COMPUTER ANALYSIS AND DESIGN OF ELECTRICAL CIRCUITS USING THE IBM 360/67 AND THE XDS 9300 COMPUTER AND THE AGT/10 DISPLAY UNIT

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THESIS

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by

Banthit Nutasara

December 1974

Thesis Advisor: Charles H. Rothauge

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Computer Analysis and Design of Electrical Circuits Using the IBM 360/67 and the XDS 9300 Computer and the AGT/10 Display Unit

by

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I. INTRODUCTION

Network analysis and synthesis, in general, continues to become less time-consuming and complex as a result of the continued upgrading of large-scale network-analysis computer programs which allow the circuit designer to economically and efficiently examine the performance of a circuit during the various stages of its design, by using a computer rather than connect the real elements in the laboratory. In this way the designer can rapidly determine the variations in circuit response that correspond to changes in circuit parameters. Studies can be made of circuits that contain costly components that may be difficult to obtain. Destructive excitation can be applied to the circuit with no fear of destroying expensive electronic circuit elements. Measurements that may be difficult to make, and time consuming to instrument, can be made quite simply on the computer. Circuit connections can be changed rapidly. In many cases the computer can leave the designer with a clearer in-sight into the operation of the circuit than could be obtained from the laboratory.

A major disadvantage of the large-scale network analysis programs such as the IBM 1620 ELECTRONIC CIRCUIT ANALYSIS PROGRAM (ECAP) WITH DISPLAY UNIT which can fulfill the requirement of the design engineer is the vast amount of core storage as well as the accessories needed. If a large computer is not available to the design engineer, many of the

more sophisticated programs will not be at his disposal. Additionally, owing to the fact that network synthesis, particularly filter design, is approached from many aspects depending on the specific application; the small special-purpose program may provide the required design parameters with the using of a smaller computer such as the XDS 9300 COMPUTER AND THE AGT/10 DISPLAY UNIT suplemented by an available large-scale program in the case of the complicated circuits.

Computer-aided design procedures are exemplified herein by analysis of the two-port network approached by state variable and solved to get the time response plotted on the screen of the display unit. The variations in circuit response that correspond to changes in circuit parameter are observed. Additionally the frequency response approached from the La Place Transform was also determined.

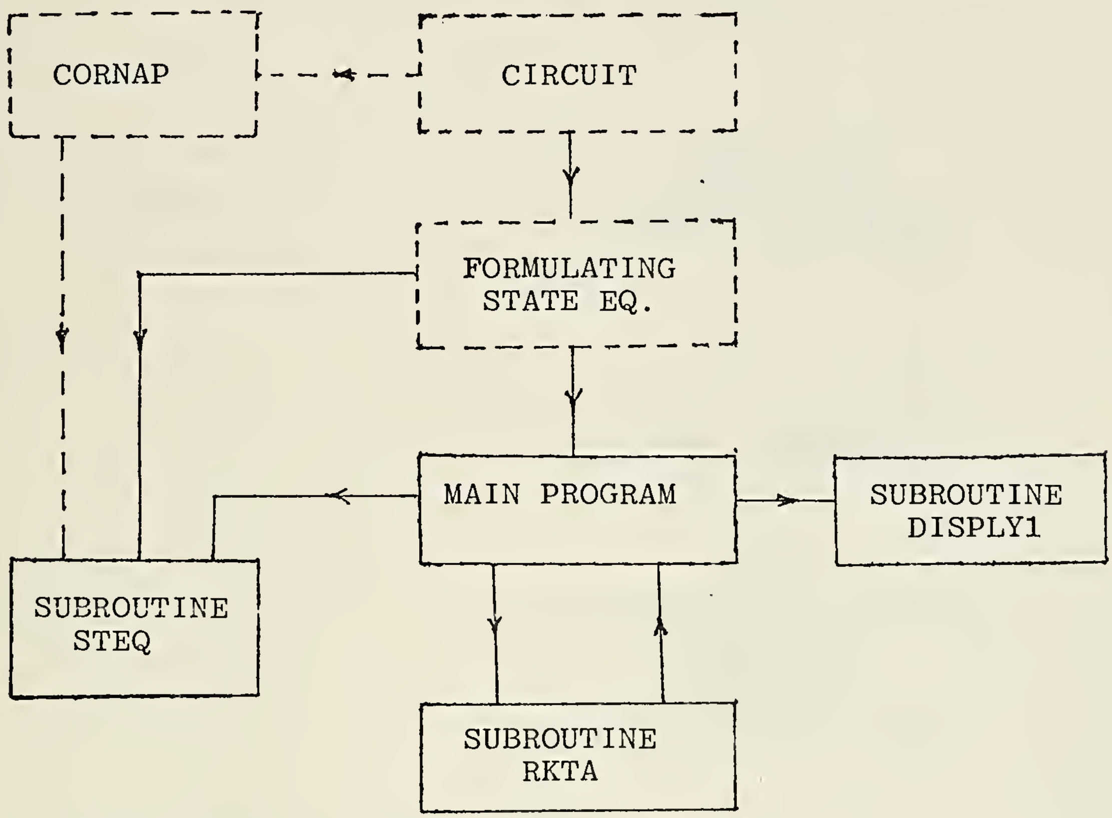
Some aspects of computer programs, the methods to formulate the state equations and transfer functions, the correlation of time and frequency response and the frequency scaling are discussed in this thesis.

Two-port networks as filters are used to illustrate the analysis and design by using the small-scale computer programs that provide the output as a time response over a wide range of the variations of parameters and to investigate the character of the time response which in some aspects can predict the character of the frequency response. The computer programs that provide the frequency response plot of the transfer function in the case of the transfer function in

the s-domain available are also used to get the exact frequency response.

II. COMPUTER PROGRAMS FOR ANALYSIS

Flow Chart for Time Response Program



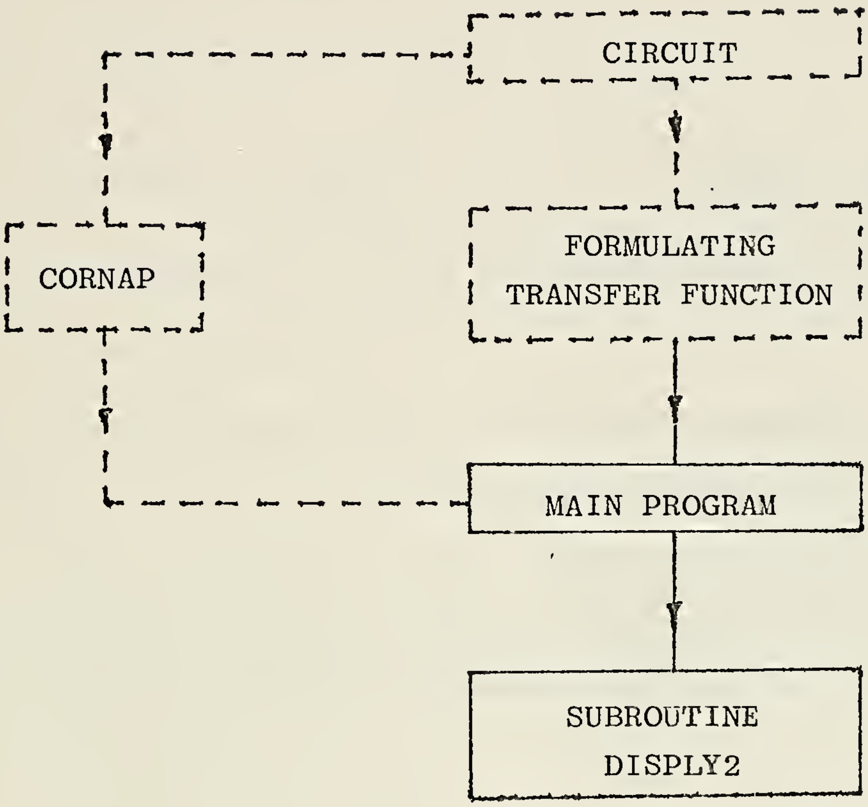
MAIN PROGRAM CONTROL PARAMETER (COEFFICIENT) of the State Equations and the curve to be displayed.

SUBROUTINE STEQ Describe the State equations to be computed.

SUBROUTINE RKTA Solve the n-order linear differential equations.

SUBROUTINE DISPLY1 Plot the result on the CRT of AGT/10.

Flow chart for Frequency Response Program



A. FORMULATING STATE EQUATIONS

The state equations may be obtained from the KVL and KCL by the use of certain combinations of the loop and node equations. The state equations are the set of differential equation of n linear first-order differential equations in n unknowns,

$$
\begin{aligned}
\dot{y}_1 &= a_{11}y_1 + a_{12}y_2 + \cdots\cdots + a_{1n}y_n + U_1 \\
\dot{y}_2 &= a_{21}y_1 + a_{22}y_2 + \cdots\cdots + a_{2n}y_n + U_2 \\
&\vdots \\
\dot{y}_n &= a_{n1}y_1 + a_{n2}y_2 + \cdots\cdots + a_{nn}y_n + U_n
\end{aligned}
$$

The state equation can also be written in matrix notation

$$[\dot{Y}] = [A][Y] + [U]$$

In a passive network (RLC), the state variables are usually taken to be the capacitor voltages and inductor currents so that the tree and cotree must be selected such that the inductances and capacitances are appropriately located. The following algorithm accomplishes the desired result for most networks [2].

1. Select a Normal Tree:

    a. Put all branches corresponding to voltage sources and capacitances in the tree. This is possible unless there are loops containing capacitances and voltage sources only.

    b. Put all branches corresponding to current sources and inductances in the cotree. This is possible unless there are cut sets containing current sources and inductances only.

    c. Put resistances in either tree or cotree.

2. Assign a Symbol (including Polarity) to each Branch:

    a. For each branch corresponding to an independent source use the source symbol.

b. For each tree branch corresponding to a capacitance or resistance assign a voltage symbol.

c. For each link corresponding to an inductance or resistance assign a current symbol.

d. For each branch corresponding to a controlled source use the control equation to label the branch in terms of symbols already defined (use only the symbols defined in a, b and c above not their derivatives or integrals).

3. For each branch of tree use KCL to write the capacitance current as a sum of link currents

$$C\dot{v}_C = \Sigma \text{ link currents}$$

For each branch of cotree use KVL to write the inductance voltage as a sum of tree branch voltages:

$$L\dot{i}_L = \Sigma \text{ tree branch voltages}$$

4. Solve the equations obtained in step 3 for the resistance voltages and current (v_R's and i_R's) in terms of inductance currents and capacitance voltages.

5. Use the step 4 equations to eliminate all resistance voltages and resistance currents from the step 3 equations.

B. SUBROUTINE STEQ (DY,Y,T,COF)

This subroutine describes the differential equations (state equations) as well as the coefficients of dependent variable which are computed or can be changed in the main program in order to get the results when the elements of the circuit are changed.

Calling Statement: CALL STEQ (DY,Y,T,COF)

DY = The array of derivatives of the dependent variable

Y = The array of dependent variable

T = Independent variable

COF = Coefficient of differential equations (state equations)

C. RUNGE-KUTTA METHOD

Among the existing numerical techniques to solve the differential equations such

$$\frac{dy}{dx} = f(x,y)$$

Runge-Kutta methods have found extensive use in the digital computation because of the distinguishing properties.

1) They are one-step methods to find y_{m+1}, we need only the information available at the preceding point, x_m, y_m.

2) They do not require the evaluation of any derivative of f(x,y) but only of the function f itself.

3) The truncation error for fourth order Runge-Kutta method is $e_T \simeq Kh^5$.

The first property makes it convenient to determine a solution of the n simultaneous differential equations.

The second property makes this method more practical than other methods such as Taylor series. However we have to evaluate f(x,y) for values of x and y. For a small error property here requires a small step size.

The Runge-Kutta method can be defined by the following five equations [1]

$$y_{m+1} = y_m + \frac{h}{6}(k_1 + 2k_2 + 2k_3 + k_4)$$

where

$$k_1 = f(x_m, y_m)$$

$$k_2 = f(x_m + \frac{h}{2}, y_m + \frac{hk_1}{2})$$

$$k_3 = f(x_m + \frac{h}{2}, y_m + \frac{hk_2}{2})$$

$$k_4 = f(x_m + h, y_m + hk)$$

$$h = \text{Step Size}$$

D. SUBROUTINE RKTA (DY,Y,NEQ,TINIT,TFINI,YINIT,YX,COF)

This subroutine computes the solution for a set of n simultaneous first-order differential equations with arbitrary initial conditions by a Runge-Kutta fourth order method and provides the output in matrix form.

Calling statement: CALL RKTA(DY,Y,NEQ,TINIT,TFINI,YINIT,YX,COF)

DY = The array of derivatives of the dependent variable with the dimension equal to number of dependent variables.

Y = The array of dependent variables.

NEQ = Numbers of equations which must be equal to the number of dependent variables.

TINIT = Time initial.

TFINI = Time finish.

YINIT = Initial Conditions of dependent variables.

YX = Output matrix which has the independent variable values in column one. The number of columns equal to n+1. The number of rows are equal to number of values of the independent variable to be computed.

COF = Coefficient of differential equation (state equations).

NOTE:

Dimension of DYF (Working matrix to find k_1, k_2, k_3, k_4 for each variable must be DYF(5,n).

Dimension of YK (Matrix for k_1, k_2, k_3, k_4 of each variable) must be YK(4,n).

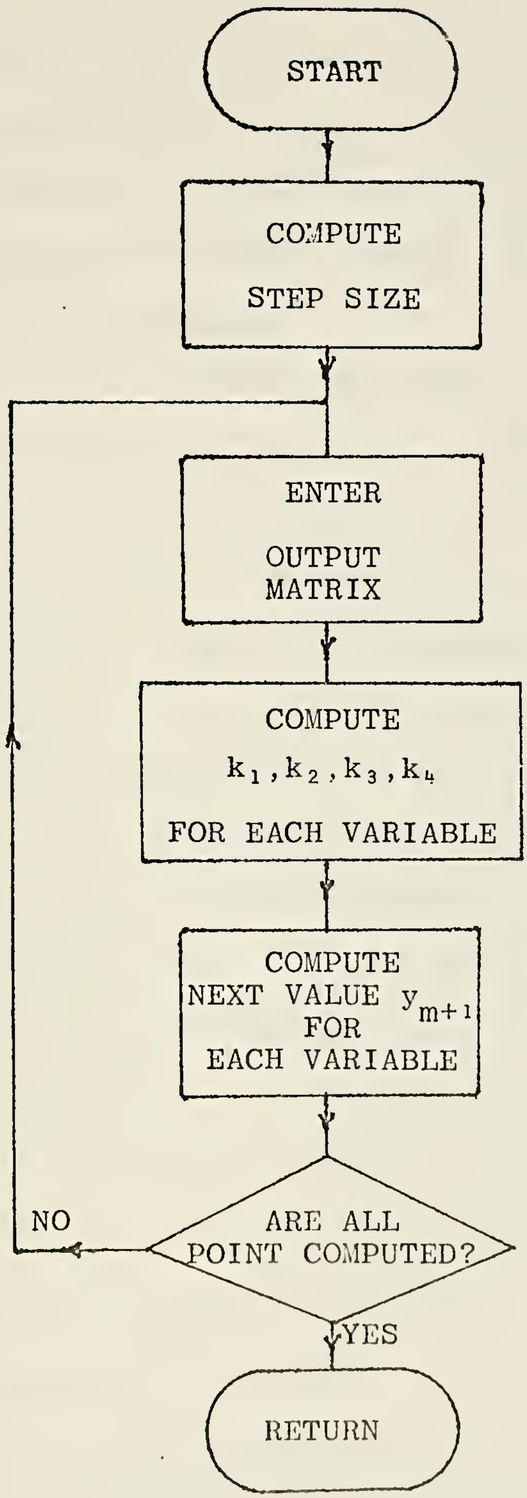
Dimension of YF (Value of dependent variable to find y_{m+1}) must be YF(1,n).

Subroutine STEQ(DY,Y,T,COF) also has to be supplied.

E. FORTRAN GRAPHICAL OPERATION [6]

There are two AGT/10s which can be connected to the XDS 9300 through a multiplexer and a word interface channel (24 bits parallel transfer) to the XDS 9300 memory. Each AGT/10 is a digital computer with 8K of core storage, two diskpacks, CRT display, lightpen and function switch inputs, and a teletypewriter. The AGT/10 is referred to as an "intelligent terminal" of the XDS 9300 because of the programmable digital computer it is built around. Use of the AGT/10 as an intelligent terminal of the XDS 9300 requires the use of the XDS 9300 CPU and main memory.

Flow Chart for Subroutine RKTA



To connect the AGT/10 with the XDS 9300 program "GATED" is used. The program "GATED" performs three tasks:

1) Refreshes the display screen. The screen is refreshed programmatically at about 40 frames per second, as a background (interrupt drive) task except during data transfers to or from the XDS 9300. During these data transfers no refreshing is performed.

2) Communicates with the graphics console operator, hereafter referred to as "operator." GATED uses the display, teletypewriter, lightpen, and function switches to communicate with the operator. The operator can create data or edit existing data. During the editing of data the screen will be refreshed but data will not be transferred between the AGT/10 and the XDS 9300. Control information is still passed between the AGT/10 and the XDS 9300.

3) Communicates with the FORTRAN callable graphics subroutines in the XDS 9300. These subroutines will be referred to as a FORTRAN graphics package hereafter. These procedures allow a FORTRAN program to send data to and retrieve data from AGT/10. Sending data changes the screen presentation. Retrieving data does not alter the display. All other operations stop during these data transfers.

F. FORTRAN GRAPHICS PACKAGE [6]

The graphic package subroutines is divided into two groups, one for the text, the other for the graphics. Because the graphics will be used in the computer program only, this part is concerned with the graphics only.

The graphics manipulation subroutines are designed to allow the graphics blocks of "GATED" to be created in the XDS 9300 sent to the AGT/10, and retrieved back into the XDS 9300 when desired.

1. Graphics Initialization Subroutine -- DGINIT

This routine must be called before any of the other graphics subroutines may be called. This routine identifies a FORTRAN array as the graphics directory, causes GATED, in the AGT/10, to initialize its graphics directory, and deletes all graphics blocks. This causes all the graphics information on the screen to be erased.

CALL DGINIT (IDEV,IDIR,NDIR,IERROR)

where:

- IDEV is an integer value specifying to the system, the AGT/10 unit number (1 or 2).
- IDIR is the graphics directory (an integer FORTRAN array).
- NDIR is the number of words in the graphics directory.
- IERROR is the error flag.

2. Graphics Output Subroutine -- GRAPHO

This routine outputs a graphics block to the specified AGT/10 and updates the graphics directory for the specified AGT/10.

CALL GRAPHO (IDEV,IMAGE,NWORD,IBLK,IERROR)

where:

IDEV is the value specifying AGT/10 unit number (1 or 2).

IMAGE is the address of the first word of the graphic data array (array name) to output. This word is more convenient to use than the special routines which will be described later.

NWORD is the number of words in the graphic data block.

IBLK is the graphic data block number.

IERROR is the error flag.

3. Graphic Output With Response Subroutine -- GRAPHR

This routine does exactly the same thing that GRAPHO does and in addition it causes "GATED" to go into the graphic edit mode for the graphic block that is in the output. This routine returns to the calling program as soon as "GATED" enters the edit mode. No graphic input occurs.

CALL GRAPHR (IDEV,IMAGE,NWORD,IBLK,IERROR)

where the parameters have the same meaning as in the call to GRAPHO.

4. Graphic Input Subroutine -- GRAPHI

This routine inputs a graphic block from the specified AGT/10 to the designated array.

CALL GRAPHI (IDEV,IMAGE,IBLK,IERROR)

where:

IDEV is the value specifying AGT/10 unit number (1 or 2).

IMAGE is the name where the graphic data block is to be placed.

IBLK is the graphic data block number.

IERROR is the error flag.

G. SPECIAL ROUTINES [6]

There are three routines which enable the user to create and use graphic blocks more easily. The first two routines, IHEAD and IPACK, are functions which construct the image array words. The third routine, UNPACK, is a subroutine that breaks out the X, Y and DM fields of the image array words for use as the FORTRAN variable.

1. Create Header Word - IHEAD

A FORTRAN function which is typically used as follows:

```
IMAGE(1) = IHEAD (IDSH,INT)
```

where:

IDSH is the dash/solid control. If IDSH = 0 the INT is the entensity. The value of INT ranges from 0 to 10. The value 0 corresponds to no intensity. The values 1 through 10 are approximately linear changes in intensity where 10 corresponds to maximum intensity and 1 corresponds to 10% of maximum intensity.

The IHEAD function fills in the header word (first word of the IMAGE array) with the proper data.

2. Create Image Word - IPACK

A FORTRAN function which is typically used as follows:

```
IMAGE(I) = IPACK (X,Y,IDM)
```

where:

X contains the value of X_i for the particular image point (word).

Y contains the value of Y_i for the particular image point (word).

IDM contains a one or a zero to denote a draw or a more respectively. Draw intensifies the line move does not.

X and Y may be integer or real value with the following ranges:

RANGES for the 20" by 20" DRAWING AREA

X or Y as INTEGER	$-2048 \leq X, Y \leq +2047$
X or Y as REAL	$-2.0 \leq X, Y \leq +2.0$

RANGES for the 10" by 10" VIEWING AREA

X or Y as INTEGER	$-1024 \leq X, Y \leq +1024$
X or Y as REAL	$-1.0 \leq X, Y \leq +1.0$

The purpose of this function is to do the following:

1) Take the value of X and put it in bits 0-10.
2) Set bit 11 to zero.
3) Take the value of Y and put it in bits 12-22.
4) Set bit 23 to the value of IDM.
5) Take the 24 bit word just formed and store it in IMAGE(I).

H. SUBROUTINE DISPLY1 (IDEV,YX,NCUR,I1,J1,I2,J2)

This subroutine obtains the matrix to be plotted from the main program and to plot the appropriate data on the screen of the CRT display. This subroutine provides the grids and

frame in order to concurrently interpret the values of the curves; two curves can be plotted at one time.

```
CALL DISPLY1 (IDEV,YX,NCUR,I1,J1,I2,J2)
```

where:

IDEV is an integer value specifying to the system, the AGT/10 unit number (1 or 2).

NCUR is number of curves in one plot (1 or 2).

YX is the matrix of data to be plotted.

$$\begin{bmatrix} \text{Indep. Var.} & \text{Dep. Var 1} & \text{Dep. Var 2} & -- & -- \\ -- & -- & -- & -- & -- \\ -- & -- & -- & -- & -- \\ -- & -- & -- & -- & -- \end{bmatrix}$$

I1 is the number of the column to be plotted on the X-axis of curve 1.

J1 is the number of the column to be plotted on the Y-axis of curve 1.

I2 is the number of the column to be plotted on the X-axis of curve 2.

J2 is the number of the column to be plotted on the Y-axis of curve 2.

I. SUBROUTINE DISPLY2 (IDEV,DBM,WL,SCALE)

This subroutine provides the plot on the screen of the display unit in log scale.

```
CALL DISPLY2 (IDEV,DBM,WL,SCALE)
```

where:

IDEV is an integer value specifying to the system, the AGT/10 unit number (1 or 2).

DBM is the array which will be plotted on Y-axis.

WL is the array which will be plotted on X-axis.

SCALE is the scale for Y-axis.

J. SUBROUTINE ILLUSTRATION

SUBROUTINE RKTA in Appendix A

SUBROUTINE DISPLY1 in Appendix B

SUBROUTINE DISPLY2 in Appendix C.

