

FREQUENCY	MAGNITUDE	PHASE
5.4170E-01	-2.2037E+01	6.8337E+01
5.4849E-01	-2.1893E+01	6.7798E+01
5.5528E-01	-2.1753E+01	6.7241E+01
5.6207E-01	-2.1615E+01	6.6665E+01
5.6887E-01	-2.1481E+01	6.6067E+01
5.7566E-01	-2.1351E+01	6.5447E+01
5.8245E-01	-2.1225E+01	6.4804E+01
5.8924E-01	-2.1104E+01	6.4135E+01
5.9603E-01	-2.0989E+01	6.3438E+01
6.0282E-01	-2.0880E+01	6.2711E+01
6.0962E-01	-2.0777E+01	6.1951E+01
6.1641E-01	-2.0683E+01	6.1156E+01
6.2320E-01	-2.0598E+01	6.0322E+01
6.2999E-01	-2.0524E+01	5.9445E+01
6.3678E-01	-2.0463E+01	5.8520E+01
6.4357E-01	-2.0416E+01	5.7544E+01
6.5036E-01	-2.0387E+01	5.6509E+01
6.5716E-01	-2.0379E+01	5.5408E+01
6.6395E-01	-2.0396E+01	5.4233E+01
6.7074E-01	-2.0445E+01	5.2973E+01
6.7753E-01	-2.0532E+01	5.1615E+01
6.8432E-01	-2.0669E+01	5.0144E+01
6.9111E-01	-2.0869E+01	4.8540E+01
6.9790E-01	-2.1151E+01	4.6779E+01
7.0470E-01	-2.1546E+01	4.4826E+01
7.1149E-01	-2.2098E+01	4.2642E+01
7.1828E-01	-2.2881E+01	4.0167E+01
7.2507E-01	-2.4026E+01	3.7328E+01
7.3186E-01	-2.5794E+01	3.4010E+01
7.3865E-01	-2.8843E+01	3.0060E+01
7.4545E-01	-3.581[illegible]+01	2.5227E+01
7.5224E-01	-4.0137E+01	1.9914E+02
7.5903E-01	-2.7334E+01	1.9116E+02
7.6582E-01	-2.1889E+01	1.7999E+02
7.7261E-01	-2.1269E+01	1.6002E+02
7.7940E-01	-6.0118E+00	2.1146E+02
7.8619E-01	-6.9356E+00	1.5589E+02
7.9299E-01	-6.3308E+00	1.3357E+02
7.9978E-01	-6.0346E+00	1.1603E+02
8.0657E-01	-6.0603E+00	1.0233E+02
8.1336E-01	-6.2332E+00	9.1757E+01
8.2015E-01	-6.4391E+00	8.3487E+01