II. COMPUTER METHODS FOR CIRCUIT ANALYSIS

A. TIME-DOMAIN

The Kirchhoff voltage law (KVL) gives a summation of terms of the following three kinds: [4]

$$Ri(t),\ L\frac{di(t)}{dt},\ \frac{1}{C}\int i(t)dt,\ \text{and}\ M\frac{di(t)}{dt}$$

Similarly, the Kirchhoff current law (KCL) gives a summation of terms of the following forms:

$$\frac{v(t)}{R}\ ,\quad C\frac{dv(t)}{dt}\ ,\quad \frac{1}{L}\int v(t)dt\ \text{and}\ \frac{1}{M}\int v(t)dt$$

where

R - Resistance

C - Capacitance

L - Inductance

M - Mutual Inductance

i(t) - Current as function of time

v(t) - Voltage as function of time

By using the terms above and the technique to formulate the state equations from the given circuit are as described before.

The state equations then must be described in the subroutine STEQ in which the coefficient of the dependent variable (value of R,L,C) is controlled by the main program for the purpose of determining the effect of the response of the circuit in the time domain when the value of the elements of

the circuit changed. Subroutine RKTA then solves the state equations by the control of the main program. Subroutine DISPLY1 then plots the curve of the time-response on the screen of display unit (AGT/10). This is controlled by the main program.

B. FREQUENCY-DOMAIN

Approached by the method of Laplace Transforms [4]

$$\mathcal{L}\, i(t) = \int_0^\infty i(t)e^{-st}dt \equiv I(s)$$

$$\mathcal{L}\, \frac{di(t)}{dt} = sI(s)-i(0^+)$$

$$\mathcal{L} \int i(t)dt = \frac{I(s)}{S} + \frac{1}{S}\int i(t)dt\Big|_{t=0^+}$$

Neglecting initial conditions, the terms for KVL are:

$$RI(s),\ LsI(s) \text{ and } \frac{1}{Cs}\, I(s)$$

and the terms for KCL are:

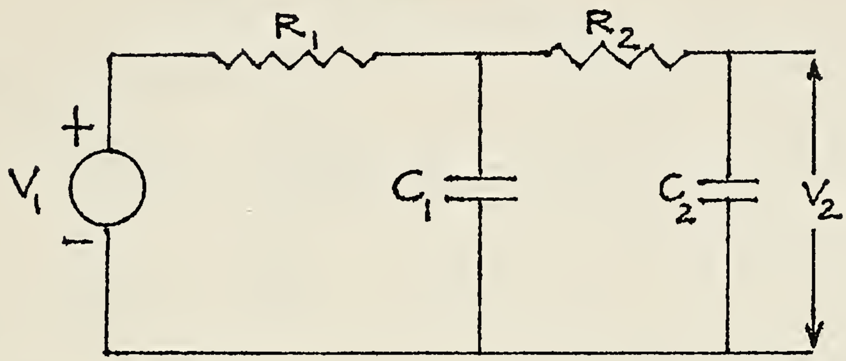
$$\frac{V(s)}{R},\ CsI(s) \text{ and } \frac{1}{Ls}\, V(s)$$

By using the terms above and the loop equations or node equations the transfer function can be formulated in the s-domain.

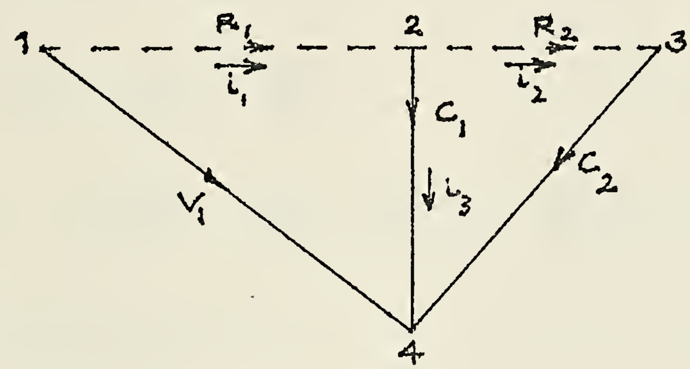
The main program for frequency response is realized by substituting jw for s and evaluating the response of the transfer function at different values of w. Subroutine DISPLY2 is then used to plot the frequency response with log scale on the screen of the display unit (AGT/10).

C. ANALYSIS OF TWO-PORT NETWORKS AS FILTERS

LOW PASS FILTER



Time-domain Analysis



KVL

$$i_1R_1+v_{C1}-v_1 = 0 \quad (1)$$

$$i_2R_2+v_{C2}-v_{C1} = 0 \quad (2)$$

KCL

$$i_3+i_2-i_1 = 0$$

$$i_1 = i_2+i_3 \quad (3)$$

$$i_2 = i_{C2} = C_2\frac{dv_{C2}}{dt}$$

$$i_3 = i_{C1} = C_1\frac{dv_{C1}}{dt}$$

From (3)

$$i_1 = C_2\frac{dv_{c2}}{dt} + C_1\frac{dv_{c1}}{dt}$$

Substitute i_1 in (1)

$$\left(C_1\frac{dv_{c1}}{dt} + C_2\frac{dv_{c2}}{dt}\right)R_1 + v_{c1} - v_1 = 0$$

$$C_1\frac{dv_{c1}}{dt} + C_2\frac{dv_{c2}}{dt} = -\frac{v_{c1}}{R_1} + \frac{v_1}{R_1} \qquad (4)$$

Substitute i_1 in (2)

$$R_2C_2\frac{dv_{c2}}{dt} + v_{c2} - v_{c1} = 0$$

$$C_2\frac{dv_{c2}}{dt} = \frac{v_{c1}}{R_2} - \frac{v_{c2}}{R_2} \qquad (5)$$

(4) - (5) $\quad C_1\frac{dv_{c1}}{dt} = -\left(\frac{1}{R_1} + \frac{1}{R_2}\right)v_{c1} + \frac{v_{c2}}{R_2} + \frac{v_1}{R_1}$

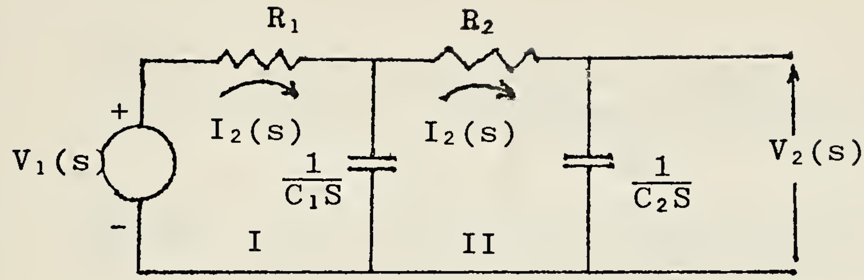
The state equations are:

$$\frac{dv_{c1}}{dt} = -\left(\frac{1}{R_1C_1} + \frac{1}{R_2C_1}\right)v_{c1} + \frac{v_{c2}}{R_2C_1} + \frac{V}{R_1C_1}$$

$$\frac{dv_{c2}}{dt} = \left(\frac{1}{R_2C_2}\right)v_{c1} - \frac{v_{c2}}{R_2C_2}$$

Output voltage $= v_{c2}$

S-domain Analysis



KVL

Loop I $\quad R_1 I_1(s) + (I_1(s) - I_2(s))\frac{1}{C_1 S} - V_1(s) = 0$

$$(R_1 + \frac{1}{C_1 S})I_1(s) - (\frac{1}{C_1 S})I_2(s) = V_1(s) \qquad (1)$$

Loop II $\quad R_2 I_2(s) + \frac{I_2(s)}{C_2 S} + (I_2(s) - I_1(s))\frac{1}{C_1 S} = 0$

$$-\frac{I_1(s)}{C_1 S} + (\frac{1}{C_1 S} + \frac{1}{C_2 S} + R_2)I_2(s) = 0 \qquad (2)$$

Matrix notation

$$\begin{bmatrix} R_1 + \frac{1}{C_1 S} & -\frac{1}{C_1 S} \\ -\frac{1}{C_1 S} & \frac{1}{C_1 S} + \frac{1}{C_2 S} + R_2 \end{bmatrix} \begin{bmatrix} I_1(s) \\ I_2(s) \end{bmatrix} = \begin{bmatrix} V_1(s) \\ 0 \end{bmatrix}$$

$$\Delta = (R_1 + \frac{1}{C_1 S})(\frac{1}{C_1 S} + \frac{1}{C_2 S} + R_2) - \frac{1}{C_1^2 S^2}$$

$$I_2(s) = \frac{1}{\Delta} \cdot \frac{V_1(s)}{C_1 S}$$

$$V_2(s) = \frac{1}{C_2 S} \cdot I_2(s) = \frac{V_1(s)}{C_1 C_2 S^2 \Delta}$$

Transfer function

$$\frac{V_2(s)}{V_1(s)} = \frac{1}{C_1C_2S^2\Delta} = \frac{1}{C_1C_2S^2[(R_1 + \frac{1}{C_1S})(\frac{1}{C_1S} + \frac{1}{C_2S} + R_2) - \frac{1}{C_1^2S^2}]}$$

$$\frac{V_2(s)}{V_1(s)} = \frac{1}{(R_1R_2C_1C_2)S^2 + (R_1C_1 + R_1C_2 + R_2C_2)S + 1}$$

For Unit step input

$R_1 = 1\ \Omega$, $R_1 = 1\ \Omega$

$R_1 = 1\ F$, $C_2 = 1\ F$

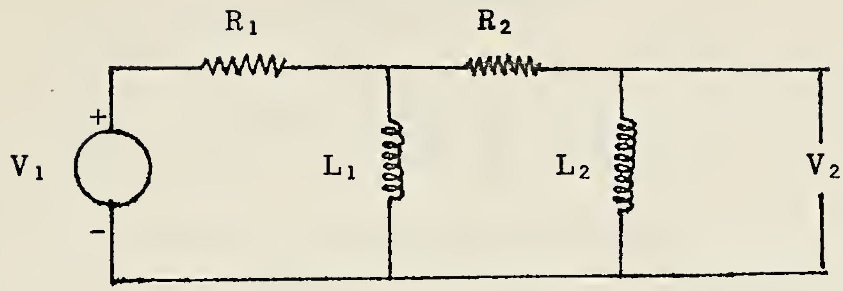
$$V_2(s) = \frac{1}{(S + 3S + 1)S}$$

$$= \frac{1}{S(S + 2.618)(S + 0.382)}$$

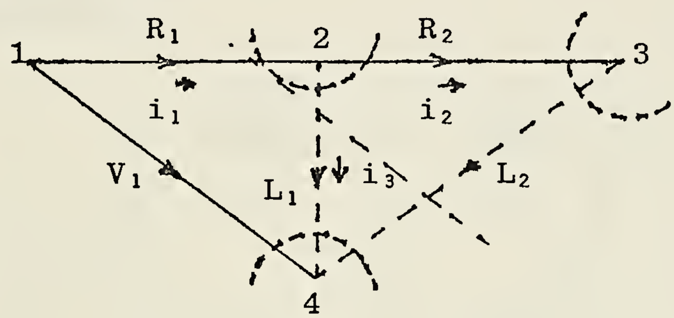
$$= \frac{1}{S} + \frac{0.17}{(S + 2.618)} - \frac{1.17}{(S + 0.382)}$$

$$v_2(t) = 1 + 0.17e^{-2.618t} - 1.17e^{-0.382t}$$

HIGH PASS FILTER



Time-domain Analysis



KVL

$$i_1 R_1 + L_1 \frac{di_{L1}}{dt} - V_1 = 0 \qquad (1)$$

$$i_1 R_1 + i_2 R_2 + L_2 \frac{di_{L2}}{dt} - V_1 = 0 \qquad (2)$$

KCL

$$i_2 = i_{L2}$$

$$i_1 - i_{L1} - i_{L2} = 0$$

$$i_1 = i_{L1} + i_{L2}$$

From (1)

$$R_1 (i_{L1} + i_{L2}) + L_1 \frac{di_{L1}}{dt} - V_1 = 0$$

$$\frac{di_{L1}}{dt} = - \frac{R_1}{L_1} i_{L1} - \frac{R_1}{L_1} i_{L2} + \frac{V_1}{L_1} \qquad (3)$$

From (2)

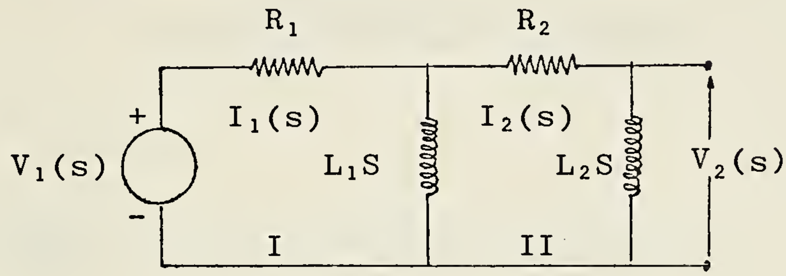
$$R_1(i_{L1}+i_{L2}) + R_2 i_{L2} + L_2\frac{di_{L2}}{dt} - V_1 = 0$$

$$\frac{di_{L2}}{dt} = -\frac{R_1 i_{L1}}{L_2} - \frac{(R_1+R_2)i_{L2}}{L_2} + \frac{V_1}{L_2} \qquad (4)$$

Equation (3) and (4) are state equations.

$$\text{Output voltage} = L_2\frac{di_{L2}}{dt} = V_1 - R_1 i_{L1} - (R_1+R_2)i_{L2}$$

S-domain Analysis



KVL

Loop I

$$R_1 I_1(s) + L_1 S(I_1(s) - I_2(s)) - V_1(s) = 0$$

$$(R_1 + L_1 S)I_1(s) - L_1 S\, I_2(s) = V_1(s) \qquad (1)$$

Loop II

$$R_2 I_2(s) + L_2 S\, I_2(s) + (I_2(s) - I_1(s))L_1 S = 0$$

$$-L_1 S\, I_1(s) + (R_2 + L_1 S + L_2 S)I_2(s) = 0 \qquad (2)$$

Matrix notation

$$\begin{pmatrix} R_1+L_1 S & -L_1 S \\ -L_1 S & R_2+L_1 S+L_2 S \end{pmatrix} \begin{pmatrix} I_1(s) \\ I_2(s) \end{pmatrix} = \begin{pmatrix} V_1(s) \\ 0 \end{pmatrix}$$

$$\Delta = (R_1+L_1S)(R_2+L_1S+L_2S) - L_1^2S^2$$

$$I_2(s) = \frac{L_1S\ V_1(s)}{\Delta}$$

$$= \frac{L_1S\ V_1(s)}{(R_1+L_1S)(R_2+L_1S+L_2S) - L_1^2S^2}$$

$$= \frac{L_1S\ V_1(s)}{L_1L_2S^2+(R_2L_1+R_1L_1+R_1L_2)S+R_1R_2}$$

$$V_2(s) = L_2S\ I_2(s)$$

$$V_2(s) = \frac{L_1L_2S^2V_1(s)}{L_1L_2S+(R_2L_1+R_1L_1+R_1L_2)S+R_1R_2}$$

Transfer function

$$\frac{V_2(s)}{V_1(s)} = \frac{L_1L_2S^2}{L_1L_2S^2+(R_2L_1+R_1L_1+R_1L_2)S+R_1R_2}$$

For $R_1 = 1\ \Omega$, $R_1 = 1\ \Omega$

$L_1 = 1$ H , $L_2 = 1$ H

$$\frac{V_2(s)}{V_1(s)} = \frac{S^2}{S + 3S + 1}$$

$$= \frac{S^2}{(S + 0.382)(S + 2.618)}$$

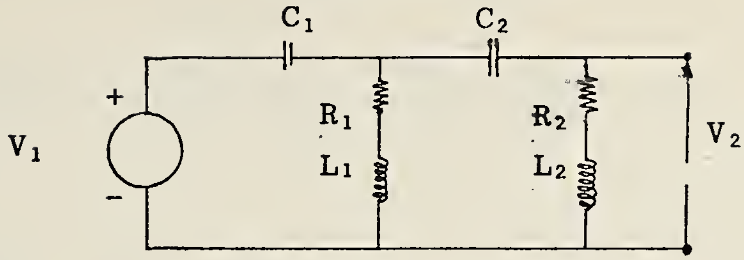
For Unit Step input

$$V_2(s) = \frac{S}{(S + 0.382)(S + 2.618)}$$

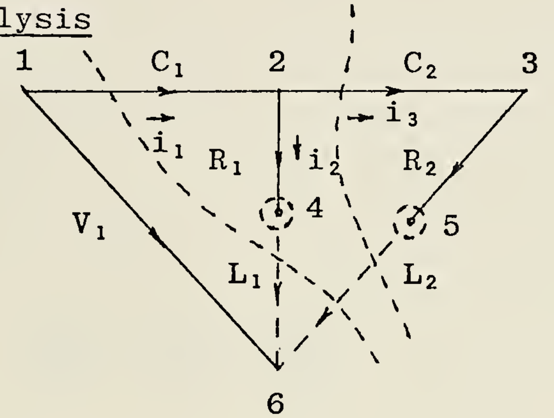
$$= \frac{1.17}{(S + 2.618)} - \frac{0.17}{(S + 0.382)}$$

$$v_2(t) = 1.17e^{-2.618t} - 0.17e^{-0.382t}$$

BANDPASS FILTER



Time-domain Analysis



KVL

$$L_1\frac{di_{L1}}{dt} - V_1 + v_{C1} + R_1 i_2 = 0 \quad (1)$$

$$L_2\frac{di_{L2}}{dt} - V_1 + v_{C1} + v_{C2} + R_2 i_3 = 0 \quad (2)$$

KCL

$$i_2 = i_{L1}$$

$$i_3 = i_{L2} = C_2\frac{dv_{C2}}{dt} \quad (3)$$

$$i_1 = i_{L1} + i_{L2} = C_1\frac{dv_{C1}}{dt} \quad (4)$$

Substitute $i_2 = i_{L2}$ in (1)

$$\frac{di_{L1}}{dt} = -\frac{R_1 i_{L1}}{L_1} - \frac{v_{C1}}{L_1} + \frac{V_1}{L_1}$$

Substitute $i_3 = i_{L2}$ in (2)

$$\frac{di_{L2}}{dt} = -\frac{R_2 i_{L2}}{L_2} - \frac{v_{c1}}{L_2} - \frac{v_{c2}}{L_2} + \frac{V_1}{L_2}$$

From (4)

$$\frac{dv_{c1}}{dt} = \frac{i_{L1}}{C_1} + \frac{i_{L2}}{C_1}$$

From (3)

$$\frac{dv_{c2}}{dt} = \frac{i_{L2}}{C_2}$$

The State-equations are:

$$\frac{di_{L1}}{dt} = -\frac{R_1 i_{L1}}{L_1} - \frac{v_{c1}}{L_1} + \frac{V_1}{L_1}$$

$$\frac{di_{L2}}{dt} = -\frac{R_2 i_{L2}}{L_2} - \frac{v_{c1}}{L_2} - \frac{v_{c2}}{L_2} + \frac{V_1}{L_2}$$

$$\frac{dv_{c1}}{dt} = \frac{i_{L1}}{C_1} + \frac{i_{L2}}{C_2}$$

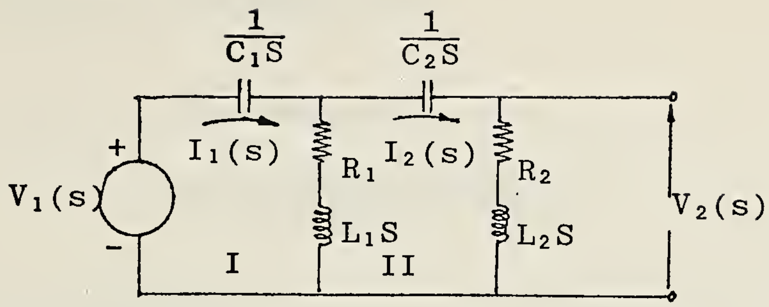
$$\frac{dv_{c2}}{dt} = \frac{i_{L2}}{C_2}$$

Output voltage

$$V_2 = V_{R2} + V_{L2}$$

$$= V_1 - v_{c1} - v_{c2}$$

S-domain Analysis



KVL

Loop I

$$\frac{I_1}{C_1S} + (I_1-I_2)R_1+(I_1-I_2)L_1S = V_1$$

$$\left(\frac{1}{C_1S} + R_1+L_1S\right)I_1(s) - (R_1+L_1S)I_2(s) = V_1 \qquad (1)$$

Loop II

$$(I_2-I_1)R + (I_2-I_1)L_1S + \frac{I_2}{C_2S} + (R_2+L_2S)I_2 = 0$$

$$-(R_1+L_1S)I_1(s)+\left(R_1+L_1S + \frac{1}{C_2S} + R_2+L_2S\right)I_2(s) = 0 \qquad (2)$$

Matrix notation

$$\begin{bmatrix} \frac{1}{C_1S} +R_1+L_1S & -(R_1+L_1S) \\ -(R_1+L_1S) & \left(R_1+L_1S+ \frac{1}{C_2S} +R_2+L_2S\right) \end{bmatrix} \begin{bmatrix} I_1(s) \\ I_2(s) \end{bmatrix} = \begin{bmatrix} V_1(s) \\ 0 \end{bmatrix}$$

$$\Delta = \left(\frac{1}{C_1S} + R_1+L_1S\right)\left(R_1+L_1S+ \frac{1}{C_2S} +R_2+L_2S\right)-(R_1+L_1S)^2$$

$$= \frac{1}{C_1C_2S^2}[(L_1L_2C_1C_2)S^4+(L_2C_1C_2R_1+L_1C_1C_2R_2)S^3$$

$$+(L_1C_2+L_2C_2+R_1R_2C_1C_2+L_1C_1)S^2+(R_1C_2+R_2C_2+R_1C_1)S+1]$$

$$I_2(s) = \frac{(R_1+L_1S)V_1(s)}{\Delta}$$

$$V_2(s) = (R_2+L_2S)I_2(s)$$

$$= \frac{(R_1+L_1S)(R_2+L_2S)V_1(s)}{\Delta}$$

Transfer function

$$\frac{V_2(s)}{V_1(s)} = \frac{C_1C_2S^2(R_1R_2+ (R_1L_2+R_2L_1)S + L_1L_2S^2)}{\Delta}$$