8.2694E-01	-6.6280E+00	7.6867E+01
8.3373E-01	-6.7768E+00	7.1386E+01
8.4053E-01	-6.8907E+00	6.6708E+01
8.4732E-01	-6.9657E+00	6.2602E+01
8.5411E-01	-7.0070E+00	5.8905E+01
8.6090E-01	-7.0220E+00	5.5515E+01
8.6769E-01	-7.0113E+00	5.2331E+01
8.7448E-01	-6.9832E+00	4.9308E+01
8.8127E-01	-6.9397E+00	4.6401E+01
8.8807E-01	-6.8844E+00	4.3572E+01
8.9486E-01	-6.8204E+00	4.0802E+01
9.0165E-01	-6.7497E+00	3.8068E+01
9.0844E-01	-6.6748E+00	3.5355E+01
9.1523E-01	-6.5981E+00	3.2653E+01
9.2202E-01	-6.5210E+00	2.9954E+01
9.2882E-01	-6.4454E+00	2.7254E+01
9.3561E-01	-6.3727E+00	2.4542E+01
9.4240E-01	-6.3042E+00	2.1824E+01
9.4919E-01	-6.2412E+00	1.9098E+01
9.5598E-01	-6.1847E+00	1.6362E+01
9.6277E-01	-6.1357E+00	1.3621E+01
9.6956E-01	-6.0949E+00	1.0876E+01
9.7636E-01	-6.0624E+00	8.1286E+00
9.8315E-01	-6.0392E+00	5.3887E+00
9.8994E-01	-6.0253E+00	2.6569E+00
9.9673E-01	-6.0209E+00	3.5675E-02
1.0035E+00	-6.0252E+00	-2.6602E+00
1.0103E+00	-6.0387E+00	-5.3414E+00
1.0171E+00	-6.0608E+00	-7.9893E+00
1.0239E+00	-6.0910E+00	-1.0611E+01
1.0307E+00	-6.1283E+00	-1.3193E+01
1.0375E+00	-6.1722E+00	-1.5740E+01
1.0443E+00	-6.2224E+00	-1.8256E+01
1.0511E+00	-6.2771E+00	-2.0726E+01
1.0579E+00	-6.3362E+00	-2.3161E+01
1.0646E+00	-6.3984E+00	-2.5558E+01
1.0714E+00	-6.4626E+00	-2.7919E+01
1.0782E+00	-6.5281E+00	-3.0245E+01
1.0850E+00	-6.5933E+00	-3.2537E+01
1.0918E+00	-6.6583E+00	-3.4809E+01
1.0986E+00	-6.7206E+00	-3.7052E+01
1.1054E+00	-6.7798E+00	-3.9280E+01
1.1122E+00	-6.8357E+00	-4.1505E+01
1.1190E+00	-6.8854E+00	-4.3720E+01
1.1258E+00	-6.9292E+00	-4.5950E+01
1.1326E+00	-6.9662E+00	-4.8205E+01
1.1394E+00	-6.9941E+00	-5.0487E+01
1.1461E+00	-7.0126E+00	-5.2821E+01
1.1529E+00	-7.0188E+00	-5.5220E+01
1.1597E+00	-7.0111E+00	-5.7699E+01
1.1665E+00	-6.9919E+00	-6.0307E+01
1.1733E+00	-6.9564E+00	-6.3062E+01
1.1801E+00	-6.9041E+00	-6.6006E+01
1.1869E+00	-6.8334E+00	-6.9191E+01
1.1937E+00	-6.7423E+00	-7.2667E+01
1.2005E+00	-6.6358E+00	-7.6541E+01
1.2073E+00	-6.5128E+00	-8.0895E+01
1.2141E+00	-6.3774E+00	-8.5863E+01
1.2208E+00	-6.2364E+00	-9.1586E+01
1.2276E+00	-6.1157E+00	-9.8261E+01

1.2344E+00	-6.0361E+00	-1.0610E+02
1.2412E+00	-6.0419E+00	-1.1529E+02
1.2480E+00	-6.1699E+00	-1.2594E+02
1.2548E+00	-6.4656E+00	-1.3813E+02
1.2616E+00	-6.8696E+00	-1.5215E+02
1.2684E+00	-6.9544E+00	-1.7119E+02
1.2752E+00	-6.2222E+00	-2.3014E+02
1.2820E+00	-2.7171E+01	-1.4779E+02
1.2888E+00	-2.0378E+01	-1.6811E+02
1.2956E+00	-2.1541E+01	-1.7860E+02
1.3023E+00	-2.4149E+01	-1.8598E+02
1.3091E+00	-2.7920E+01	-1.9185E+02
1.3159E+00	-3.3801E+01	-1.9662E+02
1.3227E+00	-4.9640E+01	-2.0064E+02
1.3295E+00	-3.8873E+01	-2.4050E+01
1.3363E+00	-3.2429E+01	-2.7022E+01
1.3431E+00	-2.9227E+01	-2.9614E+01
1.3499E+00	-2.7202E+01	-3.1921E+01
1.3567E+00	-2.5782E+01	-3.3979E+01
1.3635E+00	-2.4730E+01	-3.5831E+01
1.3703E+00	-2.3919E+01	-3.7516E+01
1.3771E+00	-2.3278E+01	-3.9050E+01
1.3838E+00	-2.2762E+01	-4.0458E+01
1.3906E+00	-2.2341E+01	-4.1756E+01
1.3974E+00	-2.1994E+01	-4.2960E+01
1.4042E+00	-2.1706E+01	-4.4082E+01
1.4110E+00	-2.1465E+01	-4.5127E+01
1.4178E+00	-2.1264E+01	-4.6108E+01
1.4246E+00	-2.1094E+01	-4.7031E+01
1.4314E+00	-2.0952E+01	-4.7898E+01
1.4382E+00	-2.0833E+01	-4.8721E+01
1.4450E+00	-2.0732E+01	-4.9498E+01
1.4518E+00	-2.0649E+01	-5.0237E+01
1.4586E+00	-2.0580E+01	-5.0940E+01
1.4653E+00	-2.0523E+01	-5.1610E+01
1.4721E+00	-2.0478E+01	-5.2249E+01
1.4789E+00	-2.0442E+01	-5.2861E+01
1.4857E+00	-2.0415E+01	-5.3446E+01
1.4925E+00	-2.0395E+01	-5.4008E+01
1.4993E+00	-2.0381E+01	-5.4548E+01
1.5061E+00	-2.0374E+01	-5.5066E+01
1.5129E+00	-2.0371E+01	-5.5565E+01
1.5197E+00	-2.0373E+01	-5.6046E+01
1.5265E+00	-2.0380E+01	-5.6510E+01
1.5333E+00	-2.0390E+01	-5.6957E+01
1.5401E+00	-2.0404E+01	-5.7390E+01
1.5468E+00	-2.0420E+01	-5.7809E+01
1.5536E+00	-2.0440E+01	-5.8214E+01
1.5604E+00	-2.0462E+01	-5.8606E+01
1.5672E+00	-2.0486E+01	-5.8987E+01
1.5740E+00	-2.0512E+01	-5.9356E+01
1.5808E+00	-2.0540E+01	-5.9714E+01
1.5876E+00	-2.0569E+01	-6.0062E+01
1.5944E+00	-2.0600E+01	-6.0400E+01
1.6012E+00	-2.0633E+01	-6.0728E+01
1.6080E+00	-2.0666E+01	-6.1048E+01
1.6148E+00	-2.0701E+01	-6.1360E+01
1.6215E+00	-2.0737E+01	-6.1663E+01
1.6283E+00	-2.0773E+01	-6.1958E+01
1.6351E+00	-2.0811E+01	-6.2246E+01

1.6419E+00	-2.0849E+01	-6.2527E+01
1.6487E+00	-2.0888E+01	-6.2801E+01
1.6555E+00	-2.0927E+01	-6.3069E+01
1.6623E+00	-2.0968E+01	-6.3330E+01
1.6691E+00	-2.1008E+01	-6.3585E+01
1.6759E+00	-2.1049E+01	-6.3834E+01
1.6827E+00	-2.1090E+01	-6.4078E+01
1.6895E+00	-2.1132E+01	-6.4316E+01
1.6963E+00	-2.1174E+01	-6.4549E+01
1.7030E+00	-2.1216E+01	-6.4778E+01
1.7098E+00	-2.1259E+01	-6.5001E+01
1.7166E+00	-2.1301E+01	-6.5219E+01
1.7234E+00	-2.1344E+01	-6.5434E+01
1.7302E+00	-2.1387E+01	-6.5643E+01
1.7370E+00	-2.1430E+01	-6.5849E+01
1.7438E+00	-2.1474E+01	-6.6050E+01
1.7506E+00	-2.1517E+01	-6.6248E+01
1.7574E+00	-2.1560E+01	-6.6442E+01
1.7642E+00	-2.1604E+01	-6.6632E+01
1.7710E+00	-2.1647E+01	-6.6818E+01
1.7778E+00	-2.1691E+01	-6.7001E+01
1.7845E+00	-2.1734E+01	-6.7180E+01
1.7913E+00	-2.1778E+01	-6.7357E+01
1.7981E+00	-2.1821E+01	-6.7530E+01
1.8049E+00	-2.1865E+01	-6.7700E+01
1.8117E+00	-2.1908E+01	-6.7867E+01
1.8185E+00	-2.1951E+01	-6.8031E+01
1.8253E+00	-2.1995E+01	-6.8193E+01
1.8321E+00	-2.2038E+01	-6.8351E+01
1.8389E+00	-2.2081E+01	-6.8507E+01
1.8457E+00	-2.2124E+01	-6.8660E+01
1.8525E+00	-2.2167E+01	-6.8811E+01
1.8593E+00	-2.2210E+01	-6.8960E+01
1.8660E+00	-2.2252E+01	-6.9106E+01
1.8728E+00	-2.2295E+01	-6.9249E+01
1.8796E+00	-2.2337E+01	-6.9390E+01
1.8864E+00	-2.2380E+01	-6.9530E+01
1.8932E+00	-2.2422E+01	-6.9667E+01
1.9000E+00	-2.2464E+01	-6.9801E+01