For $R_1 = 1$ ohm , $R_2 = 1$ ohm

$C_1 = 1$ farad, $C_2 = 1$ farad

$L_1 = 1$ henry, $L_2 = 1$ henry

Unit Step input

$$V_2(s) = \frac{S^3+2S^2+S}{S^4+2S^3+4S^2+3S+1}$$

$$= \frac{S(S+1)^2}{(S+0.5\pm j1.538)(S+0.5\pm j0.362)}$$

$$= \frac{0.585-j0.19}{S+.5-j1.538} + \frac{0.585+j0.19}{S+.5+j1.538} + \frac{-.085+j.117}{S+.5-j.362} + \frac{-.085-j.117}{S+.5+j.362}$$

$$= \frac{1.17(S+0.5)}{(S+.5)^2+(1.538)^2} + \frac{.379(1.538)}{(S+.5)^2+(1.538)^2} - \frac{.17(S+.5)}{(S+.5)^2+(.362)^2}$$

$$- \frac{.229(.362)}{(S+.5)^2+(.362)^2}$$

$$v_2(t) = 1.17e^{-.5t}\cos(1.538t)+.379e^{-.5t}\sin(1.538t)$$

$$-.17e^{-.5t}\cos(.362t)-.229e^{-.5t}\sin(.362t)$$

$$= 1.22e^{-.5t}\cos(1.538t+17.9^\circ)+0.285e^{-.5t}\cos(.362t+53.4^\circ)$$

D. COMPUTER SIMULATION OF TWO-PORT NETWORKS

COMPUTER SIMULATION

FOR LOWPASS FILTER

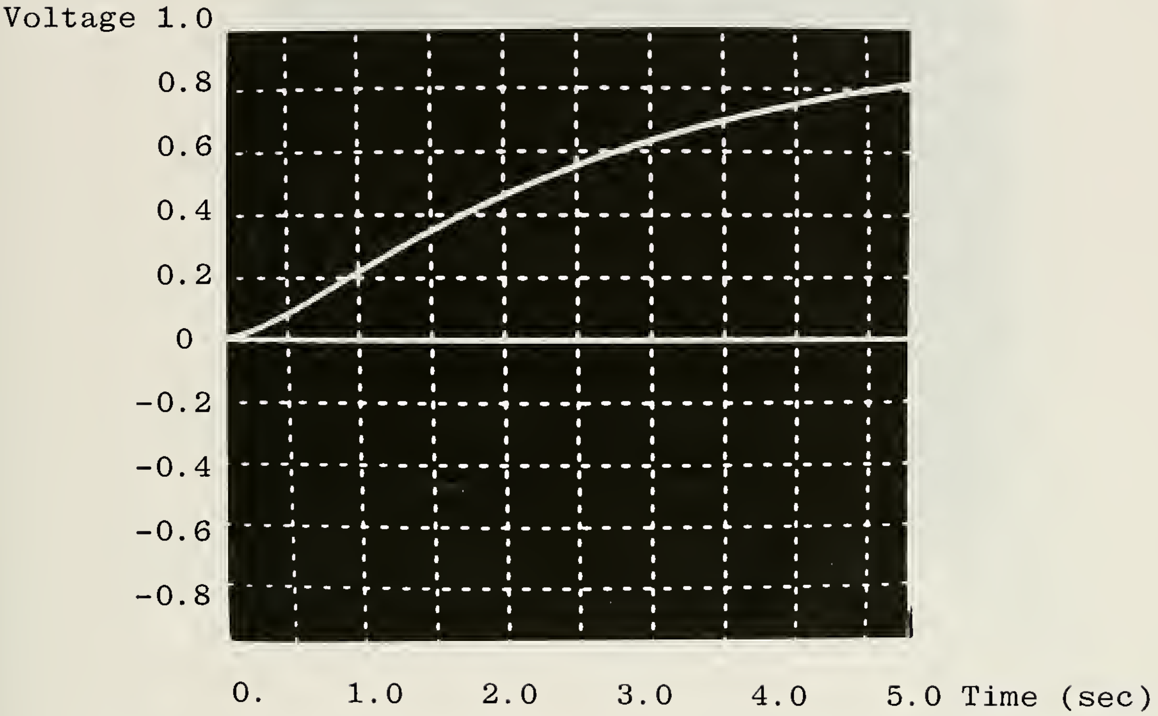


Figure 1

Time Response

R1 = 1 ohm, R2 = 1 ohm

C1 = 1 farad, C2 = 1 farad

Computer program in Appendix D.1

Computer Printout in Appendix D.2

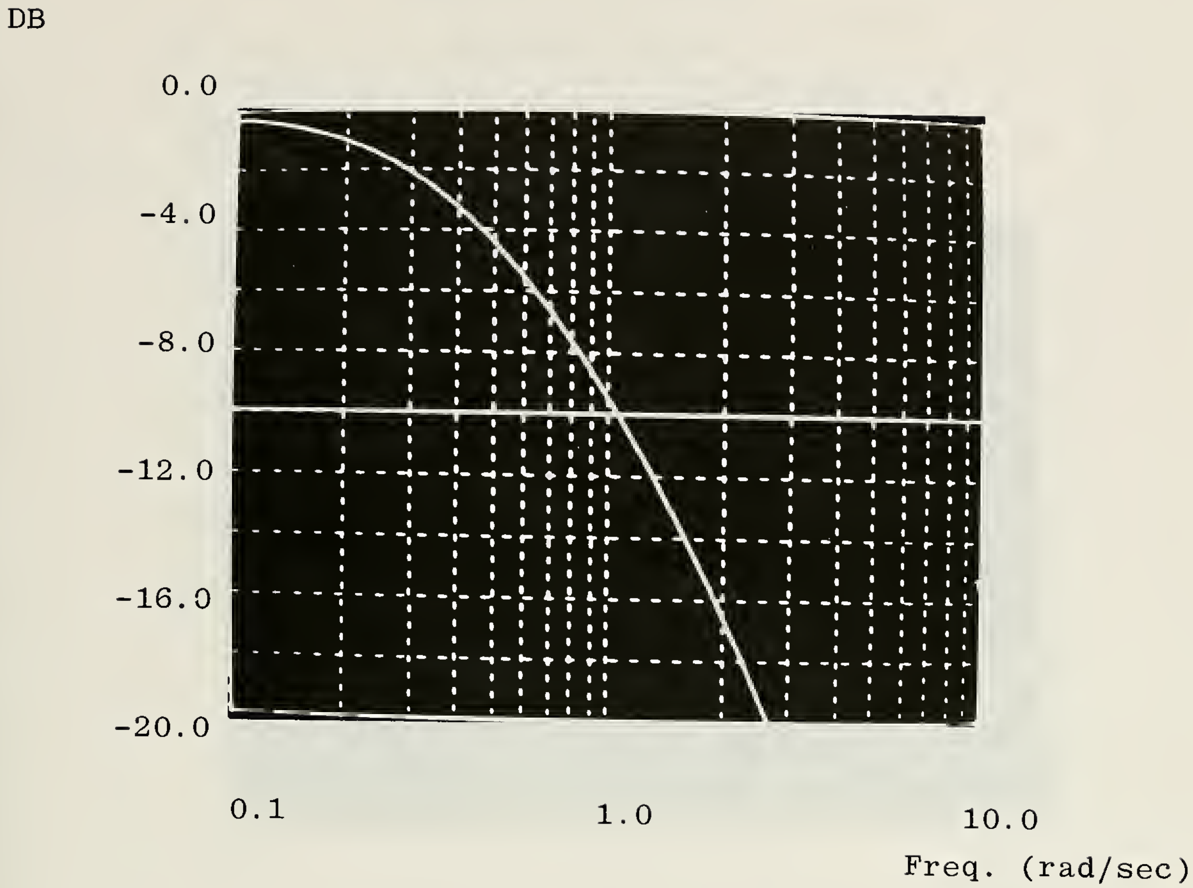


Figure 2

Frequency Response for Lowpass Filter

R1 = 1 ohm, R2 = 1 ohm

C1 = 1 farad, C2 = 1 farad

Computer program in Appendix D.3

Computer printout in Appendix D.4

COMPUTER SIMULATION

HIGHPASS FILTER

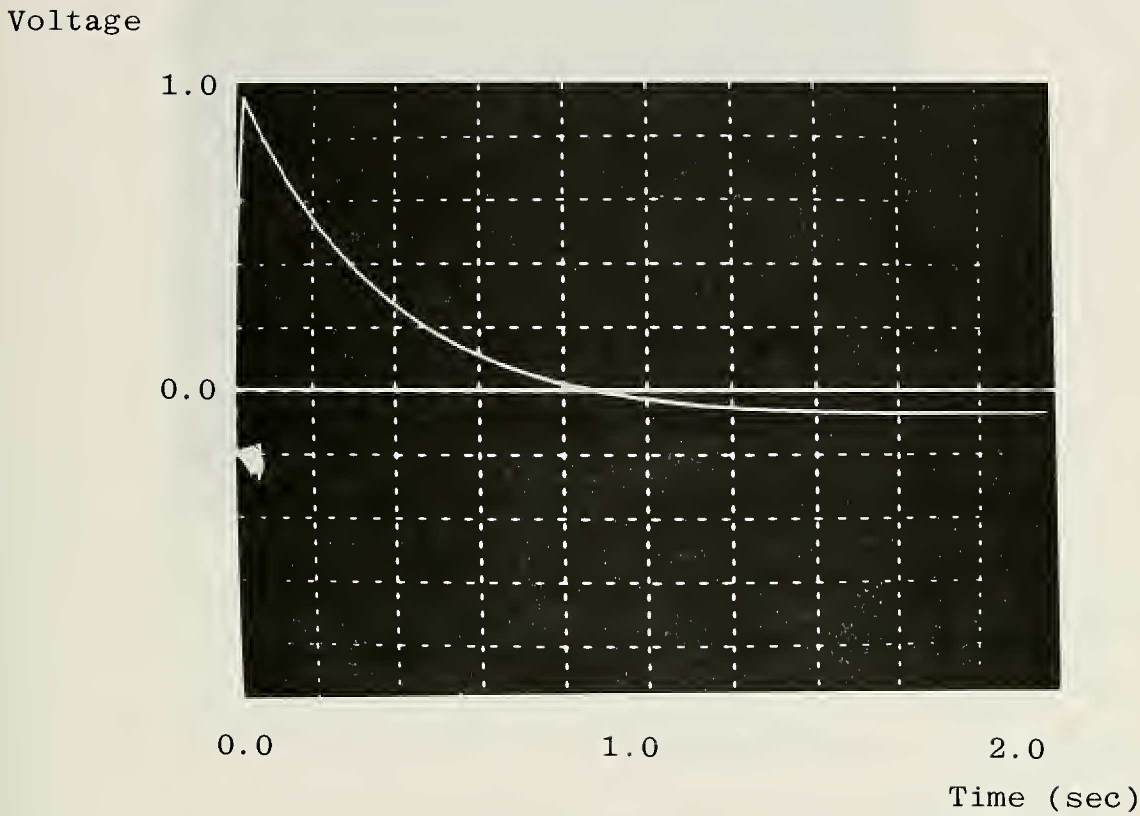


Figure 3

Time Response

R1 = 1 ohm, R2 = 1 ohm

L1 = 1 henry, L2 = 1 henry

Computer program in Appendix E.1

Computer printout in Appendix E.2

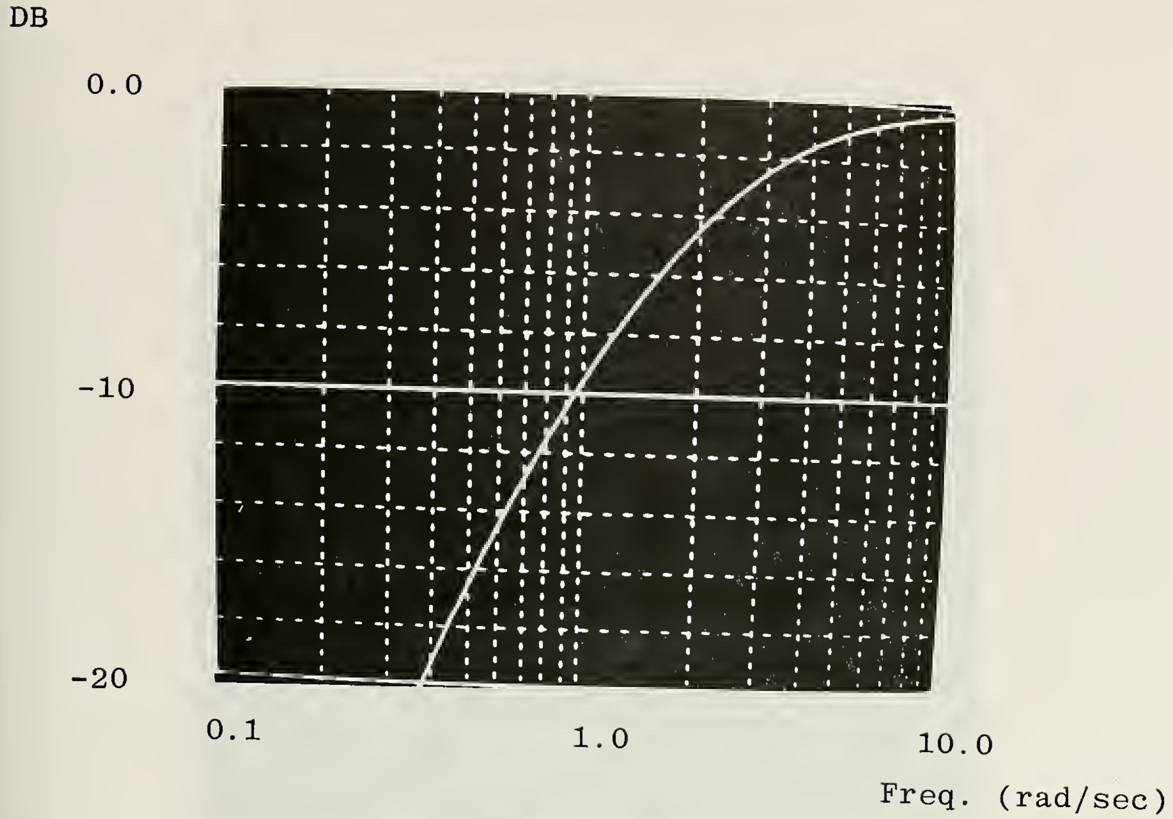


Figure 4

Frequency Response for Highpass Filter

R1 = 1 ohm, R2 = 1 ohm

L1 = 1 henry, L2 = 1 henry

Computer program in Appendix E.3

Computer printout in Appendix E.4

COMPUTER SIMULATION

BANDPASS FILTER

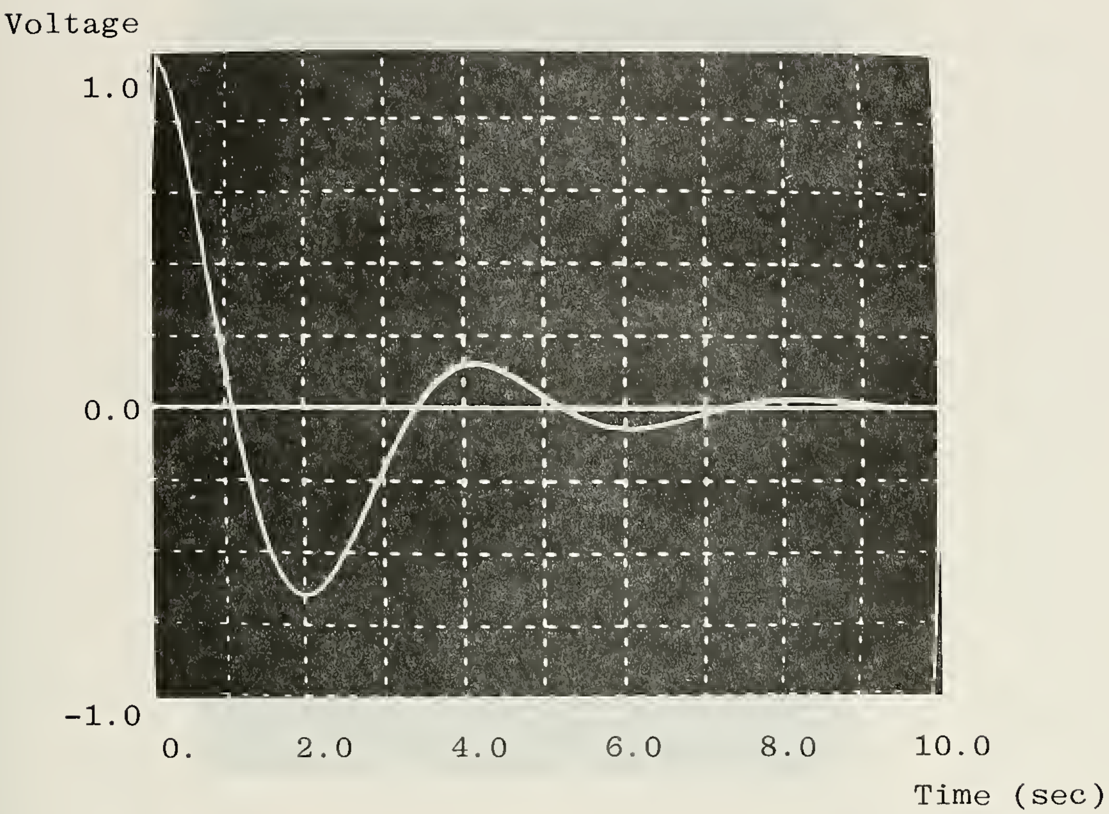


Figure 5

Time Response

R1 = 1 ohm, R2 = 1 ohm

C1 = 1 farad, C2 = 1 farad

L1 = 1 henry, L2 = 1 henry

Computer program in Appendix F.1

Computer printout in Appendix F.2

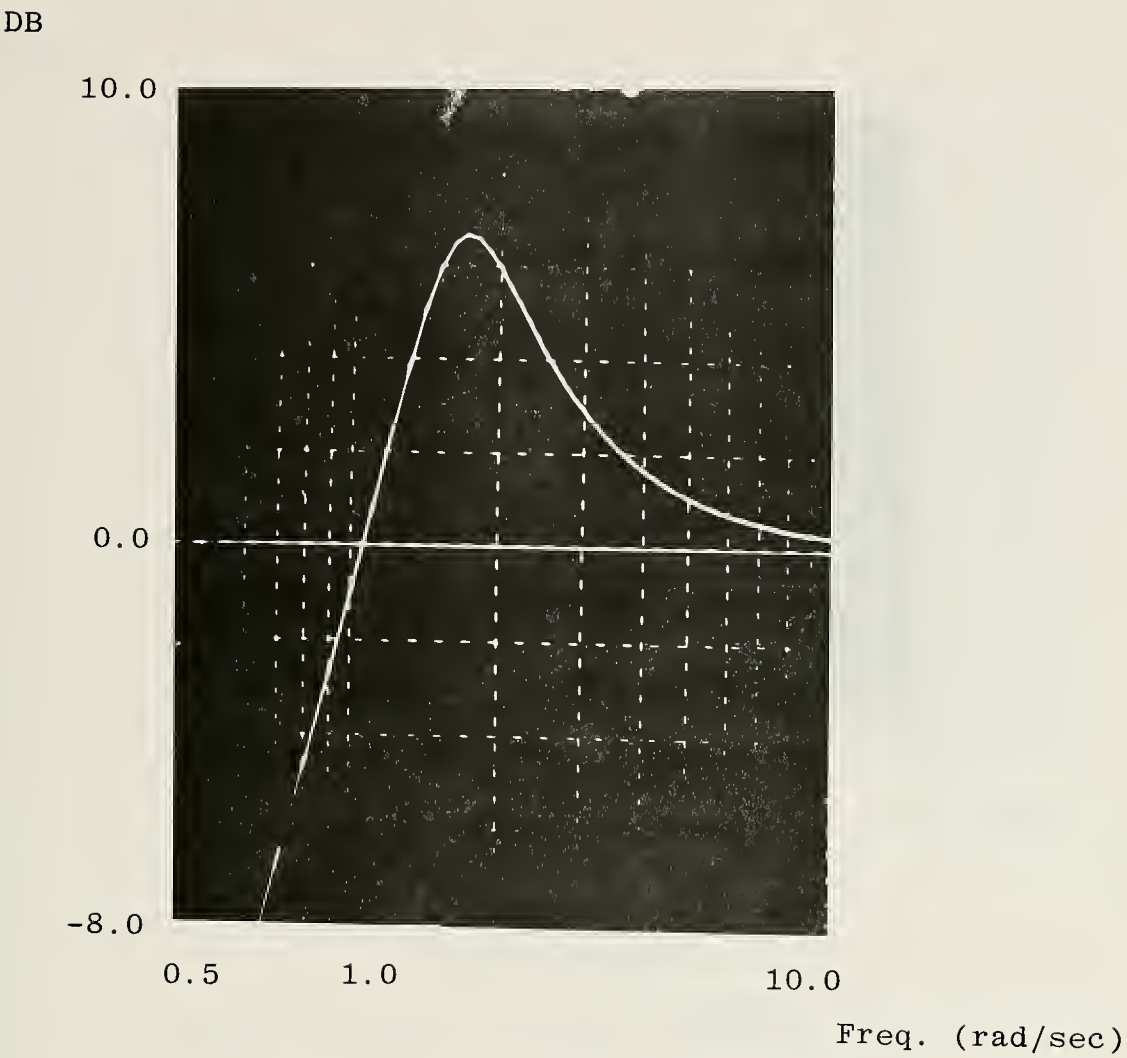


Figure 6

Frequency Response for Bandpass Filter

R1 = 1 ohm, R2 = 1 ohm

C1 = 1 farad, C2 = 1 farad

L1 = 1 henry, L2 = 1 henry

Computer program in Appendix F.3

Computer printout in Appendix F.4

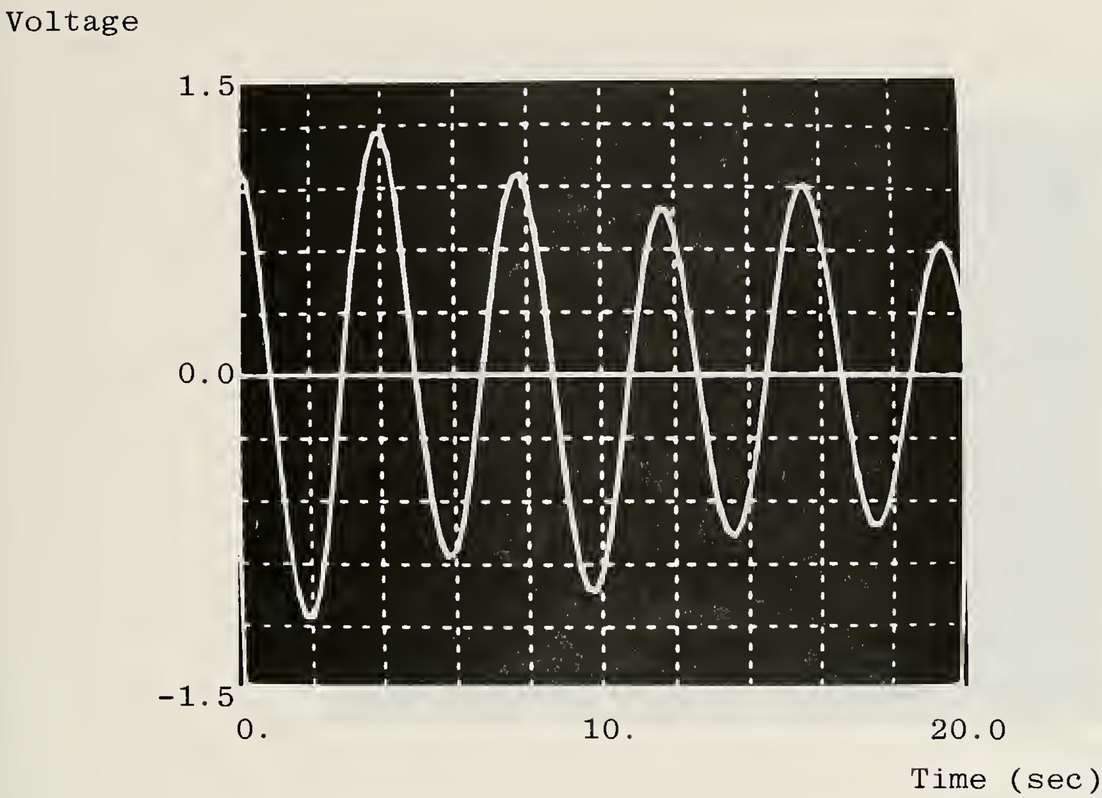


Figure 7

Time Response

R1 = 0.05 ohm, R2 = 0.05 ohm

C1 = 1 farad, C2 = 1 farad

L1 = 1 henry, L2 = 1 henry

Computer printout in Appendix F.5

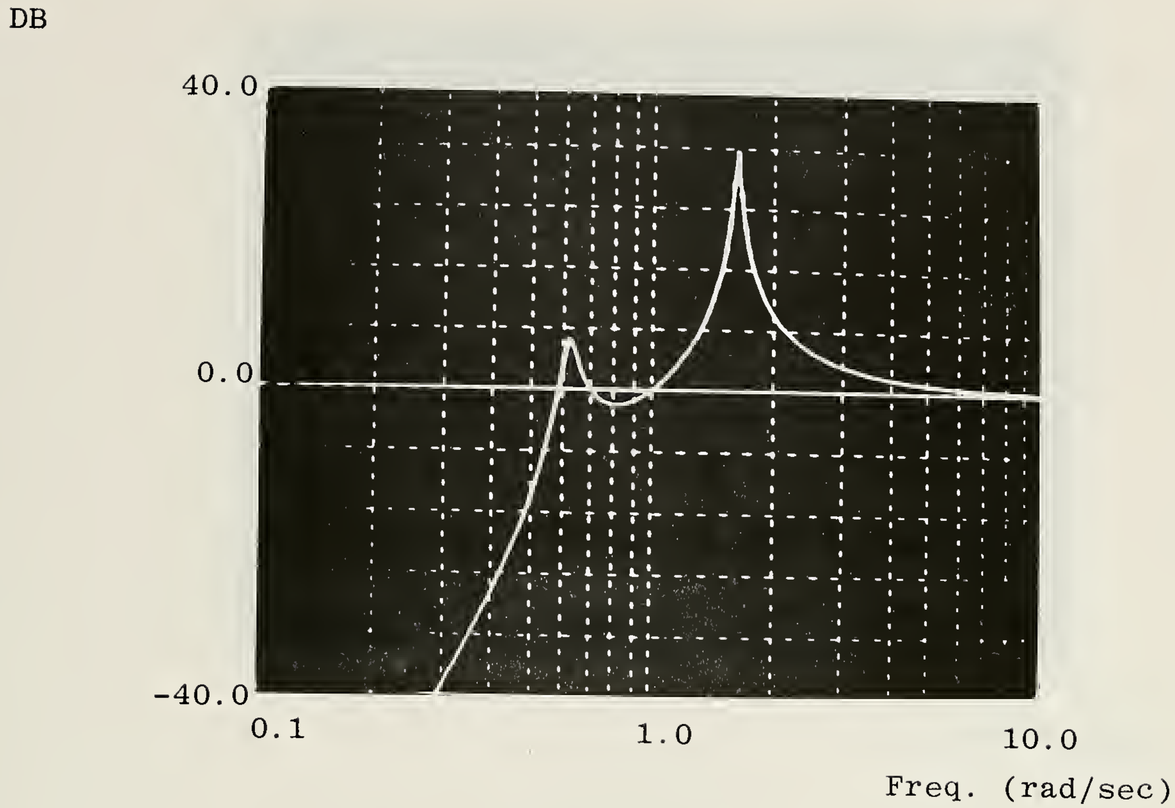


Figure 8

Frequency Response

R1 = 0.05 ohm, R2 = 0.05 ohm

C1 = 1 farad, C2 = 1 farad

L1 = 1 henry, L2 = 1 henry

Computer printout in Appendix F.6

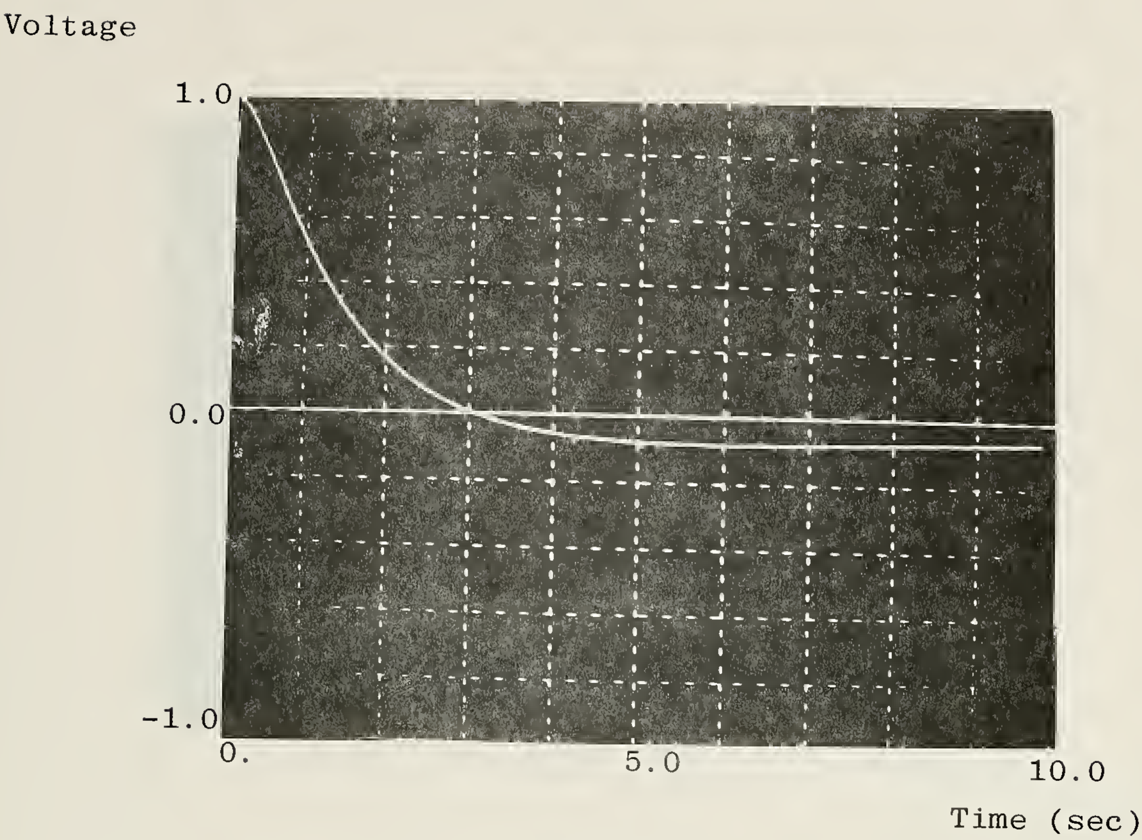


Figure 9

Time Response

R1 = 4 ohm, R2 = 4 ohm

C1 = 1 farad, C2 = 1 farad

L1 = 1 henry, L2 = 1 henry

Computer printout in Appendix F.7

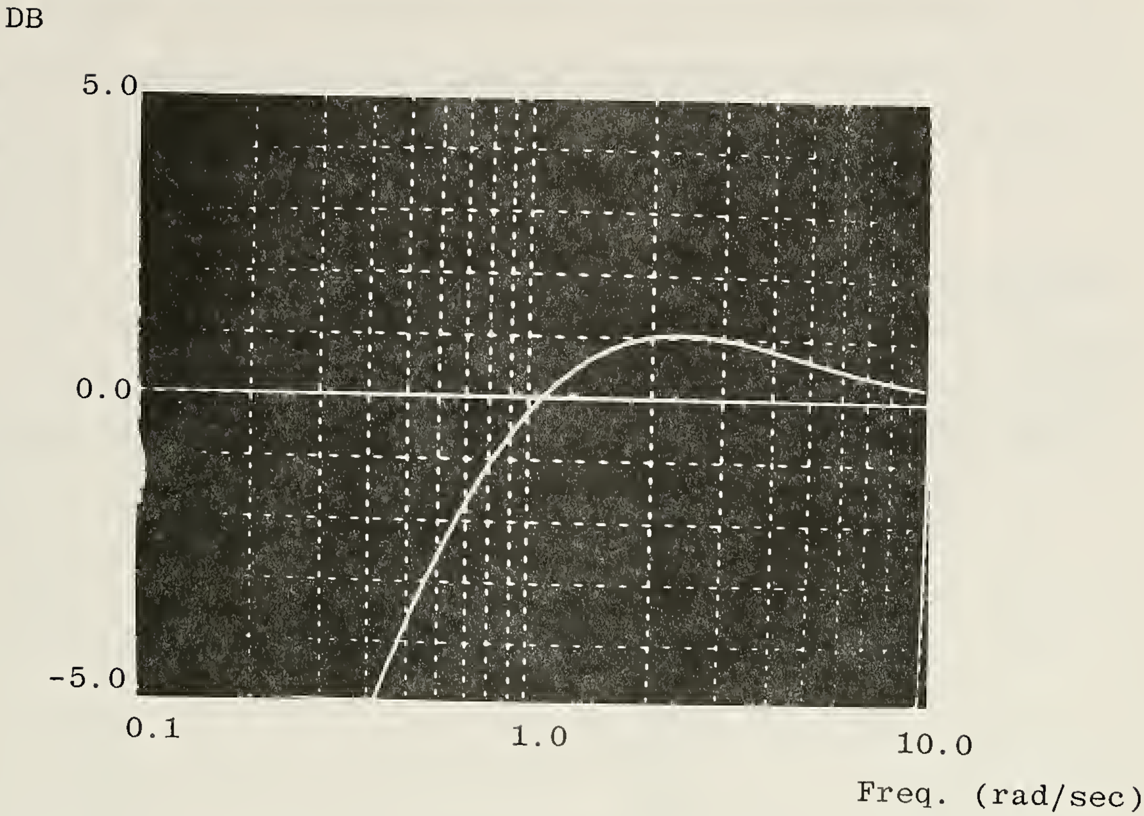


Figure 10

Frequency Response

R1 = 4 ohm, R2 = 4 ohm

C1 = 1 farad, C2 = 1 farad

L1 = 1 henry, L2 = 1 henry

Computer printout in Appendix F.8

E. CORRELATION OF TIME AND FREQUENCY RESPONSE

From the time response of the two-port network as a filter some aspects of the transfer function in s-domain can be determined that lead to the frequency response of the networks by the concept of

H(s) ⟶ H(jw) ⟶ Magnitude of the Fourier Transform

Some aspects of the time response of the two-port network to the unit step input that indicate the form of the transfer function of the network are discussed as follow:

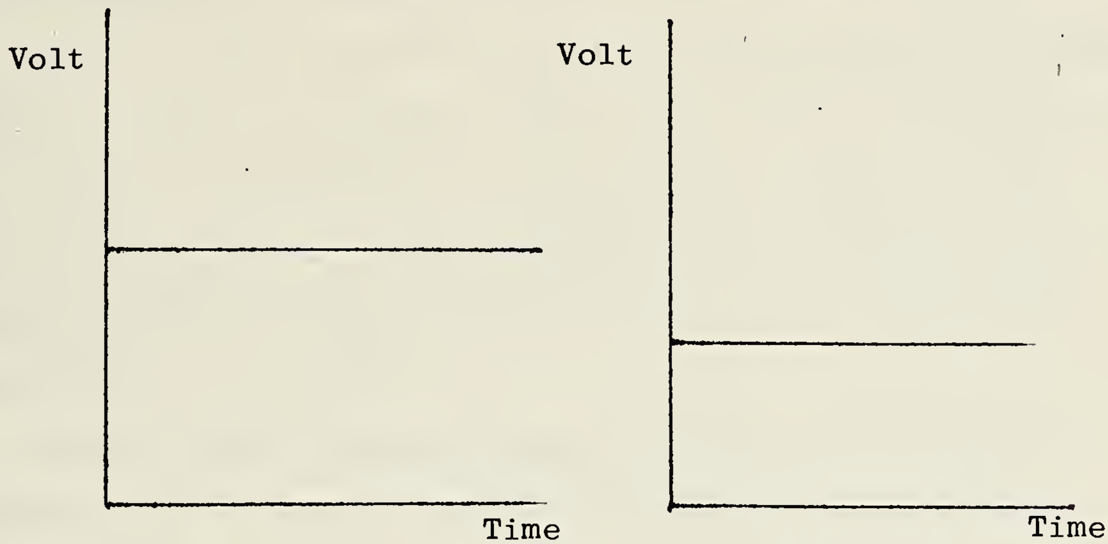


Figure 11(a)
INPUT WAVEFORM

Figure 11(b)
OUTPUT WAVEFORM

Configuration of resistive network in Time domain

From the time response (output waveform) it is immediately seen that the network is a resistive network. The transfer function of the network has no poles or zeros. Gain alone exists, so this network's response to any frequency is the same.

For an output waveform that looks such as that in Figure 12(b), the transfer function of the network has one real pole, no zeros and the time constant can be obtained by

$$\text{time constant} = \frac{1}{t_1}$$

where t_1 = time when output = 0.6321 of input.

The location of the pole is recognized as equivalent to time constant, and the network must have the characteristics of a low-pass filter which has the cut-off frequency (w/sec) at the location of pole.

For the output waveform such as in Figure 12(c) the knee indicates that the transfer function has more than one pole so the drop in magnitude as the frequency exceeds the cut-off frequency faster. The bandwidth can be determined in general from the shorter the settling time the wider the bandwidth and vise versa.

For an output waveform such as in Figure 13(b) with no undershoot the transfer function of the network can be determined to have one real pole and one zero at zero frequency. The time constant can be obtained by

$$\text{time constant} = \frac{1}{t_1}$$

where t_1 = time when output = 0.3679 of input.

The location of pole is recognized as equal to the time constant, and the network must have the characteristic of a high pass filter which has the cut-in frequency (w/sec) at the location of the pole. So the shorter the time-constant the smaller the value of cut-in frequency.

Figure 12

Configuration of Lowpass Filter in Time-domain

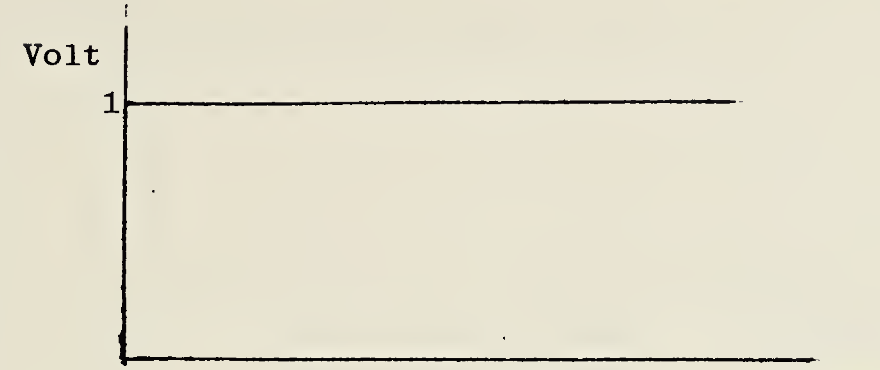


Fig. 12(a) Input

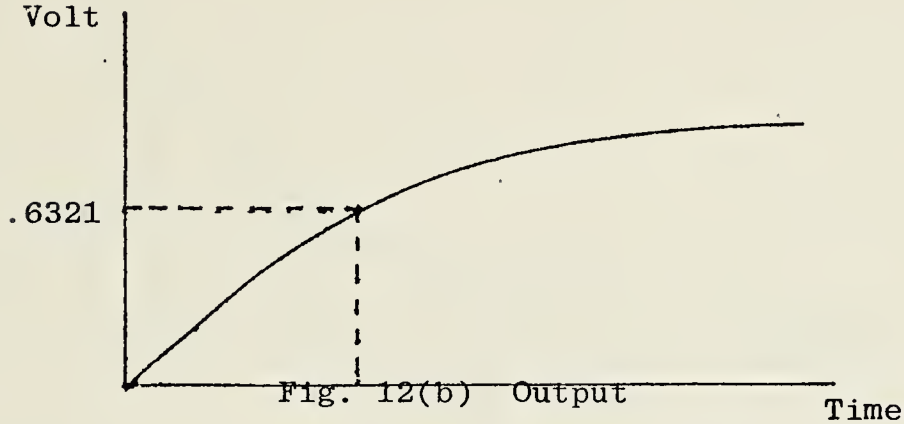


Fig. 12(b) Output

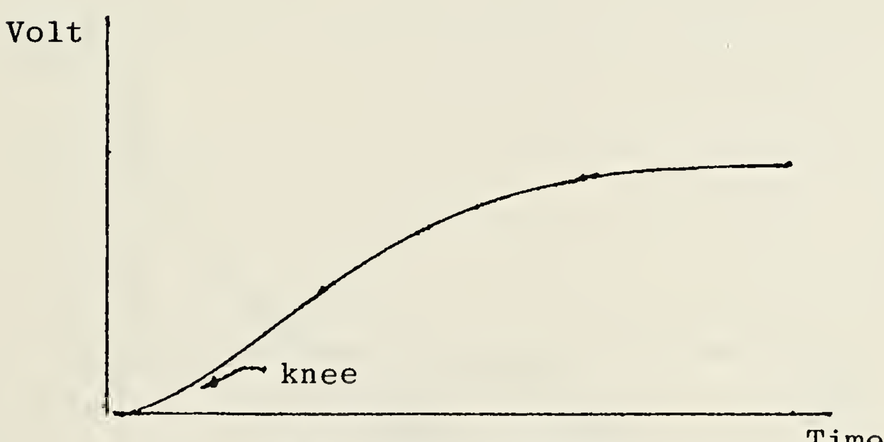


Fig. 12(c) Output

Figure 13

Configuration of Highpass Filter in Time-domain

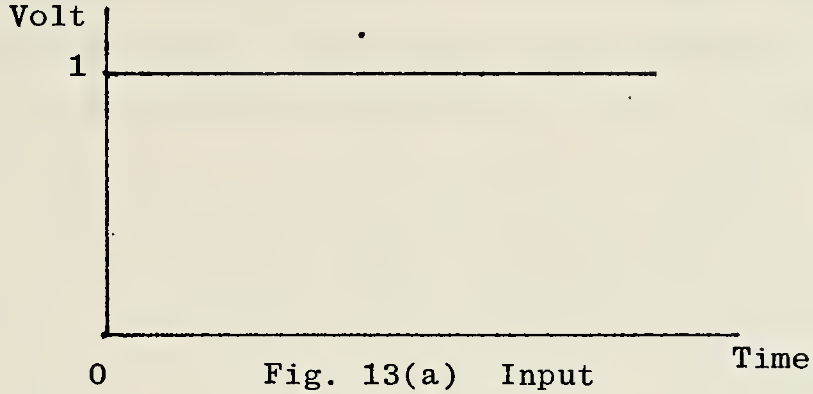


Fig. 13(a) Input

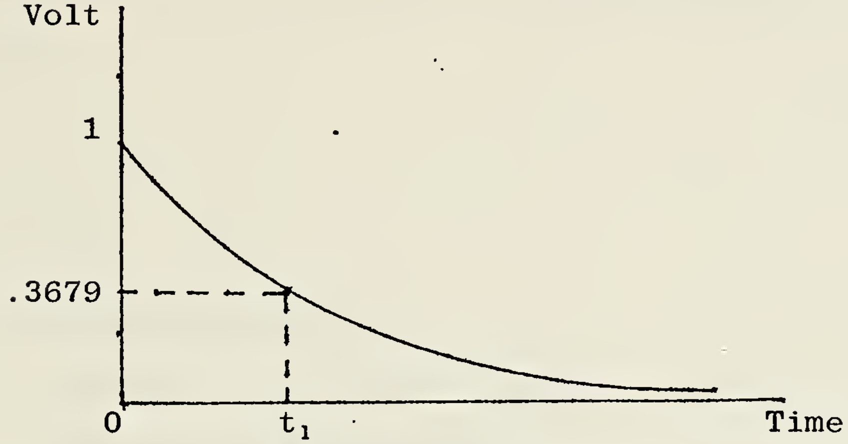


Fig. 13(b) Output

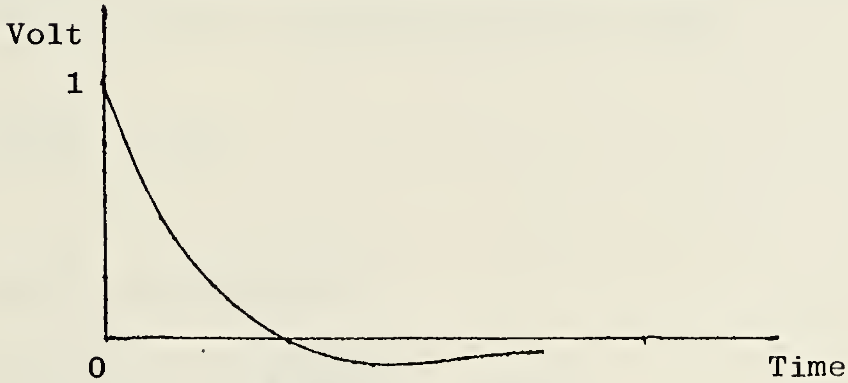


Fig. 13(c) Output

For an output waveform such as in Figure 13(c) the undershoot indicates that the transfer function has more than one zero so the increase in magnitude with frequency before cut-in frequency is steeper. The peak of the undershoot also indicates the location of another pole. The more undershoot the smaller the value of the frequency of the pole.

Figure 14(b) shows the output waveform with oscillation and damping. The transfer function of the network in the simplest contains a pair of complex poles. The imaginary part of the poles can be determined by the period of the oscillation.

$$f = \frac{1}{T}$$

$$w = 2f$$

where f = frequency in Hertz

T = period of one oscillation

w = frequency in radian/sec.

The real part of the poles can be determined by considering how fast the magnitude of oscillation dies down.

$$\ln\left(\frac{M_{t_2}}{M_{t_1}}\right) = -KT$$

where

M_{t_1} = Magnitude at time t_1

M_{t_2} = Magnitude at time t_2

t_2 is apart from t_1 by period of one oscillation T

K = real part of the poles.

Figure 14

Configuration of Bandpass Filter in Time-domain

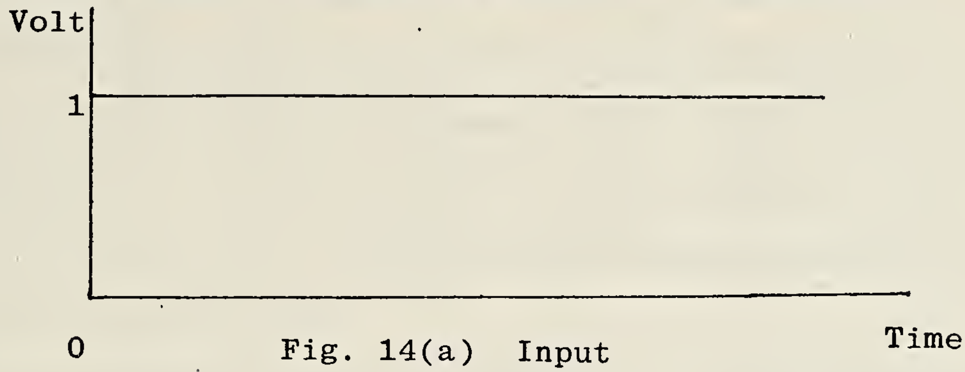


Fig. 14(a) Input

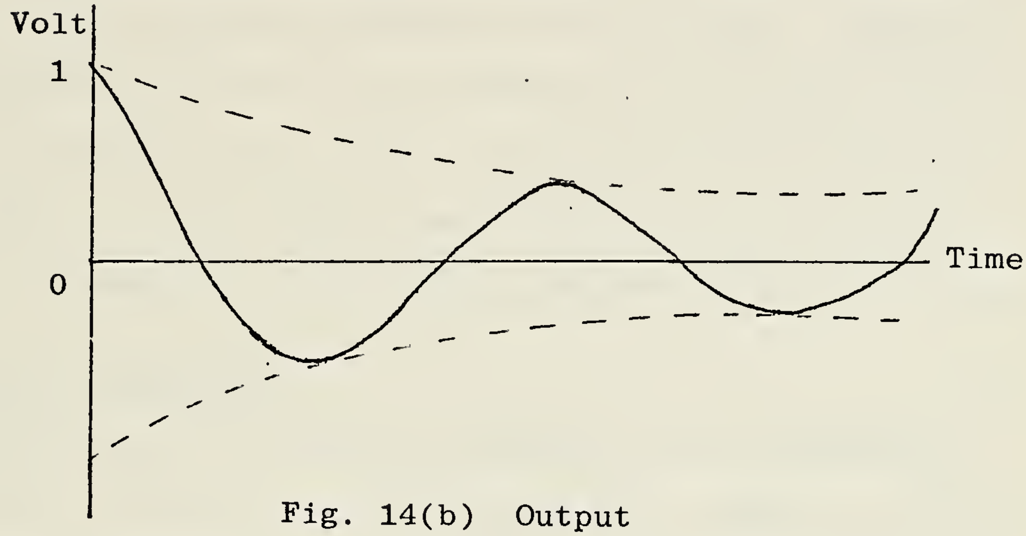


Fig. 14(b) Output

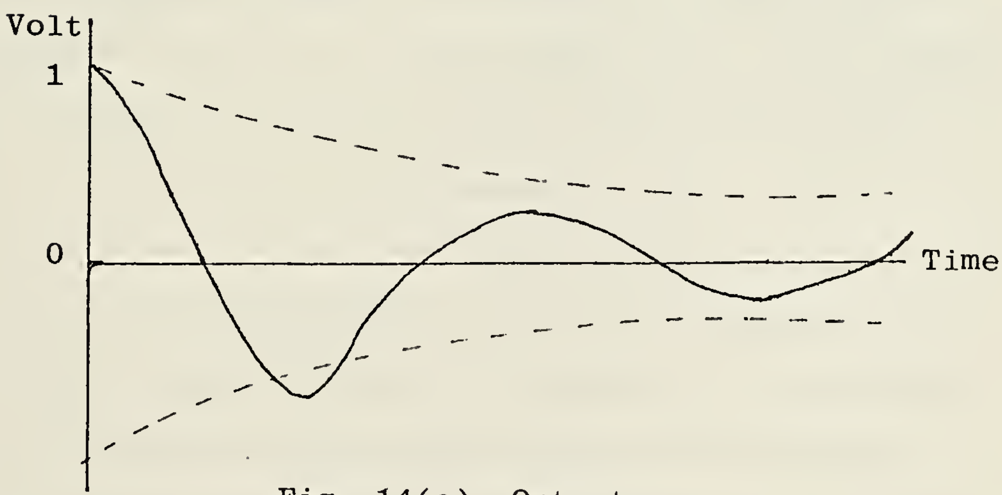


Fig. 14(c) Output

Because the transfer function of the network is determined to have complex poles; the network must have the character of a bandpass filter with the peak frequency response as the oscillation frequency in the time response and the bandwidth of the filter depend on the damping factor. The smaller the value of damping factor, the narrower the bandwidth of the filter.