TRANSFER FUNCTION

COEFFICIENTS	NUMERATOR	DENOMINATOR
S** 0	0.000000E-01	2.304034E-01
S** 1	2.649790E-02	1.094303E-01
S** 2	0.000000E-01	1.271931E+00
S** 3	1.214919E-01	4.828747E-01
S** 4	0.000000E-01	2.679184E+00
S** 5	1.922179E-01	7.513314E-01
S** 6	0.000000E-01	2.678997E+00
S** 7	1.214919E-01	4.828435E-01
S** 8	0.000000E-01	1.271670E+00
S** 9	2.649790E-02	1.094163E-01
S**10	0.000000E-01	2.303268E-01

****NYQUIST PLOT****

STARTING FREQUENCY= 5.4170001E-01 RAD/SEC

FINAL FREQUENCY= 1.9000000E+00 RAD/SEC

FREQUENCY	MAGNITUDE	PHASE
5.4170E-01	7.9095E-02	6.8337E+01
5.4849E-01	8.0415E-02	6.7798E+01
5.5528E-01	8.1728E-02	6.7241E+01
5.6207E-01	8.3033E-02	6.6665E+01
5.6887E-01	8.4324E-02	6.6067E+01
5.7566E-01	8.5596E-02	6.5447E+01
5.8245E-01	8.6845E-02	6.4804E+01
5.8924E-01	8.8062E-02	6.4135E+01
5.9603E-01	8.9240E-02	6.3438E+01
6.0282E-01	9.0370E-02	6.2711E+01
6.0962E-01	9.1440E-02	6.1951E+01
6.1641E-01	9.2436E-02	6.1156E+01
6.2320E-01	9.3344E-02	6.0322E+01
6.2999E-01	9.4144E-02	5.9445E+01
6.3678E-01	9.4814E-02	5.8520E+01
6.4357E-01	9.5325E-02	5.7544E+01
6.5036E-01	9.5645E-02	5.6509E+01
6.5716E-01	9.5735E-02	5.5408E+01
6.6395E-01	9.5542E-02	5.4233E+01
6.7074E-01	9.5006E-02	5.2973E+01
6.7753E-01	9.4054E-02	5.1615E+01
6.8432E-01	9.2587E-02	5.0144E+01
6.9111E-01	9.0481E-02	4.8540E+01
6.9790E-01	8.7585E-02	4.6779E+01
7.0470E-01	8.3695E-02	4.4826E+01
7.1149E-01	7.8537E-02	4.2642E+01
7.1828E-01	7.1770E-02	4.0167E+01
7.2507E-01	6.2909E-02	3.7328E+01
7.3186E-01	5.1322E-02	3.4010E+01
7.3865E-01	3.6128E-02	3.0060E+01
7.4545E-01	1.6198E-02	2.5227E+01
7.5224E-01	9.8432E-03	1.9914E+02
7.5903E-01	4.2983E-02	1.9116E+02
7.6582E-01	8.0456E-02	1.7999E+02
7.7261E-01	8.6408E-02	1.6002E+02
7.7940E-01	5.0051E-01	2.1146E+02
7.8619E-01	4.5001E-01	1.5589E+02
7.9299E-01	4.8246E-01	1.3357E+02
7.9978E-01	4.9920E-01	1.1603E+02
8.0657E-01	4.9772E-01	1.0233E+02
8.1336E-01	4.8791E-01	9.1757E+01
8.2015E-01	4.7648E-01	8.3487E+01

8.2694E-01	4.6623E-01	7.6867E+01
8.3373E-01	4.5821E-01	7.1386E+01
8.4053E-01	4.5234E-01	6.6708E+01
8.4732E-01	4.4845E-01	6.2602E+01
8.5411E-01	4.4632E-01	5.8905E+01
8.6090E-01	4.4555E-01	5.5515E+01
8.6769E-01	4.4610E-01	5.2331E+01
8.7448E-01	4.4755E-01	4.9308E+01
8.8127E-01	4.4979E-01	4.6401E+01
8.8807E-01	4.5267E-01	4.3572E+01
8.9486E-01	4.5602E-01	4.0802E+01
9.0165E-01	4.5974E-01	3.8068E+01
9.0844E-01	4.6372E-01	3.5355E+01
9.1523E-01	4.6784E-01	3.2653E+01
9.2202E-01	4.7201E-01	2.9954E+01
9.2882E-01	4.7613E-01	2.7254E+01
9.3561E-01	4.8014E-01	2.4542E+01
9.4240E-01	4.8394E-01	2.1824E+01
9.4919E-01	4.8746E-01	1.9098E+01
9.5598E-01	4.9064E-01	1.6362E+01
9.6277E-01	4.9342E-01	1.3621E+01
9.6956E-01	4.9574E-01	1.0876E+01
9.7636E-01	4.9760E-01	8.1286E+00
9.8315E-01	4.9893E-01	5.3887E+00
9.8994E-01	4.9973E-01	2.6569E+00
9.9673E-01	4.9998E-01	3.5675E-02
1.0035E+00	4.9974E-01	-2.6602E+00
1.0103E+00	4.9896E-01	-5.3414E+00
1.0171E+00	4.9769E-01	-7.9893E+00
1.0239E+00	4.9597E-01	-1.0611E+01
1.0307E+00	4.9384E-01	-1.3193E+01
1.0375E+00	4.9135E-01	-1.5740E+01
1.0443E+00	4.8851E-01	-1.8256E+01
1.0511E+00	4.8545E-01	-2.0726E+01
1.0579E+00	4.8216E-01	-2.3161E+01
1.0646E+00	4.7872E-01	-2.5558E+01
1.0714E+00	4.7519E-01	-2.7919E+01
1.0782E+00	4.7163E-01	-3.0245E+01
1.0850E+00	4.6810E-01	-3.2537E+01
1.0918E+00	4.6461E-01	-3.4809E+01
1.0986E+00	4.6129E-01	-3.7052E+01
1.1054E+00	4.5815E-01	-3.9280E+01
1.1122E+00	4.5521E-01	-4.1505E+01
1.1190E+00	4.5262E-01	-4.3720E+01
1.1258E+00	4.5034E-01	-4.5950E+01
1.1326E+00	4.4842E-01	-4.8205E+01
1.1394E+00	4.4699E-01	-5.0487E+01
1.1461E+00	4.4603E-01	-5.2821E+01
1.1529E+00	4.4572E-01	-5.5220E+01
1.1597E+00	4.4611E-01	-5.7699E+01
1.1665E+00	4.4710E-01	-6.0307E+01
1.1733E+00	4.4893E-01	-6.3062E+01
1.1801E+00	4.5164E-01	-6.6006E+01
1.1869E+00	4.5533E-01	-6.9191E+01
1.1937E+00	4.6013E-01	-7.2667E+01
1.2005E+00	4.6581E-01	-7.6541E+01
1.2073E+00	4.7245E-01	-8.0895E+01
1.2141E+00	4.7988E-01	-8.5863E+01
1.2208E+00	4.8773E-01	-9.1586E+01
1.2276E+00	4.9455E-01	-9.8261E+01