A time response such as in Figure 14(c) indicates that there is more than one frequency of oscillation. Therefore, the transfer function of the network must have more than one pair of complex poles, however the dominant poles have the most effect, so the method that is described above can be used as an approximation without too much error.

E. DESIGN PROCEDURES

From a circuit the state equations can be formulated along with the transfer functions in the s-domain. Then the computer programs are used to present the time response of the network on the screen of the display unit. The computer program recomputes and presents the display every time the elements of the networks are changed in value. Thus the effect on the time response due to the change in values of the elements can be investigated. For two-port networks (as filters) some aspects of the time response as described in the previous section are used to approach the frequency response by changing the value of the elements of the network. Thus the time response waveform can be reshaped to have the aspect that indicates the frequency response. This includes

the bandwidth, cut-off frequency, etc. If the transfer function of the network in the s-domain is available the computer program is used to get the frequency response presented on the display.

Sometimes it is not convenient to compute with actual circuit values the responses needed. Then the network may be frequency scaled.

1. Frequency-Scaling [2]

A frequency-scaled network will exhibit the same characteristics at frequency w' = kw that the original network exhibited at frequency w; if each element in the frequency-scaled network behaves at the new frequency w' = kw the way the original element behaved at frequency w. Therefore, to frequency-scale a network by a factor of k, we must frequency-scale each element that is affected by frequency with a factor of k.

Element Value	Element Value After Frequency-Scaling by k
R	R
L	L/k
C	C/k

2. Magnitude-Scaling [2]

A network is to be impedance-scaled by a factor of k if each impedance in the network is scaled by a factor of k. Since the impedance of a resistance is R, impedance-scaling a resistance corresponds to scaling the resistance by a

factor of k. The impedance for an inductance is jwL. Hence, impedance-scaling an L-henry inductance corresponds to scaling the inductance by a factor of k. On the other hand, the impedance of a C-farad capacitance is 1/jwC. Hence, impedance-scaling a C-farad capacitance corresponds to scaling the capacitance by k^{-1}.

Element Value	Element Impedance	Element Impedance After Impedance-Scaling By k	Element Value After Impedance-Scaling by k
R	R	$k(R) = kR$	kR
L	jwL	$k(jwL) = jw(kL)$	kL
C	$\frac{1}{jwC}$	$k(\frac{1}{jwC}) = \frac{1}{jw(C/k)}$	C/k

For example in the design of the bandpass filter use the value of R in order of an ohm, C in order of a farad, L in order of a henry. By using the method described above the peak frequency can be obtained along with the bandwidth as a percentage of peak frequency.

The scale factor may then be used to calculate actual values.

IV. CONCLUSIONS

The use of small-scale programs that are designed to provide an output over a wide range of parameter variations can sometimes be as effective as the large-scale programs. Plotting of the output waveform can be interpreted easily because the scales can be changed. Design problems can be handled as long as the circuit is not too complicated. For the complicated circuit, the state equations and the transfer functions are difficult to formulate. Then it is necessary to use the large-scale program to get the state-equations and also the transfer function.

The possibility of modification of the small-scale programs to make them useful to secure the solutions of larger networks exists. In addition, programs may be used to secure from the time response to a frequency response.

APPENDIX A.

```
      SUBROUTINE RKTA(DY,Y,NEQ,TINIT,TFINI,YINIT,YX,COF)
      DIMENSION DY(1),Y(1),TIME(102),YX(101,3),YF(1,2),DYF(5,2),COF(5),
     *BK(4),YINIT(2),YK(4,2)
      DATA BK/0.5,0.5,1.0,0.0/
C     DY=THE ARRAY OF DERIVATIVES OF THE DEPENDENT VARIABLE
C     Y=THE ARRAY OF DEPENDENT VARIABLES
C     NEQ=NUMBER OF EQUATIONS WHICH MUST BE EQUAL TO THE# OF DEP. VAR
C     TINIT=TIME INITIAL
C     TFINI=TIME FINISH
C     YINIT=INITIAL CONDITIONS OF DEPENDENT VARIABLES
C     YX=OUT PUT MATRIX
C     COF=COEFICIENT OF STATE EQUATIONS
C     NUMBER OF INTERVAL
      PT=100.
C     COMPUTE STEP SIZE
      DELT=(TFINI-TINIT)/PT
      NPT=PT+1
      RKCON=1./6.
      DO 1 I=1,NEQ
    1 Y(I)=YINIT(I)
      TIME(1)=TINIT
C     ENTER OUT PUT MATRIX
      DO 10 L=1,NPT
      YX(L,1)=TIME(L)
      DO 9 N=1,NEQ
    9 YX(L,N+1)=Y(N)
      T=TIME(L)
      CALL STEQ(DY,Y,T,COF)
      DO 3 I=1,NEQ
      DYF(1,I)=DY(I)
      YF(1,I)=Y(I)
    3 CONTINUE
C     COMPUTE K1,K2,K3,K4
      DO 4 K=1,4
      DO 5 M=1,NEQ
      YK(K,M)=DELT*DYF(K,M)
      Y(M)=YF(1,M)+BK(K)*YK(K,M)
    5 CONTINUE
      T=TIME(L)+BK(K)*DELT
      CALL STEQ(DY,Y,T,COF)
      DO 6 N=1,NEQ
      DYF(K+1,N)=DY(N)
```

```
    6 CONTINUE
    4 CONTINUE
      DO 8 I=1,NEQ
C     COMPUTE NEXT VALUE OF DEPENDENT VARIABLE
      Y(I)=YF(1,I)+(YK(1,I)+2.0*(YK(2,I)+YK(3,I))+YK(4,I))*RKCON
    8 CONTINUE
      TIME(L+1)=TIME(L)+DELT
   10 CONTINUE
      RETURN
      END
```

APPENDIX B.

```
      SUBROUTINE DISPLY1(IDEV,YX,NCUR,I1,J1,I2,J2)
      INTEGER FRAME,AXES,CURV1,CURV2
      DIMENSION FRAME(9),AXES(42),CURV1(104),CURV2(104),IGD(4),YX(101,5)
      FRAME(1)=IHEAD(0,10)
      FRAME(2)=IPACK(-1.0,1.0,0)
      FRAME(3)=IPACK(1.0,1.0,1)
      FRAME(4)=IPACK(1.0,-1.0,1)
      FRAME(5)=IPACK(-1.0,-1.0,1)
      FRAME(6)=IPACK(-1.0,1.0,1)
      FRAME(7)=IPACK(-1.0,0.,0)
      FRAME(8)=IPACK(1.0,0.0,1)
      FRAME(9)=0
      CALL DGINIT(IDEV,IGD,4,IER)
      IF(IER.NE.0) OUTPUT(101)IER,'  INIT'
      CALL GRAPHO(IDEV,FRAME,9,1,IER)
      IF(IER.NE.0) OUTPUT(101)IER,' GBLK1'
      AXES(1)=IHEAD(1,6)
      XA=-1.0
      XB=1.0
      DO 6000 I=2,18,2
      XB=XB-0.2
      AXES(I)=IPACK(XA,XB,0)
      J=I+1
      XA=XA*(-1.)
      AXES(J)=IPACK(XA,XB,1)
      XA=XA*(-1.)
 6000 CONTINUE
      AXES(20)=0
      XA=1.0
      XB=-1.0
      DO 7000 I=21,39,2
      XA=XA-0.2
      AXES(I)=IPACK(XA,XB,0)
      J=I+1
      XB=XB*(-1.)
      AXES(J)=IPACK(XA,XB,1)
      XB=XB*(-1.)
 7000 CONTINUE
      AXES(41)=0
      CALL GRAPHO(IDEV,AXES,41,2,IER)
      IF(IER.NE.0) OUTPUT(101)IER,' GBLK2'
      CURV1(1)=IHEAD(0,10)
```

```
      CURV1(2)=IPACK(-1.0,0.0,0)
      DO 8000 I=1,101
      K=I+2
 8000 CURV1(K)=IPACK(YX(I,I1),YX(I,J1),1)
      CURV1(104)=0
      CALL GRAPHO(IDEV,CURV1,104,3,IER)
      IF(IER.NE.0)OUTPUT(101)IER,' GBLK3'
      IF(NCUR.LT.2) GO TO 9
      CURV2(1)=IHEAD(0,10)
      CURV2(2)=IPACK(-1.0,0.0,0)
      DO 9000 I=1,101
      K=I+2
 9000 CURV2(K)=IPACK(YX(I,I2),YX(I,J2),1)
      CURV2(104)=0
      CALL GRAPHO(IDEV,CURV2,104,4,IER)
      IF(IER.NE.0)OUTPUT(101)IER,' GBLK4'
    9 CONTINUE
      RETURN
      END
```

```
      AXES(I)=IPACK(XA,XB,0)
      J=I+1
      XB=XB*(-1.)
      AXES(J)=IPACK(XA,XB,1)
      XZ=XZ+1.0
8000  CONTINUE
      AXES(59)=0
      CALL GRAPHO(IDEV,AXES,59,2,IER)
      IF(IER.NE.0) OUTPUT(101)IER,' GBLK2'
      CURVE(1)=IHEAD(0,10)
      DBM(1)=DBM(1)/SCALE+1.0
      CURVE(2)=IPACK(WL(1),DBM(1),0)
      DO 9000 I=3,200
      DBM(I)=DBM(I)/SCALE
9000  CURVE(I)=IPACK(WL(I),DBM(I),1)
      CURVE(201)=0
      CALL GRAPHO(IDEV,CURVE,201,3,IER)
      IF(IER.NE.0)OUTPUT(101)IER,' GBLK3'
      RETURN
      END
```

APPENDIX D.1

```
C     MAIN PROGRAM FOR TIME RESPONSE OF LOWPASS FILTER
      DIMENSION DY(2),Y(2),YX(101,3),COF(5),YINIT(2)
      DATA YINIT/0.0,0.0/
C     YINIT=INITIAL CONDITION
    1 RESET=0.
      NAMELIST IDEV,R1,R2,C1,C2,TFINI,XSCAL,YSCAL
      INPUT(101)
C     SET THE VALUE OF THE STATE EQUATIONS
      COF(1)=1.0/(R1*C1)+1.0/(R2*C1)
      COF(2)=1.0/(R2*C1)
      COF(3)=1.0/(R1*C1)
      COF(4)=1.0/(R2*C2)
      COF(5)=1.0/(R2*C2)
      IF(IDEV.EQ.0) GO TO 2
C     TIME INITIAL
      TINIT=0.0
C     NUMBER OF THE STATE EQUATIONS
      NEQ=2
      WRITE(6,10)R1,R2,C1,C2
      CALL RKTA(DY,Y,NEQ,TINIT,TFINI,YINIT,YX,COF)
      DO 13 I=1,101
C     OUT PUT VOLTAGE
      WRITE(6,8)YX(I,1),YX(I,3)
C     X-SCALE
      YX(I,1)=YX(I,1)/XSCAL-1.0
      YX(I,3)=YX(I,3)/YSCAL
   13 CONTINUE
C     NUMBER OF CURVE TO BE PLOTTED
      NCUR=1
C     COLUMN THAT WILL BE PLOTON X-AXIS
      I1=1
C     COLUMN THAT WILL BE PLOT ON Y-AXIS
      J1=3
      CALL DISPLY1(IDEV,YX,NCUR,I1,J1,I2,J2)
      GO TO 1
    2 CONTINUE
    8 FORMAT(15H          TIME=,F12.8,16H OUTPUT VOLTAGE=,F12.8)
   10 FORMAT(1H10X3HR1=,F6.3,3HR2=,F6.3,3HC1=F6.3,3HC2=,F6.3)
      STOP
      END
      SUBROUTINE STEQ(DY,Y,T,COF)
      DIMENSION Y(1),DY(1),COF(1)
```

```
C      THE STATE EQUATIONS ARE DESCRIBED
       DY(1)=-COF(1)*Y(1)+COF(2)*Y(2)+COF(3)
       DY(2)=COF(4)*Y(1)-COF(5)*Y(2)
       RETURN
       END
```

APPENDIX D.2

TIME RESPØNSE ØF LØWPASS FILTER

R1=1.000 R2=1.000 C1=1.000 C2=1.000

TIME=	.00000000	ØUTPUT VØLTAGE=	.00000000
TIME=	.05000000	ØUTPUT VØLTAGE=	.00118958
TIME=	.10000000	ØUTPUT VØLTAGE=	.00453175
TIME=	.15000000	ØUTPUT VØLTAGE=	.00971891
TIME=	.20000000	ØUTPUT VØLTAGE=	.01648202
TIME=	.25000000	ØUTPUT VØLTAGE=	.02458588
TIME=	.30000000	ØUTPUT VØLTAGE=	.03382492
TIME=	.35000000	ØUTPUT VØLTAGE=	.04401957
TIME=	.40000000	ØUTPUT VØLTAGE=	.05501306
TIME=	.45000000	ØUTPUT VØLTAGE=	.06666861
TIME=	.50000000	ØUTPUT VØLTAGE=	.07886694
TIME=	.55000000	ØUTPUT VØLTAGE=	.09150414
TIME=	.60000000	ØUTPUT VØLTAGE=	.10448973
TIME=	.65000000	ØUTPUT VØLTAGE=	.11774506
TIME=	.70000000	ØUTPUT VØLTAGE=	.13120179
TIME=	.75000000	ØUTPUT VØLTAGE=	.14480062
TIME=	.80000000	ØUTPUT VØLTAGE=	.15849021
TIME=	.85000000	ØUTPUT VØLTAGE=	.17222613
TIME=	.90000000	ØUTPUT VØLTAGE=	.18597005
TIME=	.95000000	ØUTPUT VØLTAGE=	.19968896
TIME=	1.00000000	ØUTPUT VØLTAGE=	.21335449
TIME=	1.05000000	ØUTPUT VØLTAGE=	.22694237
TIME=	1.10000000	ØUTPUT VØLTAGE=	.24043187
TIME=	1.15000000	ØUTPUT VØLTAGE=	.25380538
TIME=	1.20000000	ØUTPUT VØLTAGE=	.26704803
TIME=	1.25000000	ØUTPUT VØLTAGE=	.28014730
TIME=	1.30000000	ØUTPUT VØLTAGE=	.29309276
TIME=	1.35000000	ØUTPUT VØLTAGE=	.30587578
TIME=	1.40000000	ØUTPUT VØLTAGE=	.31848933
TIME=	1.45000000	ØUTPUT VØLTAGE=	.33092774
TIME=	1.50000000	ØUTPUT VØLTAGE=	.34318652
TIME=	1.55000000	ØUTPUT VØLTAGE=	.35526225
TIME=	1.60000000	ØUTPUT VØLTAGE=	.36715240
TIME=	1.65000000	ØUTPUT VØLTAGE=	.37885521
TIME=	1.70000000	ØUTPUT VØLTAGE=	.39036963
TIME=	1.75000000	ØUTPUT VØLTAGE=	.40169516
TIME=	1.80000000	ØUTPUT VØLTAGE=	.41283133
TIME=	1.85000000	ØUTPUT VØLTAGE=	.42378009
TIME=	1.90000000	ØUTPUT VØLTAGE=	.43454079
TIME=	1.95000000	ØUTPUT VØLTAGE=	.44511507
TIME=	2.00000000	ØUTPUT VØLTAGE=	.45550435
TIME=	2.05000000	ØUTPUT VØLTAGE=	.46571028
TIME=	2.10000000	ØUTPUT VØLTAGE=	.47573473
TIME=	2.15000000	ØUTPUT VØLTAGE=	.48557970
TIME=	2.20000000	ØUTPUT VØLTAGE=	.49524733
TIME=	2.25000000	ØUTPUT VØLTAGE=	.50473990
TIME=	2.30000000	ØUTPUT VØLTAGE=	.51405975
TIME=	2.35000000	ØUTPUT VØLTAGE=	.52320932

```
TIME=   2.40000000 ØUTPUT VØLTAGE=    .53219107
TIME=   2.45000000 ØUTPUT VØLTAGE=    .54100755
TIME=   2.50000000 ØUTPUT VØLTAGE=    .54966131
TIME=   2.55000000 ØUTPUT VØLTAGE=    .55815493
TIME=   2.60000000 ØUTPUT VØLTAGE=    .56649099
TIME=   2.65000000 ØUTPUT VØLTAGE=    .57467211
TIME=   2.70000000 ØUTPUT VØLTAGE=    .58270087
TIME=   2.75000000 ØUTPUT VØLTAGE=    .59057986
TIME=   2.80000000 ØUTPUT VØLTAGE=    .59831165
TIME=   2.85000000 ØUTPUT VØLTAGE=    .60589881
TIME=   2.90000000 ØUTPUT VØLTAGE=    .61334386
TIME=   2.95000000 ØUTPUT VØLTAGE=    .62064933
TIME=   3.00000000 ØUTPUT VØLTAGE=    .62781770
TIME=   3.05000000 ØUTPUT VØLTAGE=    .63485142
TIME=   3.10000000 ØUTPUT VØLTAGE=    .64175293
TIME=   3.15000000 ØUTPUT VØLTAGE=    .64852462
TIME=   3.20000000 ØUTPUT VØLTAGE=    .65516886
TIME=   3.25000000 ØUTPUT VØLTAGE=    .66168799
TIME=   3.30000000 ØUTPUT VØLTAGE=    .66808429
TIME=   3.35000000 ØUTPUT VØLTAGE=    .67436003
TIME=   3.40000000 ØUTPUT VØLTAGE=    .68051743
TIME=   3.45000000 ØUTPUT VØLTAGE=    .68655870
TIME=   3.50000000 ØUTPUT VØLTAGE=    .69248597
TIME=   3.55000000 ØUTPUT VØLTAGE=    .69830138
TIME=   3.60000000 ØUTPUT VØLTAGE=    .70400701
TIME=   3.65000000 ØUTPUT VØLTAGE=    .70960490
TIME=   3.70000000 ØUTPUT VØLTAGE=    .71509708
TIME=   3.75000000 ØUTPUT VØLTAGE=    .72048551
TIME=   3.80000000 ØUTPUT VØLTAGE=    .72577214
TIME=   3.85000000 ØUTPUT VØLTAGE=    .73095889
TIME=   3.90000000 ØUTPUT VØLTAGE=    .73604762
TIME=   3.95000000 ØUTPUT VØLTAGE=    .74104017
TIME=   4.00000000 ØUTPUT VØLTAGE=    .74593837
TIME=   4.05000000 ØUTPUT VØLTAGE=    .75074397
TIME=   4.10000000 ØUTPUT VØLTAGE=    .75545873
TIME=   4.15000000 ØUTPUT VØLTAGE=    .76008435
TIME=   4.20000000 ØUTPUT VØLTAGE=    .76462251
TIME=   4.25000000 ØUTPUT VØLTAGE=    .76907487
TIME=   4.30000000 ØUTPUT VØLTAGE=    .77344304
TIME=   4.35000000 ØUTPUT VØLTAGE=    .77772861
TIME=   4.40000000 ØUTPUT VØLTAGE=    .78193313
TIME=   4.45000000 ØUTPUT VØLTAGE=    .78605815
TIME=   4.50000000 ØUTPUT VØLTAGE=    .79010515
TIME=   4.55000000 ØUTPUT VØLTAGE=    .79407561
TIME=   4.60000000 ØUTPUT VØLTAGE=    .79797098
TIME=   4.65000000 ØUTPUT VØLTAGE=    .80179268
TIME=   4.70000000 ØUTPUT VØLTAGE=    .80554209
TIME=   4.75000000 ØUTPUT VØLTAGE=    .80922059
TIME=   4.80000000 ØUTPUT VØLTAGE=    .81282951
TIME=   4.85000000 ØUTPUT VØLTAGE=    .81637016
TIME=   4.90000000 ØUTPUT VØLTAGE=    .81984335
TIME=   4.95000000 ØUTPUT VØLTAGE=    .82325183
TIME=   5.00000000 ØUTPUT VØLTAGE=    .82659535
```

APPENDIX D.3

```
C      MAIN PROGRAM FOR FREQUENCY RESPONSE OF LOWPASS FILTER
C      FROM THE TRANSFER FUNCTION IN POLYNOMIAL FORM
       COMPLEX COMP,COMZ
       DIMENSION W(201),COFZ(5),COFP(5),AMAG(201),DBM(201),WL(201),SW(5)
     2 RESET=0
       NAMELIST IDEV,R1,R2,C1,C2,SCALE
       INPUT(101)
       WRITE(6,12)R1,R2,C1,C2
       IF(R1.LT.0) GO TO 3
C      COEFICIENT OF THE NOMINATOR
       COFZ(1)=1.0
C      COEFICIENT OF THE DENOMINATOR
       COFP(1)=1.0
       COFP(2)=R1*C1+R1*C2+R2*C2
       COFP(3)=R1*R2*C1*C2
       WMAX=10.0
       WMIN=0.1
C      NUMBER OF POINT = 200 WILL BE COMPUTED
       DW=WMAX/WMIN
C      SET STEP SIZE
       DLW=ALOG10(DW)/200.0
       WL(1)=ALOG10(WMIN)
       WRITE(6,10)
C      SUBSTITUTE S BY JW
       DO 1 I=1,200
       W(I)=10.0**WL(I)
       SW(1)=W(I)
       SW(2)=W(I)**2
       SW(3)=W(I)**3
       SW(4)=W(I)**4
       ZI=0.0
       ZR=COFZ(1)
       COMZ=CMPLX(ZR,ZI)
       PR=COFP(1)-COFP(3)*SW(2)
       PI=COFP(2)*SW(1)
       CCMP=CMPLX(PR,PI)
C      COMPUTE THE MAGNITUDE OF THE NOMINATOR
       ZMAG=CABS(COMZ)
C      COMPUTE THE MAGNITUDE OF THE DENOMINATOR
       PMAG=CABS(COMP)
C      COMPUTE THE MAGNITUDE OF THE TRANSFER FUNCTION
       AMAG(I)=ZMAG/PMAG
```

```
C     COMPUTE MAG. IN DB
      DBM(I)=20.0*ALOG10(AMAG(I))
      WL(I+1)=WL(I)+DLW
      WRITE(6,11)W(I),AMAG(I),DBM(I)
    1 CONTINUE
      CALL DISPLY2(IDEV,DBM,WL,SCALE)
      GO TO 2
    3 CONTINUE
   10 FORMAT(23H           FREQ(RAD/SEC),19H          MAGNITUDE,23H
     *    MAGNITUDE(DB))
   11 FORMAT(10H          ,F12.9,10H          ,F12.9,9H         ,F12.8)
   12 FORMAT(1H10X3HR1=,F6.3,3HR2=,F6.3,3HC1=,F6.3,3HC2=,F6.3)
      STOP
      END
```

APPENDIX D.4

FREQUENCY RESPONSE OF LOWPASS FILTER

R1=1.000 R2=1.000 C1=1.000 C2=1.000

FREQ(RAD/SEC)	MAGNITUDE	MAGNITUDE(DB)
.100000000	.966691318	-.29424364
.102329299	.965200316	-.30765089
.104712855	.963646203	-.32164771
.107151931	.962026635	-.33625808
.109647820	.960339206	-.35150681
.112201845	.958581458	-.36741952
.114815362	.956750873	-.38402265
.117489755	.954844884	-.40134349
.120226443	.952860868	-.41941016
.123026877	.950796158	-.43825164
.125892541	.948648037	-.45789775
.128824955	.946413748	-.47837919
.131825674	.944090495	-.49972749
.134896288	.941675448	-.52197505
.138038426	.939165747	-.54515511
.141253754	.936558508	-.56930173
.144543977	.933850830	-.59444982
.147910839	.931039798	-.62063509
.151356125	.928122494	-.64789403
.154881662	.925096002	-.67626392
.158489319	.921957416	-.70578276
.162181010	.918703850	-.73648928
.165958691	.915332446	-.76842286
.169824365	.911840384	-.80162355
.173780083	.908224894	-.83613197
.177827941	.904483264	-.87198930
.181970086	.900612854	-.90923718
.186208714	.896611105	-.94791773
.190546072	.892475555	-.98807341
.194984460	.888203848	-1.02974699
.199526231	.883793751	-1.07298147
.204173794	.879243162	-1.11782001
.208929613	.874550123	-1.16430554
.213796209	.869712858	-1.21248218
.218776162	.864729734	-1.26239215
.223872114	.859599329	-1.31407865
.229086765	.854320414	-1.36758432
.234422881	.848891950	-1.42295139
.239883292	.843313243	-1.48022159
.245470892	.837583660	-1.53943607
.251188643	.831702942	-1.60063525
.257039578	.825671060	-1.66385874
.263026799	.819488262	-1.72914525
.269153480	.813155078	-1.79653243
.275422870	.806672329	-1.86605681
.281838293	.800041133	-1.93775368

.288403150	.793262914	-2.01165698
.295120923	.786339403	-2.08779923
.301995172	.779272644	-2.16621138
.309029543	.772064992	-2.24692280
.316227766	.764719113	-2.32996110
.323593657	.757237986	-2.41535216
.331131121	.749624896	-2.50311996
.338844156	.741883429	-2.59328659
.346736850	.734017463	-2.68587215
.354813389	.726031165	-2.78089473
.363078055	.717928975	-2.87837037
.371535229	.709715595	-2.97831303
.380189396	.701395978	-3.08073458
.389045145	.692975309	-3.18564478
.398107170	.684458993	-3.29305131
.407380278	.675852635	-3.40295978
.416869383	.667162019	-3.51537372
.426579519	.658393093	-3.63029468
.436515832	.649551946	-3.74772224
.446683592	.640644787	-3.86765406
.457088189	.631677926	-3.99008599
.467735141	.622657746	-4.11501209
.478630092	.613590691	-4.24242476
.489778819	.604483233	-4.37231483
.501187233	.595341859	-4.50467161
.512861384	.586173048	-4.63948308
.524807460	.576983247	-4.77673594
.537031796	.567778853	-4.91641573
.549540874	.558566196	-5.05850701
.562341325	.549351518	-5.20299342
.575439937	.540140955	-5.34985784
.588843655	.530940524	-5.49908251
.602559586	.521756107	-5.65064918
.616595002	.512593435	-5.80453921
.630957344	.503458077	-5.96073374
.645654229	.494355432	-6.11921378
.660693448	.485290714	-6.27996037
.676082975	.476268946	-6.44295469
.691830971	.467294954	-6.60817818
.707945784	.458373358	-6.77561265
.724435960	.449508572	-6.94524043
.741310241	.440704797	-7.11704444
.758577575	.431966020	-7.29100830
.776247116	.423296012	-7.46711645
.794328234	.414698332	-7.64535422
.812830516	.406176323	-7.82570793
.831763771	.397733117	-8.00816493
.851138038	.389371637	-8.19271375
.870963590	.381094601	-8.37934408
.891250938	.372904527	-8.56804688
.912010839	.364803737	-8.75881442
.933254300	.356794363	-8.95164031
.954992586	.348678353	-9.14651954

.977237221	.341057476	-9.34344852
1.000000000	.333333333	-9.54242509
1.023292992	.325707361	-9.74344852
1.047128548	.318180839	-9.94651954
1.071519305	.310754900	-10.15164031
1.096478196	.303430532	-10.35881442
1.122018454	.296208595	-10.56804688
1.148153621	.289089818	-10.77934408
1.174897554	.282074815	-10.99271375
1.202264434	.275164088	-11.20816493
1.230268770	.268358035	-11.42570792
1.258925411	.261656958	-11.64535422
1.288249551	.255061070	-11.86711645
1.318256738	.248570499	-12.09100830
1.348962882	.242185299	-12.31704444
1.380384264	.235905452	-12.54524043
1.412537544	.229730875	-12.77561265
1.445439770	.223661427	-13.00817818
1.479108388	.217696910	-13.24295469
1.513561248	.211837080	-13.47996037
1.548816618	.206081644	-13.71921378
1.584893192	.200430271	-13.96073374
1.621810097	.194882589	-14.20453921
1.659586907	.189438192	-14.45064918
1.698243652	.184096645	-14.69908251
1.737800828	.178857480	-14.94985784
1.778279409	.173720203	-15.20299342
1.819700858	.168684295	-15.45850701
1.862087136	.163749210	-15.71641573
1.905460717	.158914382	-15.97673593
1.949844599	.154179221	-16.23948308
1.995262314	.149543114	-16.50467161
2.041737944	.145005428	-16.77231482
2.089296130	.140565507	-17.04242476
2.137962089	.136222672	-17.31501209
2.187761623	.131976225	-17.59008599
2.238721138	.127825440	-17.86765406
2.290867652	.123769572	-18.14772223
2.344228814	.119807848	-18.43029468
2.398832919	.115939471	-18.71537372
2.454708915	.112163618	-19.00295977
2.511886430	.108479440	-19.29305131
2.570395782	.104886057	-19.58564478
2.630267991	.101382564	-19.88073453
2.691534803	.097968024	-20.17831303
2.754228702	.094641471	-20.47837037
2.818382930	.091401908	-20.78089473
2.884031503	.088248309	-21.08587214
2.951209225	.085179615	-21.39328658
3.019951719	.082194735	-21.70311996
3.090295431	.079292551	-22.01535216

3.162277659	.076471911	-22.32996110
3.235936568	.073731634	-22.64692279
3.311311213	.071070510	-22.96621138
3.388441560	.068487299	-23.28779922
3.467368503	.065980735	-23.61165698
3.548133890	.063549526	-23.93775367
3.630780546	.061192354	-24.26605680
3.715352289	.058907878	-24.59653242
3.801893961	.056694736	-24.92914524
3.890451448	.054551546	-25.26385874
3.981071703	.052476908	-25.60063524
4.073802776	.050469406	-25.93943606
4.168693832	.048527612	-26.28022159
4.265795186	.046650084	-26.62295138
4.365158320	.044835373	-26.96758431
4.466835919	.043082021	-27.31407864
4.570881894	.041388567	-27.66239214
4.677351410	.039753548	-28.01248218
4.786300921	.038175498	-28.36430584
4.897788191	.036652956	-28.71782001
5.011872333	.035184463	-29.07298146
5.128613837	.033768569	-29.42974698
5.248074600	.032403829	-29.78807340
5.370317961	.031088811	-30.14791772
5.495408735	.029822094	-30.50923717
5.623413249	.028602272	-30.87198929
5.754399370	.027427953	-31.23613196
5.888436550	.026297764	-31.60162354
6.025595857	.025210349	-31.96842285
6.165950015	.024164373	-32.33648927
6.309573441	.023158523	-32.70578275
6.456542286	.022191507	-33.07626391
6.606934476	.021262058	-33.44789402
6.760829750	.020368931	-33.82063507
6.918309705	.019510909	-34.19444981
7.079457839	.018686799	-34.56930172
7.244359596	.017895434	-34.94515510
7.413102408	.017135676	-35.32197504
7.585775745	.016406412	-35.69972748
7.762471161	.015706559	-36.07837918
7.943282342	.015035058	-36.45789774
8.128305156	.014390882	-36.83825163
8.317637706	.013773030	-37.21941015
8.511380376	.013180529	-37.60134348
8.709635894	.012612433	-37.98402264
8.912509376	.012067826	-38.36741951
9.120108386	.011545817	-38.75150630
9.332543002	.011045544	-39.13625807
9.549925854	.010566171	-39.52164769
9.772372203	.010106883	-39.90765088
.000000000	.000000000	.00000000

APPENDIX E.1

```
C     MAIN PROGRAM FOR TIME RESPONSE OF HIGHPASS FILTER
      DIMENSION DY(2),Y(2),YX(101,3),COF(5),YINIT(2)
      DATA YINIT/0.0,0.0/
C     YINIT=INITIAL CONDITION
    1 RESET=0.
      NAMELIST IDEV,R1,R2,HL1,HL2,TFINI,XSCAL,YSCAL
      INPUT(101)
C     SET THE VALUE OF THE STATE EQUATIONS
      COF(1)=R1/HL1
      COF(2)=1.0/HL1
      COF(3)=R1/HL2
      COF(4)=(R1+R2)/HL2
      COF(5)=1.0/HL2
      IF(IDEV.EQ.0) GO TO 2
C     TIME INITIAL
      TINIT=0.0
C     NUMBER OF THE STATE EQUATIONS
      NEQ=2
      WRITE(6,10)R1,R2,HL1,HL2
      CALL RKTA(DY,Y,NEQ,TINIT,TFINI,YINIT,YX,COF)
      DO 13 I=1,101
C     OUT PUT VOLTAGE
      YX(I,3)=1.0-R1*YX(I,2)-(R1+R2)*YX(I,3)
      WRITE(6,8)YX(I,1),YX(I,3)
C     X-SCALE
      YX(I,1)=YX(I,1)/XSCAL-1.0
      YX(I,3)=YX(I,3)/YSCAL
   13 CONTINUE
C     NUMBER OF CURVE TO BE PLOTTED
      NCUR=1
C     COLUMN THAT WILL BE PLOTON X-AXIS
      I1=1
C     COLUMN THAT WILL BE PLOT ON Y-AXIS
      J1=3
      CALL DISPLY1(IDEV,YX,NCUR,I1,J1,I2,J2)
      GO TO 1
    2 CONTINUE
    8 FORMAT(15H          TIME=,F12.8,16H OUTPUT VOLTAGE=,F12.8)
   10 FORMAT(1H10X3HR1=,F6.3,3HR2=,F6.3,3HL1=,F6.3,3HL2=,F6.3)
      STOP
      END
      SUBROUTINE STEQ(DY,Y,T,COF)
```

```
      DIMENSION Y(1),DY(1),COF(1)
C     THE STATE EQUATIONS ARE DESCRIBED
      DY(1)=-COF(1)*Y(1)-COF(1)*Y(2)+COF(2)*1.0
      DY(2)=-COF(3)*Y(1)-COF(4)*Y(2)+COF(5)*1.0
      RETURN
      END
```

APPENDIX E.2

```
TIME RESPØNSE ØF HIGHPASS FILTER

R1=1.000 R2=1.000 L1=1.000 L2=1.000

TIME=    .00000000 ØUTPUT VØLTAGE=  1.00000000
TIME=    .02000000 ØUTPUT VØLTAGE=   .94157237
TIME=    .04000000 ØUTPUT VØLTAGE=   .88618175
TIME=    .06000000 ØUTPUT VØLTAGE=   .83367280
TIME=    .08000000 ØUTPUT VØLTAGE=   .78389808
TIME=    .10000000 ØUTPUT VØLTAGE=   .73671769
TIME=    .12000000 ØUTPUT VØLTAGE=   .69199885
TIME=    .14000000 ØUTPUT VØLTAGE=   .64961559
TIME=    .16000000 ØUTPUT VØLTAGE=   .60944834
TIME=    .18000000 ØUTPUT VØLTAGE=   .57138365
TIME=    .20000000 ØUTPUT VØLTAGE=   .53531385
TIME=    .22000000 ØUTPUT VØLTAGE=   .50113677
TIME=    .24000000 ØUTPUT VØLTAGE=   .46875545
TIME=    .26000000 ØUTPUT VØLTAGE=   .43807789
TIME=    .28000000 ØUTPUT VØLTAGE=   .40901679
TIME=    .30000000 ØUTPUT VØLTAGE=   .38148928
TIME=    .32000000 ØUTPUT VØLTAGE=   .35541674
TIME=    .34000000 ØUTPUT VØLTAGE=   .33072457
TIME=    .36000000 ØUTPUT VØLTAGE=   .30734196
TIME=    .38000000 ØUTPUT VØLTAGE=   .28520174
TIME=    .40000000 ØUTPUT VØLTAGE=   .26424013
TIME=    .42000000 ØUTPUT VØLTAGE=   .24439665
TIME=    .44000000 ØUTPUT VØLTAGE=   .22561389
TIME=    .46000000 ØUTPUT VØLTAGE=   .20783736
TIME=    .48000000 ØUTPUT VØLTAGE=   .19101537
TIME=    .50000000 ØUTPUT VØLTAGE=   .17509885
TIME=    .52000000 ØUTPUT VØLTAGE=   .16004127
TIME=    .54000000 ØUTPUT VØLTAGE=   .14579844
TIME=    .56000000 ØUTPUT VØLTAGE=   .13232844
TIME=    .58000000 ØUTPUT VØLTAGE=   .11959151
TIME=    .60000000 ØUTPUT VØLTAGE=   .10754988
TIME=    .62000000 ØUTPUT VØLTAGE=   .09616775
TIME=    .64000000 ØUTPUT VØLTAGE=   .08541113
TIME=    .66000000 ØUTPUT VØLTAGE=   .07524777
TIME=    .68000000 ØUTPUT VØLTAGE=   .06564707
TIME=    .70000000 ØUTPUT VØLTAGE=   .05657998
TIME=    .72000000 ØUTPUT VØLTAGE=   .04801895
TIME=    .74000000 ØUTPUT VØLTAGE=   .03993783
TIME=    .76000000 ØUTPUT VØLTAGE=   .03231182
TIME=    .78000000 ØUTPUT VØLTAGE=   .02511736
TIME=    .80000000 ØUTPUT VØLTAGE=   .01833213
TIME=    .82000000 ØUTPUT VØLTAGE=   .01193492
TIME=    .84000000 ØUTPUT VØLTAGE=   .00590563
TIME=    .86000000 ØUTPUT VØLTAGE=   .00022516
TIME=    .88000000 ØUTPUT VØLTAGE=  -.00512460
TIME=    .90000000 ØUTPUT VØLTAGE=  -.01016081
TIME=    .92000000 ØUTPUT VØLTAGE=  -.01489980
TIME=    .94000000 ØUTPUT VØLTAGE=  -.01935703
```

```
TIME=    .96000000 OUTPUT VOLTAGE=  -.02354717
TIME=    .98000000 OUTPUT VOLTAGE=  -.02748416
TIME=   1.00000000 OUTPUT VOLTAGE=  -.03118120
TIME=   1.02000000 OUTPUT VOLTAGE=  -.03465084
TIME=   1.04000000 OUTPUT VOLTAGE=  -.03790497
TIME=   1.06000000 OUTPUT VOLTAGE=  -.04095488
TIME=   1.08000000 OUTPUT VOLTAGE=  -.04381128
TIME=   1.10000000 OUTPUT VOLTAGE=  -.04648432
TIME=   1.12000000 OUTPUT VOLTAGE=  -.04898365
TIME=   1.14000000 OUTPUT VOLTAGE=  -.05131842
TIME=   1.16000000 OUTPUT VOLTAGE=  -.05349730
TIME=   1.18000000 OUTPUT VOLTAGE=  -.05552852
TIME=   1.20000000 OUTPUT VOLTAGE=  -.05741989
TIME=   1.22000000 OUTPUT VOLTAGE=  -.05917883
TIME=   1.24000000 OUTPUT VOLTAGE=  -.06081236
TIME=   1.26000000 OUTPUT VOLTAGE=  -.06232715
TIME=   1.28000000 OUTPUT VOLTAGE=  -.06372953
TIME=   1.30000000 OUTPUT VOLTAGE=  -.06502550
TIME=   1.32000000 OUTPUT VOLTAGE=  -.06622075
TIME=   1.34000000 OUTPUT VOLTAGE=  -.06732069
TIME=   1.36000000 OUTPUT VOLTAGE=  -.06833044
TIME=   1.38000000 OUTPUT VOLTAGE=  -.06925486
TIME=   1.40000000 OUTPUT VOLTAGE=  -.07009856
TIME=   1.42000000 OUTPUT VOLTAGE=  -.07086591
TIME=   1.44000000 OUTPUT VOLTAGE=  -.07156106
TIME=   1.46000000 OUTPUT VOLTAGE=  -.07218795
TIME=   1.48000000 OUTPUT VOLTAGE=  -.07275031
TIME=   1.50000000 OUTPUT VOLTAGE=  -.07325167
TIME=   1.52000000 OUTPUT VOLTAGE=  -.07369540
TIME=   1.54000000 OUTPUT VOLTAGE=  -.07408467
TIME=   1.56000000 OUTPUT VOLTAGE=  -.07442252
TIME=   1.58000000 OUTPUT VOLTAGE=  -.07471180
TIME=   1.60000000 OUTPUT VOLTAGE=  -.07495523
TIME=   1.62000000 OUTPUT VOLTAGE=  -.07515538
TIME=   1.64000000 OUTPUT VOLTAGE=  -.07531470
TIME=   1.66000000 OUTPUT VOLTAGE=  -.07543550
TIME=   1.68000000 OUTPUT VOLTAGE=  -.07551998
TIME=   1.70000000 OUTPUT VOLTAGE=  -.07557023
TIME=   1.72000000 OUTPUT VOLTAGE=  -.07558820
TIME=   1.74000000 OUTPUT VOLTAGE=  -.07557579
TIME=   1.76000000 OUTPUT VOLTAGE=  -.07553476
TIME=   1.78000000 OUTPUT VOLTAGE=  -.07546679
TIME=   1.80000000 OUTPUT VOLTAGE=  -.07537349
TIME=   1.82000000 OUTPUT VOLTAGE=  -.07525636
TIME=   1.84000000 OUTPUT VOLTAGE=  -.07511683
TIME=   1.86000000 OUTPUT VOLTAGE=  -.07495626
TIME=   1.88000000 OUTPUT VOLTAGE=  -.07477595
TIME=   1.90000000 OUTPUT VOLTAGE=  -.07457710
TIME=   1.92000000 OUTPUT VOLTAGE=  -.07436029
TIME=   1.94000000 OUTPUT VOLTAGE=  -.07412839
TIME=   1.96000000 OUTPUT VOLTAGE=  -.07388066
TIME=   1.98000000 OUTPUT VOLTAGE=  -.07361867
TIME=   2.00000000 OUTPUT VOLTAGE=  -.07334336
```

APPENDIX E.3

```
C     MAIN PROGRAM FOR FREQUENCY RESPONSE OF HIGHPASS FILTER
C     FROM THE TRANSFER FUNCTION IN POLYNOMIAL FORM
      COMPLEX COMP,COMZ
      DIMENSION W(201),COFZ(5),COFP(5),AMAG(201),DBM(201),WL(201),SW(5)
    2 RESET=0
      NAMELIST IDEV,R1,R2,HL1,HL2,SCALE
      INPUT(101)
      WRITE(6,12) R1,R2,HL1,HL2
      IF(R1.LT.0) GO TO 3
C     COEFICIENT OF THE NOMINATOR
      COFZ(1)=0.0
      COFZ(2)=0.0
      COFZ(3)=HL1*HL2
C     COEFICIENT OF THE DENOMINATOR
      COFP(1)=R1*R2
      COFP(2)=R1*HL1+R1*HL2+R2*HL1
      COFP(3)=HL1*HL2
      WMAX=10.0
      WMIN=0.1
C     NUMBER OF POINT = 200 WILL BE COMPUTED
      DW=WMAX/WMIN
C     SET STEP SIZE
      DLW=ALOG10(DW)/200.0
      WL(1)=ALOG10(WMIN)
      WRITE(6,10)
C     SUBSTITUTE S BY JW
      DO 1 I=1,200
      W(I)=10.0**WL(I)
      SW(1)=W(I)
      SW(2)=W(I)**2
      SW(3)=W(I)**3
      SW(4)=W(I)**4
      ZR=COFZ(1)-COFZ(3)*SW(2)
      ZI=COFZ(2)*SW(1)
      COMZ=CMPLX(ZR,ZI)
      PR=COFP(1)-COFP(3)*SW(2)
      PI=COFP(2)*SW(1)
      COMP=CMPLX(PR,PI)
C     COMPUTE THE MAGNITUDE OF THE NOMINATOR
      ZMAG=CABS(COMZ)
C     COMPUTE THE MAGNITUDE OF THE DENOMINATOR
      PMAG=CABS(COMP)
```

```
C     COMPUTE THE MAGNITUDE OF THE TRANSFER FUNCTION
      AMAG(I)=ZMAG/PMAG
C     COMPUTE MAG. IN DB
      DBM(I)=20.0*ALOG10(AMAG(I))
      WL(I+1)=WL(I)+DLW
      WRITE(6,11)W(I),AMAG(I),DBM(I)
    1 CONTINUE
      CALL DISPLY2(IDEV,DBM,WL,SCALE)
      GO TO 2
    3 CONTINUE
   10 FORMAT(23H          FREQ(RAD/SEC),19H          MAGNITUDE,23H
     *    MAGNITUDE(DB))
   11 FORMAT(10H          ,F12.9,10H          ,F12.9,9H          ,F12.8)
   12 FORMAT(1H10X3HR1=,F8.3,3HR2=,F8.3,3HL1=,F8.3,3HL2=,F8.3)
      STOP
      END
```

APPENDIX E.4

FREQUENCY RESPONSE OF HIGHPASS FILTER

R1=1.000 R2=1.000 L1=1.000 L2=1.000

FREQ(RAD/SEC)	MAGNITUDE	MAGNITUDE(DB)
.100000000	.009666913	-40.29424364
.102329299	.010106888	-39.90765089
.104712855	.010566171	-39.52164771
.107151931	.011045544	-39.13625808
.109647820	.011545817	-38.75150682
.112201845	.012067826	-38.36741953
.114815362	.012612433	-37.98402266
.117489755	.013180529	-37.60134350
.120226443	.013773030	-37.21941016
.123026877	.014390882	-36.83825164
.125892541	.015035058	-36.45789776
.128824955	.015706559	-36.07837919
.131825674	.016406412	-35.69972750
.134896288	.017135676	-35.32197506
.138038426	.017895434	-34.94515511
.141253754	.018686799	-34.56930173
.144543977	.019510909	-34.19444982
.147910839	.020368931	-33.82063509
.151356125	.021262058	-33.44789403
.154881662	.022191507	-33.07626392
.158489319	.023158523	-32.70578276
.162181010	.024164373	-32.33648928
.165958691	.025210349	-31.96842286
.169824365	.026297764	-31.60162355
.173780083	.027427953	-31.23613198
.177827941	.028602272	-30.87198930
.181970086	.029822094	-30.50923719
.186208714	.031088811	-30.14791774
.190546072	.032403629	-29.78807341
.194984460	.033768568	-29.42974699
.199526231	.035124463	-29.07298148
.204173794	.036652955	-28.71782002
.208929613	.038175498	-28.36430585
.213796209	.039753548	-28.01248219
.218776162	.041388567	-27.66239215
.223872114	.043082021	-27.31407865
.229086765	.044835373	-26.96758432
.234422881	.046650084	-26.62295139
.239883292	.048527612	-26.28022160
.245470892	.050469406	-25.93943607
.251188643	.052476908	-25.60063525
.257039578	.054551546	-25.26385875
.263026799	.056694736	-24.92914526
.269153480	.058907878	-24.59653244
.275422870	.061192354	-24.26605681
.281838293	.063549526	-23.93775368