1.2344E+00	4.9911E-01	-1.0610E+02
1.2412E+00	4.9878E-01	-1.1529E+02
1.2480E+00	4.9148E-01	-1.2594E+02
1.2548E+00	4.7503E-01	-1.3813E+02
1.2616E+00	4.5344E-01	-1.5215E+02
1.2684E+00	4.4904E-01	-1.7119E+02
1.2752E+00	4.8853E-01	-2.3014E+02
1.2820E+00	4.3796E-02	-1.4779E+02
1.2888E+00	9.5747E-02	-1.6811E+02
1.2956E+00	8.3740E-02	-1.7860E+02
1.3023E+00	6.2019E-02	-1.8598E+02
1.3091E+00	4.0178E-02	-1.9185E+02
1.3159E+00	2.0416E-02	-1.9662E+02
1.3227E+00	3.2962E-03	-2.0064E+02
1.3295E+00	1.1386E-02	-2.4050E+01
1.3363E+00	2.3910E-02	-2.7022E+01
1.3431E+00	3.4567E-02	-2.9614E+01
1.3499E+00	4.3641E-02	-3.1921E+01
1.3567E+00	5.1391E-02	-3.3979E+01
1.3635E+00	5.8008E-02	-3.5831E+01
1.3703E+00	6.3689E-02	-3.7516E+01
1.3771E+00	6.8566E-02	-3.9050E+01
1.3838E+00	7.2762E-02	-4.0458E+01
1.3906E+00	7.6375E-02	-4.1756E+01
1.3974E+00	7.9487E-02	-4.2960E+01
1.4042E+00	8.2165E-02	-4.4082E+01
1.4110E+00	8.4475E-02	-4.5127E+01
1.4178E+00	8.6458E-02	-4.6108E+01
1.4246E+00	8.8161E-02	-4.7031E+01
1.4314E+00	8.9620E-02	-4.7898E+01
1.4382E+00	9.0859E-02	-4.8721E+01
1.4450E+00	9.1916E-02	-4.9498E+01
1.4518E+00	9.2803E-02	-5.0237E+01
1.4586E+00	9.3543E-02	-5.0940E+01
1.4653E+00	9.4152E-02	-5.1610E+01
1.4721E+00	9.4648E-02	-5.2249E+01
1.4789E+00	9.5039E-02	-5.2861E+01
1.4657E+00	9.5340E-02	-5.3446E+01
1.4925E+00	9.5560E-02	-5.4008E+01
1.4993E+00	9.5708E-02	-5.4548E+01
1.5061E+00	9.5791E-02	-5.5066E+01
1.5129E+00	9.5817E-02	-5.5565E+01
1.5197E+00	9.5792E-02	-5.6046E+01
1.5265E+00	9.5720E-02	-5.6510E+01
1.5333E+00	9.5608E-02	-5.6957E+01
1.5401E+00	9.5458E-02	-5.7390E+01
1.5468E+00	9.5275E-02	-5.7809E+01
1.5536E+00	9.5063E-02	-5.8214E+01
1.5604E+00	9.4824E-02	-5.8606E+01
1.5672E+00	9.4561E-02	-5.8987E+01
1.5740E+00	9.4278E-02	-5.9356E+01
1.5808E+00	9.3975E-02	-5.9714E+01
1.5876E+00	9.3656E-02	-6.0062E+01
1.5944E+00	9.3322E-02	-6.0400E+01
1.6012E+00	9.2974E-02	-6.0728E+01
1.6080E+00	9.2615E-02	-6.1048E+01
1.6148E+00	9.2246E-02	-6.1360E+01
1.6215E+00	9.1867E-02	-6.1663E+01
1.6283E+00	9.1480E-02	-6.1958E+01
1.6351E+00	9.1087E-02	-6.2246E+01