.288403150	.065980735	-23.61165699
.295120923	.068487299	-23.28779923
.301995172	.071070510	-22.96621139
.309029543	.073731634	-22.64692280
.316227766	.076471911	-22.32996111
.323593657	.079292551	-22.01535217
.331131121	.082194735	-21.70311997
.338844156	.085179615	-21.39328659
.346736850	.088248309	-21.08587216
.354813389	.091401908	-20.78089474
.363078055	.094641471	-20.47837038
.371535229	.097968024	-20.17831304
.380189396	.101382564	-19.88073459
.389045145	.104886057	-19.58564479
.398107170	.108479440	-19.29305132
.407380278	.112163618	-19.00295978
.416869383	.115939471	-18.71537373
.426579519	.119807848	-18.43029469
.436515832	.123769572	-18.14772224
.446683592	.127825440	-17.86765407
.457088189	.131976225	-17.59008600
.467735141	.136222672	-17.31501210
.478630092	.140565506	-17.04242477
.489778819	.145005428	-16.77231483
.501187233	.149543114	-16.50467162
.512861384	.154179221	-16.23948309
.524807460	.158914382	-15.97673594
.537031796	.163749210	-15.71641574
.549540874	.168684294	-15.45850702
.562341325	.173720203	-15.20299343
.575439937	.178857480	-14.94985785
.588843655	.184096645	-14.69908252
.602559586	.189438192	-14.45064919
.616595002	.194882588	-14.20453922
.630957344	.200430271	-13.96073375
.645654229	.206081644	-13.71921379
.660693448	.211837080	-13.47996038
.676082975	.217696910	-13.24295470
.691830971	.223661427	-13.00817818
.707945784	.229730875	-12.77561266
.724435960	.235905452	-12.54524044
.741310241	.242185299	-12.31704445
.758577575	.248570499	-12.09100831
.776247116	.255061070	-11.86711646
.794328234	.261656958	-11.64535423
.812830516	.268358035	-11.42570793
.831763771	.275164088	-11.20816494
.851138038	.282074815	-10.99271375
.870963590	.289059818	-10.77934409
.891250938	.296208595	-10.56804689
.912010839	.303430532	-10.35381443
.933254300	.310754899	-10.15164031
.954992586	.318180839	-9.94651955

.977237221	.325707361	-9.74344853
1.000000000	.333333333	-9.54242510
1.023292992	.341057476	-9.34344853
1.047128548	.348878352	-9.14651955
1.071519305	.356794363	-8.95164031
1.096478196	.364803737	-8.75881443
1.122018454	.372904527	-8.56804689
1.148153621	.381094601	-8.37934408
1.174897554	.389371636	-8.19271375
1.202264434	.397733116	-8.00816494
1.230268770	.406176323	-7.82570793
1.258925411	.414698332	-7.64535423
1.288249551	.423296012	-7.46711646
1.318256738	.431966020	-7.29100831
1.348962882	.440704797	-7.11704444
1.380384264	.449508572	-6.94524044
1.412537544	.458373358	-6.77561266
1.445439770	.467294953	-6.60817818
1.479108388	.476268946	-6.44295470
1.513561248	.485290714	-6.27996038
1.548816618	.494355432	-6.11921379
1.584893192	.503458077	-5.96073374
1.621810097	.512593434	-5.80453922
1.659586907	.521756107	-5.65064918
1.698243652	.530940524	-5.49908252
1.737800828	.540140955	-5.34985785
1.778279409	.549351518	-5.20299343
1.819700858	.558566196	-5.05850702
1.862087136	.567778853	-4.91641574
1.905460717	.576983247	-4.77673594
1.949844599	.586173048	-4.63948309
1.995262314	.595341859	-4.50467162
2.041737944	.604483232	-4.37231483
2.089296130	.613590690	-4.24242477
2.137962089	.622657746	-4.11501210
2.187761623	.631677925	-3.99008599
2.238721138	.640644787	-3.86765407
2.290867652	.649551946	-3.74772224
2.344228814	.658393093	-3.63029468
2.398832918	.667162018	-3.51537372
2.454708915	.675852634	-3.40295978
2.511886430	.684458993	-3.29305132
2.570395782	.692975309	-3.18564479
2.630267991	.701395977	-3.08073458
2.691534803	.709715595	-2.97831304
2.754228702	.717928975	-2.87837038
2.818382930	.726031165	-2.78089473
2.884031503	.734017463	-2.68587215
2.951209225	.741883429	-2.59328659
3.019951719	.749624896	-2.50311997
3.090295431	.757237986	-2.41535216

3.162277659	.764719113	-2.32996111
3.235936568	.772064991	-2.24692280
3.311311213	.779272644	-2.16621139
3.388441560	.786339403	-2.08779923
3.467368503	.793262914	-2.01165698
3.548133890	.800041133	-1.93775368
3.630780546	.806672328	-1.86605681
3.715352289	.813155078	-1.79653243
3.801893961	.819488262	-1.72914525
3.890451448	.825671060	-1.66385875
3.981071703	.831702942	-1.60063525
4.073802776	.837583660	-1.53943607
4.168693832	.843313243	-1.48022159
4.265795186	.848891980	-1.42295139
4.365158320	.854320414	-1.36758432
4.466835919	.859599328	-1.31407865
4.570881894	.864729734	-1.26239215
4.677351410	.869712858	-1.21248219
4.786300921	.874550128	-1.16430585
4.897788191	.879243162	-1.11782001
5.011872333	.883793751	-1.07298147
5.128613837	.888203848	-1.02974699
5.248074600	.892475555	-.98807341
5.370317961	.896611105	-.94791773
5.495408735	.900612853	-.90923718
5.623413249	.904483264	-.87198930
5.754399370	.908224894	-.83613197
5.888436550	.911840384	-.80162355
6.025595857	.915332445	-.76842286
6.165950015	.918703850	-.73648928
6.309573441	.921957416	-.70578276
6.456542286	.925096002	-.67626392
6.606934476	.928122494	-.64789403
6.760829750	.931039798	-.62063509
6.918309705	.933850830	-.59444982
7.079457839	.936558508	-.56930173
7.244359596	.939165747	-.54515511
7.413102408	.941675448	-.52197505
7.585775745	.944090495	-.49972749
7.762471161	.946413748	-.47837919
7.943282342	.948648037	-.45789775
8.128305156	.950796158	-.43825164
8.317637706	.952860868	-.41941016
8.511380376	.954844884	-.40134349
8.709635894	.956750873	-.38402265
8.912509376	.958581458	-.36741952
9.120108338	.960339206	-.35150681
9.332543002	.962026635	-.33625508
9.549925854	.963646203	-.32164771
9.772372203	.965200316	-.30765089
.000000000	.000000000	.00000000

APPENDIX F.1

```
C      MAIN PROGRAM FOR TIME RESPONSE OF BANDPASS FILTER
       DIMENSION DY(4),Y(4),YX(101,5),COF(10),YINIT(4)
       DATA YINIT/0.0,0.0,0.0,0.0/
C      YINIT=INITIAL CONDITION
     1 RESET=0.
       NAMELIST IDEV,R1,R2,C1,C2,HL1,HL2,TFINI,XSCAL,YSCAL
       INPUT(101)
C      SET THE VALUE OF THE STATE EQUATIONS
       COF(1)=R1/HL1
       COF(2)=1.0/HL1
       COF(3)=1.0/HL1
       COF(4)=R2/HL2
       COF(5)=1.0/HL2
       COF(6)=1.0/HL2
       COF(7)=1.0/HL2
       COF(8)=1.0/C1
       COF(9)=1.0/C2
       COF(10)=1.0/C2
       IF(IDEV.EQ.0) GO TO 2
       WRITE(6,10)R1,R2,C1,C2,HL1,HL2
C      TIME INITIAL
       TINIT=0.0
C      NUMBER OF THE STATE EQUATIONS
       NEQ=4
       CALL RKTA(DY,Y,NEQ,TINIT,TFINI,YINIT,YX,COF)
       DO 13 I=1,101
C      OUT PUT VOLTAGE
       YX(I,2)=1.0-YX(I,4)-YX(I,5)
       WRITE(6,8)YX(I,1),YX(I,2)
C      X-SCALE
       YX(I,1)=YX(I,1)/XSCAL-1.0
       YX(I,2)=YX(I,2)/YSCAL
    13 CONTINUE
C      NUMBER OF CURVE TO BE PLOTTED
       NCUR=1
C      COLUMN THAT WILL BE PLOTON X-AXIS
       I1=1
C      COLUMN THAT WILL BE PLOT ON Y-AXIS
       J1=2
       CALL DISPLY1(IDEV,YX,NCUR,I1,J1,I2,J2)
       GO TO 1
     2 CONTINUE
```

```
 8 FORMAT(15H            TIME=,F12.8,16H OUTPUT VOLTAGE=,F12.8)
10 FORMAT(1H10X3HR1=,F6.3,3HR2=,F6.3,3HC1=,F6.3,3HC2=,F6.3,3HL1=,
  *F6.3,3HL2=,F6.3)
   STOP
   END
   SUBROUTINE STEQ(DY,Y,T,COF)
   DIMENSION Y(1),DY(1),COF(1)
C  THE STATE EQUATIONS ARE DESCRIBED
   DY(1)=-COF(1)*Y(1)-COF(2)*Y(3)+COF(3)*1.0
   DY(2)=-COF(4)*Y(2)-COF(5)*Y(3)-COF(6)*Y(4)+COF(7)*1.0
   DY(3)=COF(8)*Y(1)+COF(9)*Y(2)
   DY(4)=COF(10)*Y(2)
   RETURN
   END
```

APPENDIX F.2

```
TIME RESPØNSE ØF BANDPASS FILTER

R1=1.000 R2=1.000 C1=1.000 C2=1.000 L1=1.000 L2=1.000

TIME=    .00000000 ØUTPUT VØLTAGE=  1.00000000
TIME=    .10000000 ØUTPUT VØLTAGE=   .98552083
TIME=    .20000000 ØUTPUT VØLTAGE=   .94430088
TIME=    .30000000 ØUTPUT VØLTAGE=   .87992873
TIME=    .40000000 ØUTPUT VØLTAGE=   .79623830
TIME=    .50000000 ØUTPUT VØLTAGE=   .69718895
TIME=    .60000000 ØUTPUT VØLTAGE=   .58675407
TIME=    .70000000 ØUTPUT VØLTAGE=   .46881992
TIME=    .80000000 ØUTPUT VØLTAGE=   .34709630
TIME=    .90000000 ØUTPUT VØLTAGE=   .22504029
TIME=   1.00000000 ØUTPUT VØLTAGE=   .10579347
TIME=   1.10000000 ØUTPUT VØLTAGE=  -.00786688
TIME=   1.20000000 ØUTPUT VØLTAGE=  -.11356292
TIME=   1.30000000 ØUTPUT VØLTAGE=  -.20933797
TIME=   1.40000000 ØUTPUT VØLTAGE=  -.29366573
TIME=   1.50000000 ØUTPUT VØLTAGE=  -.36544778
TIME=   1.60000000 ØUTPUT VØLTAGE=  -.42400070
TIME=   1.70000000 ØUTPUT VØLTAGE=  -.46903408
TIME=   1.80000000 ØUTPUT VØLTAGE=  -.50062068
TIME=   1.90000000 ØUTPUT VØLTAGE=  -.51916055
TIME=   2.00000000 ØUTPUT VØLTAGE=  -.52534023
TIME=   2.10000000 ØUTPUT VØLTAGE=  -.52008874
TIME=   2.20000000 ØUTPUT VØLTAGE=  -.50453176
TIME=   2.30000000 ØUTPUT VØLTAGE=  -.47994509
TIME=   2.40000000 ØUTPUT VØLTAGE=  -.44770896
TIME=   2.50000000 ØUTPUT VØLTAGE=  -.40926395
TIME=   2.60000000 ØUTPUT VØLTAGE=  -.36606959
TIME=   2.70000000 ØUTPUT VØLTAGE=  -.31956648
TIME=   2.80000000 ØUTPUT VØLTAGE=  -.27114236
TIME=   2.90000000 ØUTPUT VØLTAGE=  -.22210277
TIME=   3.00000000 ØUTPUT VØLTAGE=  -.17364654
TIME=   3.10000000 ØUTPUT VØLTAGE=  -.12684616
TIME=   3.20000000 ØUTPUT VØLTAGE=  -.08263327
TIME=   3.30000000 ØUTPUT VØLTAGE=  -.04178890
TIME=   3.40000000 ØUTPUT VØLTAGE=  -.00493843
TIME=   3.50000000 ØUTPUT VØLTAGE=   .02744909
TIME=   3.60000000 ØUTPUT VØLTAGE=   .05505775
TIME=   3.70000000 ØUTPUT VØLTAGE=   .07771807
TIME=   3.80000000 ØUTPUT VØLTAGE=   .09539722
TIME=   3.90000000 ØUTPUT VØLTAGE=   .10818693
TIME=   4.00000000 ØUTPUT VØLTAGE=   .11623934
TIME=   4.10000000 ØUTPUT VØLTAGE=   .12000147
TIME=   4.20000000 ØUTPUT VØLTAGE=   .11969890
TIME=   4.30000000 ØUTPUT VØLTAGE=   .11581398
TIME=   4.40000000 ØUTPUT VØLTAGE=   .10884410
TIME=   4.50000000 ØUTPUT VØLTAGE=   .09923547
TIME=   4.60000000 ØUTPUT VØLTAGE=   .08766776
TIME=   4.70000000 ØUTPUT VØLTAGE=   .07451477
```

```
TIME=   4.80000000 ØUTPUT VØLTAGE=    .06033661
TIME=   4.90000000 ØUTPUT VØLTAGE=    .04561833
TIME=   5.00000000 ØUTPUT VØLTAGE=    .03081034
TIME=   5.10000000 ØUTPUT VØLTAGE=    .01632055
TIME=   5.20000000 ØUTPUT VØLTAGE=    .00250837
TIME=   5.30000000 ØUTPUT VØLTAGE=   -.01031959
TIME=   5.40000000 ØUTPUT VØLTAGE=   -.02191201
TIME=   5.50000000 ØUTPUT VØLTAGE=   -.03207382
TIME=   5.60000000 ØUTPUT VØLTAGE=   -.04066562
TIME=   5.70000000 ØUTPUT VØLTAGE=   -.04760175
TIME=   5.80000000 ØUTPUT VØLTAGE=   -.05284732
TIME=   5.90000000 ØUTPUT VØLTAGE=   -.05641410
TIME=   6.00000000 ØUTPUT VØLTAGE=   -.05835578
TIME=   6.10000000 ØUTPUT VØLTAGE=   -.05876257
TIME=   6.20000000 ØUTPUT VØLTAGE=   -.05775543
TIME=   6.30000000 ØUTPUT VØLTAGE=   -.05548007
TIME=   6.40000000 ØUTPUT VØLTAGE=   -.05210091
TIME=   6.50000000 ØUTPUT VØLTAGE=   -.04779520
TIME=   6.60000000 ØUTPUT VØLTAGE=   -.04274727
TIME=   6.70000000 ØUTPUT VØLTAGE=   -.03714330
TIME=   6.80000000 ØUTPUT VØLTAGE=   -.03116640
TIME=   6.90000000 ØUTPUT VØLTAGE=   -.02499234
TIME=   7.00000000 ØUTPUT VØLTAGE=   -.01878583
TIME=   7.10000000 ØUTPUT VØLTAGE=   -.01269741
TIME=   7.20000000 ØUTPUT VØLTAGE=   -.00686104
TIME=   7.30000000 ØUTPUT VØLTAGE=   -.00139230
TIME=   7.40000000 ØUTPUT VØLTAGE=    .00361280
TIME=   7.50000000 ØUTPUT VØLTAGE=    .00807834
TIME=   7.60000000 ØUTPUT VØLTAGE=    .01194853
TIME=   7.70000000 ØUTPUT VØLTAGE=    .01518721
TIME=   7.80000000 ØUTPUT VØLTAGE=    .01777692
TIME=   7.90000000 ØUTPUT VØLTAGE=    .01971757
TIME=   8.00000000 ØUTPUT VØLTAGE=    .02102484
TIME=   8.10000000 ØUTPUT VØLTAGE=    .02172830
TIME=   8.20000000 ØUTPUT VØLTAGE=    .02186939
TIME=   8.30000000 ØUTPUT VØLTAGE=    .02149928
TIME=   8.40000000 ØUTPUT VØLTAGE=    .02067671
TIME=   8.50000000 ØUTPUT VØLTAGE=    .01946582
TIME=   8.60000000 ØUTPUT VØLTAGE=    .01793407
TIME=   8.70000000 ØUTPUT VØLTAGE=    .01615025
TIME=   8.80000000 ØUTPUT VØLTAGE=    .01418271
TIME=   8.90000000 ØUTPUT VØLTAGE=    .01209764
TIME=   9.00000000 ØUTPUT VØLTAGE=    .00995775
TIME=   9.10000000 ØUTPUT VØLTAGE=    .00782097
TIME=   9.20000000 ØUTPUT VØLTAGE=    .00573951
TIME=   9.30000000 ØUTPUT VØLTAGE=    .00375916
TIME=   9.40000000 ØUTPUT VØLTAGE=    .00191870
TIME=   9.50000000 ØUTPUT VØLTAGE=    .00024968
TIME=   9.60000000 ØUTPUT VØLTAGE=   -.00122369
TIME=   9.70000000 ØUTPUT VØLTAGE=   -.00248443
TIME=   9.80000000 ØUTPUT VØLTAGE=   -.00352254
TIME=   9.90000000 ØUTPUT VØLTAGE=   -.00433452
TIME=  10.00000000 ØUTPUT VØLTAGE=   -.00492288
```

APPENDIX F.3

```
C      MAIN PROGRAM FOR FREQUENCY RESPONSE OF BANDPASS FILTER
C      FROM THE TRANSFER FUNCTION IN POLYNOMIAL FORM
       COMPLEX COMP,COMZ
       DIMENSION W(201),COFZ(5),COFP(5),AMAG(201),DBM(201),WL(201),SW(5)
     2 RESET=0
       NAMELIST IDEV,R1,R2,C1,C2,HL1,HL2,SCALE
       INPUT(101)
       WRITE(6,12) R1,R2,C1,C2,HL1,HL2
       IF(R1.LT.0) GO TO 3
C      COEFICIENT OF THE NOMINATOR
       COFZ(1)=0.
       COFZ(2)=0.
       COFZ(3)=C1*C2*R1*R2
       COFZ(4)=R1*C1*C2*HL2+R2*C1*C2*HL1
       COFZ(5)=HL1*HL2*C1*C2
C      COEFICIENT OF THE DENOMINATOR
       COFP(1)=1.0
       COFP(2)=R1*C1+R2*C2+R1*C2
       COFP(3)=HL1*C2+HL2*C2+R1*R2*C1*C2+HL1*C1
       COFP(4)=HL2*C1*C2*R1+HL1*C1*C2*R2
       COFP(5)=HL1*HL2*C1*C2
       WMAX=10.0
       WMIN=0.1
C      NUMBER OF POINT = 200 WILL BE COMPUTED
       DW=WMAX/WMIN
C      SET STEP SIZE
       DLW=ALOG10(DW)/200.0
       WL(1)=ALOG10(WMIN)
       WRITE(6,10)
C      SUBSTITUTE S BY JW
       DO 1 I=1,200
       W(I)=10.0**WL(I)
       SW(1)=W(I)
       SW(2)=W(I)**2
       SW(3)=W(I)**3
       SW(4)=W(I)**4
       ZR=COFZ(1)-COFZ(3)*SW(2)+COFZ(5)*SW(4)
       ZI=COFZ(2)*SW(1)-COFZ(4)*SW(3)
       COMZ=CMPLX(ZR,ZI)
       PR=COFP(1)-COFP(3)*SW(2)+COFP(5)*SW(4)
       PI=COFP(2)*SW(1)-COFP(4)*SW(3)
       COMP=CMPLX(PR,PI)
```

```
C     COMPUTE THE MAGNITUDE OF THE NOMINATOR
      ZMAG=CABS(COMZ)
C     COMPUTE THE MAGNITUDE OF THE DENOMINATOR
      PMAG=CABS(COMP)
C     COMPUTE THE MAGNITUDE OF THE TRANSFER FUNCTION
      AMAG(I)=ZMAG/PMAG
C     COMPUTE MAG. IN DB
      DBM(I)=20.0*ALOG10(AMAG(I))
      WL(I+1)=WL(I)+DLW
      WRITE(6,11)W(I),AMAG(I),DBM(I)
    1 CONTINUE
      CALL DISPLY2(IDEV,DBM,WL,SCALE)
      GO TO 2
    3 CONTINUE
   10 FORMAT(23H          FREQ(RAD/SEC),19H          MAGNITUDE,23H
     *    MAGNITUDE(DB))
   11 FORMAT(10H          ,F12.9,10H          ,F12.9,9H         ,F12.8)
   12 FORMAT(1H10X3HR1=,F6.3,3HR2=,F6.3,3HC1=,F6.3,3HC2=,F6.3,4HHL1=,
     *F6.3,4HHL2=,F6.3)
      STOP
      END
```

APPENDIX F.4

FREQUENCY RESPONSE OF BANDPASS FILTER

R1=1.000 R2=1.000 C1=1.000 C2=1.000 L1=1.000 L2=1.000

FREQ(RAD/SEC)	MAGNITUDE	MAGNITUDE(DB)
.100000000	.010046912	-39.95934832
.102329299	.010522566	-39.55756720
.104712855	.011020829	-39.15571490
.107151931	.011542783	-38.75378926
.109647820	.012089563	-38.35178813
.112201845	.012662356	-37.94970937
.114815362	.013262410	-37.54755089
.117489755	.013891031	-37.14531063
.120226443	.014549587	-36.74298658
.123026877	.015239515	-36.34057682
.125892541	.015962320	-35.93807951
.128824955	.016719580	-35.53549292
.131825674	.017512947	-35.13281548
.134896288	.018344155	-34.73004574
.138038426	.019215022	-34.32718247
.141253754	.020127451	-33.92422463
.144543977	.021083438	-33.52117145
.147910839	.022085075	-33.11802245
.151356125	.023134554	-32.71477745
.154881662	.024234171	-32.31143666
.158489319	.025386333	-31.90800070
.162181010	.026593559	-31.50447066
.165958691	.027858491	-31.10084817
.169824365	.029183893	-30.69713541
.173780083	.030572661	-30.29333525
.177827941	.032027824	-29.88945125
.181970086	.033552556	-29.48548780
.186208714	.035150175	-29.08145016
.190546072	.036824154	-28.67734455
.194984460	.038578122	-28.27317826
.199526231	.040415873	-27.86895975
.204173794	.042341385	-27.46469873
.208929613	.044358789	-27.06040633
.213796209	.046472415	-26.65609514
.218776162	.048686778	-26.25177939
.223872114	.051006585	-25.84747506
.229086765	.053436745	-25.44320002
.234422881	.055982372	-25.03897416
.239883292	.058648786	-24.63481952
.245470892	.061441524	-24.23076046
.251188643	.064366339	-23.82682379
.257039578	.067429207	-23.42303890
.263026799	.070636326	-23.01943791
.269153480	.073994120	-22.61605581
.275422870	.077509239	-22.21293057
.281838293	.081188560	-21.81010324

.288403150	.085039186	-21.40761811
.295120923	.089068444	-21.00552271
.301995172	.093283881	-20.60386790
.309029543	.097693260	-20.20270792
.316227766	.102304558	-19.80210031
.323593657	.107125954	-19.40210596
.331131121	.112165825	-19.00278892
.338844156	.117432738	-18.60421629
.346736850	.122935440	-18.20645802
.354813389	.128682849	-17.80958662
.363078055	.134684048	-17.41367677
.371535229	.140948271	-17.01880496
.380189396	.147484899	-16.62504889
.389045145	.154303457	-16.23248690
.398107170	.161413605	-15.84119725
.407380278	.168825147	-15.45125728
.416869383	.176548029	-15.06274253
.426579519	.184592357	-14.67572568
.436515832	.192968413	-14.29027548
.446683592	.201686684	-13.90645550
.457088189	.210757897	-13.52432286
.467735141	.220193075	-13.14392686
.478630092	.230003594	-12.76530756
.489778819	.240201262	-12.38849431
.501187233	.250798414	-12.01350428
.512861384	.261808023	-11.64034098
.524807460	.273243826	-11.26899283
.537031796	.285120478	-10.89943178
.549540874	.297453717	-10.53161199
.562341325	.310260556	-10.16546868
.575439937	.323559492	-9.80091711
.588843655	.337370741	-9.43785171
.602559586	.351716489	-9.07614542
.616595002	.366621167	-8.71564929
.630957344	.382111746	-8.35619224
.645654229	.398218050	-7.99758117
.660693448	.414973091	-7.63960129
.676082975	.432413421	-7.28201671
.691830971	.450579503	-6.92457137
.707945784	.469516099	-6.56699024
.724435960	.489272674	-6.20898078
.741310241	.509903814	-5.85023479
.758577575	.531469657	-5.49043050
.776247116	.554036334	-5.12923506
.794328234	.577676411	-4.76630733
.812830516	.602469328	-4.40130116
.831763771	.628501826	-4.03386912
.851138038	.655868333	-3.66366674
.870963590	.684671305	-3.29035747
.891250938	.715021463	-2.91361844
.912010839	.747037906	-2.53314722
.933254300	.780848014	-2.14366980
.954992586	.816537059	-1.75995014

.977237221	.854397415	-1.36680149
1.000000000	.894427190	-.96910014
1.023292992	.936828097	-.56680185
1.047128548	.981752274	-.15996168
1.071519305	1.029347729	.25124221
1.096478196	1.079751987	.66648024
1.122018454	1.133083433	1.08523780
1.148153621	1.189429781	1.50677616
1.174897554	1.248833054	1.93008770
1.202264434	1.311270527	2.35384600
1.230268770	1.376631239	2.77635241
1.258925411	1.444688156	3.19548225
1.288249551	1.515066799	3.60863562
1.318256738	1.587212403	4.01270097
1.348962882	1.660359412	4.40404217
1.380384264	1.733509201	4.77852302
1.412537544	1.805424036	5.13158440
1.445439770	1.874646525	5.45838782
1.479108388	1.939553041	5.75403322
1.513561248	1.998445583	6.01384654
1.548816618	2.049678773	6.23371607
1.584893192	2.091808263	6.41043748
1.621810097	2.123736969	6.54201454
1.659586907	2.144830734	6.62786048
1.698243652	2.154978690	6.66885960
1.737800828	2.154585868	6.66727614
1.778279409	2.144502152	6.62652973
1.819700858	2.125906193	6.55088194
1.862087136	2.100170195	6.44508982
1.905460717	2.068730325	6.31407761
1.949844599	2.032980202	6.16266298
1.995262314	1.994195608	5.99535511
2.041737944	1.953490518	5.81622615
2.089296130	1.911799453	5.62884666
2.137962089	1.869879074	5.43627043
2.187761623	1.828322007	5.24105373
2.238721138	1.787577087	5.04529559
2.290867652	1.747971857	4.85068872
2.344228814	1.709734595	4.65857399
2.398832918	1.673014371	4.46999343
2.454708915	1.637898416	4.28573926
2.511886430	1.604426676	4.10639748
2.570395782	1.572603673	3.93238571
2.630267991	1.542407989	3.76398532
2.691534803	1.513799718	3.60136840
2.754228702	1.486726243	3.44462015
2.818382930	1.461126647	3.29375722
2.884031502	1.436935056	3.14374280
2.951209225	1.414033118	3.00949875
3.019951719	1.392501832	2.87591550
3.090295431	1.372122863	2.74786002

3.162277659	1.352879471	2.62518214
3.235936568	1.334707142	2.50771969
3.311311213	1.317543998	2.39530254
3.388441560	1.301331048	2.28775583
3.467368503	1.286012304	2.18490247
3.548133890	1.271534823	2.08656517
3.630780546	1.257848677	1.99256795
3.715352289	1.244906880	1.90273734
3.801893961	1.232665283	1.81690329
3.890451448	1.221082458	1.73489984
3.981071703	1.210119558	1.65656560
4.073802776	1.199740182	1.58174409
4.168693832	1.189910234	1.51028399
4.265795186	1.180597780	1.44203924
4.365158320	1.171772919	1.37686913
4.466835919	1.163407646	1.31463827
4.570881894	1.155475734	1.25521659
4.677351410	1.147952610	1.19847920
4.786300921	1.140815249	1.14430635
4.897788191	1.134042064	1.09258327
5.011872333	1.127612815	1.04320005
5.128613837	1.121508511	.99605147
5.248074600	1.115711329	.95103686
5.370317961	1.110204534	.90805993
5.495408735	1.104972405	.86702865
5.623413249	1.100000165	.82785500
5.754399370	1.095273920	.79045493
5.888436550	1.090780600	.75474811
6.025595857	1.086507902	.72065779
6.165950015	1.082444242	.68811069
6.309573441	1.078578706	.65703684
6.456542286	1.074901007	.62736940
6.606934476	1.071401446	.59904456
6.760829750	1.068070870	.57200141
6.918309705	1.064900644	.54618180
7.079457839	1.061882613	.52153020
7.244359596	1.059009073	.49799362
7.413102408	1.056272745	.47552148
7.585775745	1.053666748	.45406549
7.762471161	1.051184571	.43357956
7.943282342	1.048820058	.41401969
8.128305156	1.046567381	.39534390
8.317637706	1.044421023	.37751210
8.511380376	1.042375756	.36048604
8.709635894	1.040426631	.34422920
8.912509376	1.038568956	.32870673
9.120108383	1.036798281	.31388537
9.332543002	1.035110389	.29973335
9.549925854	1.033501278	.28622036
9.772372203	1.031967153	.27331748
.000000000	.000000000	.00000000

APPENDIX F.5

```
     TIME RESPØNSE ØF BANDPASS FILTER

R1= .050 R2= .050 C1=1.000 C2=1.000 L1=1.000 L2=1.000

TIME=    .00000000 ØUTPUT VØLTAGE=  1.00000000
TIME=    .20000000 ØUTPUT VØLTAGE=   .94073283
TIME=    .40000000 ØUTPUT VØLTAGE=   .76996910
TIME=    .60000000 ØUTPUT VØLTAGE=   .50679503
TIME=    .80000000 ØUTPUT VØLTAGE=   .17986854
TIME=   1.00000000 ØUTPUT VØLTAGE=  -.17564639
TIME=   1.20000000 ØUTPUT VØLTAGE=  -.52178977
TIME=   1.40000000 ØUTPUT VØLTAGE=  -.82177023
TIME=   1.60000000 ØUTPUT VØLTAGE= -1.04377202
TIME=   1.80000000 ØUTPUT VØLTAGE= -1.16421242
TIME=   2.00000000 ØUTPUT VØLTAGE= -1.17011839
TIME=   2.20000000 ØUTPUT VØLTAGE= -1.06038519
TIME=   2.40000000 ØUTPUT VØLTAGE=  -.84579804
TIME=   2.60000000 ØUTPUT VØLTAGE=  -.54782626
TIME=   2.80000000 ØUTPUT VØLTAGE=  -.19632632
TIME=   3.00000000 ØUTPUT VØLTAGE=   .17359845
TIME=   3.20000000 ØUTPUT VØLTAGE=   .52524930
TIME=   3.40000000 ØUTPUT VØLTAGE=   .82411279
TIME=   3.60000000 ØUTPUT VØLTAGE=  1.04137941
TIME=   3.80000000 ØUTPUT VØLTAGE=  1.15683974
TIME=   4.00000000 ØUTPUT VØLTAGE=  1.16086555
TIME=   4.20000000 ØUTPUT VØLTAGE=  1.05528058
TIME=   4.40000000 ØUTPUT VØLTAGE=   .85304252
TIME=   4.60000000 ØUTPUT VØLTAGE=   .57678096
TIME=   4.80000000 ØUTPUT VØLTAGE=   .25635393
TIME=   5.00000000 ØUTPUT VØLTAGE=  -.07431473
TIME=   5.20000000 ØUTPUT VØLTAGE=  -.38078333
TIME=   5.40000000 ØUTPUT VØLTAGE=  -.63165527
TIME=   5.60000000 ØUTPUT VØLTAGE=  -.80178902
TIME=   5.80000000 ØUTPUT VØLTAGE=  -.87482699
TIME=   6.00000000 ØUTPUT VØLTAGE=  -.84478927
TIME=   6.20000000 ØUTPUT VØLTAGE=  -.71657684
TIME=   6.40000000 ØUTPUT VØLTAGE=  -.50534363
TIME=   6.60000000 ØUTPUT VØLTAGE=  -.23481351
TIME=   6.80000000 ØUTPUT VØLTAGE=   .06527302
TIME=   7.00000000 ØUTPUT VØLTAGE=   .36230986
TIME=   7.20000000 ØUTPUT VØLTAGE=   .62424237
TIME=   7.40000000 ØUTPUT VØLTAGE=   .82289457
TIME=   7.60000000 ØUTPUT VØLTAGE=   .93686343
TIME=   7.80000000 ØUTPUT VØLTAGE=   .95368520
TIME=   8.00000000 ØUTPUT VØLTAGE=   .87105715
TIME=   8.20000000 ØUTPUT VØLTAGE=   .69699736
TIME=   8.40000000 ØUTPUT VØLTAGE=   .44893645
TIME=   8.60000000 ØUTPUT VØLTAGE=   .15184531
TIME=   8.80000000 ØUTPUT VØLTAGE=  -.16439858
TIME=   9.00000000 ØUTPUT VØLTAGE=  -.46812686
TIME=   9.20000000 ØUTPUT VØLTAGE=  -.72915184
TIME=   9.40000000 ØUTPUT VØLTAGE=  -.92185458
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TIME=  9.60000000 ØUTPUT VØLTAGE= -1.02777274
TIME=  9.80000000 ØUTPUT VØLTAGE= -1.03742600
TIME= 10.00000000 ØUTPUT VØLTAGE=  -.95119826
TIME= 10.20000000 ØUTPUT VØLTAGE=  -.77919506
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TIME= 10.60000000 ØUTPUT VØLTAGE=  -.25916593
TIME= 10.80000000 ØUTPUT VØLTAGE=   .03446565
TIME= 11.00000000 ØUTPUT VØLTAGE=   .31079623
TIME= 11.20000000 ØUTPUT VØLTAGE=   .54207367
TIME= 11.40000000 ØUTPUT VØLTAGE=   .70562395
TIME= 11.60000000 ØUTPUT VØLTAGE=   .78612913
TIME= 11.80000000 ØUTPUT VØLTAGE=   .77712108
TIME= 12.00000000 ØUTPUT VØLTAGE=   .68154463
TIME= 12.20000000 ØUTPUT VØLTAGE=   .51134159
TIME= 12.40000000 ØUTPUT VØLTAGE=   .28610864
TIME= 12.60000000 ØUTPUT VØLTAGE=   .03097721
TIME= 12.80000000 ØUTPUT VØLTAGE=  -.22605764
TIME= 13.00000000 ØUTPUT VØLTAGE=  -.45707765
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TIME= 13.40000000 ØUTPUT VØLTAGE=  -.74686555
TIME= 13.60000000 ØUTPUT VØLTAGE=  -.77436129
TIME= 13.80000000 ØUTPUT VØLTAGE=  -.71643531
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TIME= 14.20000000 ØUTPUT VØLTAGE=  -.37558557
TIME= 14.40000000 ØUTPUT VØLTAGE=  -.12747080
TIME= 14.60000000 ØUTPUT VØLTAGE=   .14016669
TIME= 14.80000000 ØUTPUT VØLTAGE=   .40007945
TIME= 15.00000000 ØUTPUT VØLTAGE=   .62594042
TIME= 15.20000000 ØUTPUT VØLTAGE=   .79504743
TIME= 15.40000000 ØUTPUT VØLTAGE=   .89062895
TIME= 15.60000000 ØUTPUT VØLTAGE=   .90351665
TIME= 15.80000000 ØUTPUT VØLTAGE=   .83301852
TIME= 16.00000000 ØUTPUT VØLTAGE=   .68691031
TIME= 16.20000000 ØUTPUT VØLTAGE=   .48055466
TIME= 16.40000000 ØUTPUT VØLTAGE=   .23524774
TIME= 16.60000000 ØUTPUT VØLTAGE=  -.02402853
TIME= 16.80000000 ØUTPUT VØLTAGE=  -.27121076
TIME= 17.00000000 ØUTPUT VØLTAGE=  -.48184240
TIME= 17.20000000 ØUTPUT VØLTAGE=  -.63556814
TIME= 17.40000000 ØUTPUT VØLTAGE=  -.71317866
TIME= 17.60000000 ØUTPUT VØLTAGE=  -.72299955
TIME= 17.80000000 ØUTPUT VØLTAGE=  -.65148760
TIME= 18.00000000 ØUTPUT VØLTAGE=  -.51298114
TIME= 18.20000000 ØUTPUT VØLTAGE=  -.32363885
TIME= 18.40000000 ØUTPUT VØLTAGE=  -.10468515
TIME= 18.60000000 ØUTPUT VØLTAGE=   .11984973
TIME= 18.80000000 ØUTPUT VØLTAGE=   .32565600
TIME= 19.00000000 ØUTPUT VØLTAGE=   .49067327
TIME= 19.20000000 ØUTPUT VØLTAGE=   .59736079
TIME= 19.40000000 ØUTPUT VØLTAGE=   .63447680
TIME= 19.60000000 ØUTPUT VØLTAGE=   .59818798
TIME= 19.80000000 ØUTPUT VØLTAGE=   .49240094
TIME= 20.00000000 ØUTPUT VØLTAGE=   .32828920
```

APPENDIX F.6

FREQUENCY RESPONSE OF BANDPASS FILTER

R1= .050 R2= .050 C1=1.000 C2=1.000 L1=1.000 L2=1.000

FREQ(RAD/SEC)	MAGNITUDE	MAGNITUDE(DB)
.100000000	.000128841	-77.79893045
.102329299	.000140202	-77.06492835
.104712855	.000152626	-76.32745402
.107151931	.000166216	-75.58655828
.109647820	.000181086	-74.84228982
.112201845	.000197363	-74.09469498
.114815362	.000215184	-73.34381757
.117489755	.000234701	-72.58969861
.120226443	.000256083	-71.83237613
.123026877	.000279515	-71.07188497
.125892541	.000305202	-70.30825656
.128824955	.000333368	-69.54151870
.131825674	.000364263	-68.77169539
.134896288	.000398162	-67.99880655
.138038426	.000435368	-67.22286791
.141253754	.000476218	-66.44389065
.144543977	.000521082	-65.66188132
.147910839	.000570372	-64.87684152
.151356125	.000624542	-64.08876764
.154881662	.000684097	-63.29765071
.158489319	.000749594	-62.50347602
.162181010	.000821654	-61.70622291
.165958691	.000900963	-60.90586446
.169824365	.000988284	-60.10236712
.173780083	.001084465	-59.29569044
.177827941	.001190449	-58.48578666
.181970086	.001307284	-57.67260027
.186208714	.001436139	-56.85606767
.190546072	.001578317	-56.03611658
.194984460	.001735269	-55.21266562
.199526231	.001908617	-54.38562366
.204173794	.002100175	-53.55488923
.208929613	.002311972	-52.72034982
.213796209	.002546279	-51.88188110
.218776162	.002805645	-51.03934609
.223872114	.003092931	-50.19259419
.229086765	.003411356	-49.34146014
.234422881	.003764539	-48.48576284
.239883292	.004156567	-47.62530405
.245470892	.004592051	-46.75986688
.251188643	.005076207	-45.88921417
.257039578	.005614947	-45.01308658
.263026799	.006214983	-44.13120049
.269153480	.006883950	-43.24324560
.275422870	.007630551	-42.34888217
.281838293	.008464730	-41.44773794

.283403150	.009397877	-40.53940447
.295120923	.010443074	-39.62343310
.301995172	.011615382	-38.69933015
.309029543	.012932201	-37.76655141
.316227766	.014413691	-36.82449572
.323593657	.016083299	-35.87249741
.331131121	.017968388	-34.90981751
.338844156	.020101031	-33.93563326
.346736850	.022518980	-32.94902563
.354813389	.025266889	-31.94896450
.363078055	.028397850	-30.93429067
.371535229	.031975349	-29.90369409
.380189396	.036075772	-28.85568734
.389045145	.040791658	-27.78857276
.398107170	.046235963	-26.70040180
.407380278	.052547712	-25.58892381
.416869383	.059899602	-24.45152125
.426579519	.068508376	-23.28512652
.436515832	.078649193	-22.08611405
.446683592	.090675943	-20.85015836
.457088189	.105050414	-19.57204462
.467735141	.122385338	-18.24541214
.478630092	.143509271	-16.86240085
.489778819	.169567340	-15.41315583
.501187233	.202182687	-13.88512071
.512861384	.243724577	-12.26201348
.524807460	.297771846	-10.52232735
.537031796	.369949526	-8.63715050
.549540874	.469506038	-6.56717636
.562341325	.612378099	-4.25960700
.575439937	.826949663	-1.65041851
.588843655	1.161130204	1.29761844
.602559586	1.655207554	4.37704919
.616595002	2.105161296	6.46570754
.630957344	2.027099732	6.13750232
.645654229	1.670332914	4.45606078
.660693448	1.377323454	2.78071886
.676082975	1.179948190	1.43725877
.691830971	1.048291257	.40963927
.707945784	.958765581	-.36575131
.724435960	.897006882	-.94408450
.741310241	.854410450	-1.36666897
.758577575	.825684758	-1.66371465
.776247116	.807471647	-1.85745437
.794328234	.797583190	-1.96448016
.812830516	.794570021	-1.99735650
.831763771	.797469472	-1.96571866
.851138038	.805654328	-1.97702511
.870963590	.812740058	-1.73707921
.891250938	.836527506	-1.55039549
.912010839	.858968106	-1.32045923
.933254300	.886144303	-1.04991100
.954992586	.918261023	-.74067699

.977237221	.955646057	-.39405855
1.000000000	.998758542	-.01078987
1.023292992	1.048205790	.40893109
1.047128548	1.104769762	.86543558
1.071519305	1.169445612	1.35960058
1.096478196	1.243496379	1.89289050
1.122018454	1.328530155	2.46742833
1.148153621	1.426609726	3.08610361
1.174897554	1.540410479	3.75272929
1.202264434	1.673452254	4.47226652
1.230268770	1.830447933	5.25114760
1.258925411	2.017842692	6.09774613
1.288249551	2.244676724	7.02307606
1.318256738	2.524021489	8.04186096
1.348962882	2.875487246	9.17422891
1.380384264	3.329860408	10.44852055
1.412537544	3.938311702	11.90620172
1.445439770	4.792399892	13.61106099
1.479108388	6.072923524	15.66795624
1.513561248	8.189586587	18.26523958
1.548816618	12.276446609	21.78145359
1.584893192	22.370030673	26.99333159
1.621810097	37.533451612	31.48837009
1.659586907	20.056424521	26.04507027
1.698243652	11.909088481	21.51757044
1.737800828	8.409988749	18.49590830
1.778279409	6.524010434	16.29029294
1.819700858	5.354669381	14.57465322
1.862087136	4.561744490	13.18261912
1.905460717	3.990003694	12.01946595
1.949844599	3.558968444	11.02648275
1.995262314	3.222873265	10.16486456
2.041737944	2.953812032	9.40765710
2.089296130	2.733816219	8.73538632
2.137962089	2.550799650	8.13352698
2.187761623	2.396336613	7.59095646
2.233721138	2.264375209	7.09896783
2.290867652	2.150457229	6.65061618
2.344228814	2.051226437	6.24027210
2.398832918	1.964108188	5.86330812
2.454708915	1.887094595	5.51587341
2.511886430	1.813596822	5.19472855
2.570395782	1.757341250	4.89712207
2.630267991	1.702295046	4.62069671
2.691534803	1.652611854	4.36341727
2.754228702	1.607591547	4.12351428
2.818382930	1.566649968	3.89943948
2.884031502	1.529295881	3.68983038
2.951209225	1.495113206	3.49342155
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3.090295431	1.434893460	3.13630312

3.162277659	1.408289487	2.97383874
3.235936568	1.383707541	2.82088616
3.311311213	1.360949156	2.67683801
3.388441560	1.339840567	2.54106246
3.467368503	1.320228982	2.41298525
3.548133890	1.301979515	2.29208303
3.630780546	1.284972635	2.17787758
3.715352289	1.269102042	2.06993086
3.801893961	1.254272888	1.96784070
3.890451448	1.240400277	1.87123709
3.981071703	1.227407991	1.77977893
4.073802776	1.215227414	1.69315116
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4.265795186	1.193059508	1.53324212
4.365158320	1.182965274	1.45943992
4.466835919	1.173467669	1.38942257
4.570881894	1.164524562	1.32297306
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4.786300921	1.148151250	1.19998206
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5.011872333	1.133574892	1.08900436
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5.248074600	1.120567529	.98876067
5.370317961	1.114590601	.94230753
5.495408735	1.108935718	.89812744
5.623413249	1.103583070	.85610059
5.754399370	1.098514302	.81611432
5.888436550	1.093712383	.77806258
6.025595857	1.089161487	.74184553
6.165950015	1.084846899	.70736904
6.309573441	1.080754911	.67454435
6.456542286	1.076872748	.64328773
6.606934476	1.073188488	.61352011
6.760829750	1.069690994	.58516679
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7.585775745	1.054662908	.46227345
7.762471161	1.052089033	.44104987
7.943282342	1.049641435	.42081932
8.128305156	1.047313452	.40153364
8.317637706	1.045098820	.38314714
8.511380376	1.042991638	.36561653
8.709635894	1.040986349	.34890069
8.912509376	1.039077714	.33296061
9.120108388	1.037260791	.31775924
9.332543002	1.035530918	.30326140
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.000000000	.000000000	.00000000

APPENDIX F.7

TIME RESPØNSE ØF BANDPASS FILTER

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TIME=   9.40000000 ØUTPUT VØLTAGE=   -.06913582
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APPENDIX F.8

FREQUENCY RESPONSE OF BANDPASS FILTER

R1=4.000 R2=4.000 C1=1.000 C2=1.000 L1=1.000 L2=1.000

FREQ(RAD/SEC)	MAGNITUDE	MAGNITUDE(DB)
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.107151931	.122841164	-18.21312153
.109647820	.126958376	-17.92677281
.112201845	.131176808	-17.64285882
.114815362	.135497507	-17.36137394
.117489755	.139921506	-17.08231060
.120226443	.144449829	-16.80565937
.123026877	.149083489	-16.53140904
.125892541	.153823492	-16.25954670
.128824955	.158670835	-15.99005787
.131825674	.163626512	-15.72292655
.134896288	.168691512	-15.45813540
.138038426	.173866819	-15.19566581
.141253754	.179153418	-14.93549803
.144543977	.184552289	-14.67761130
.147910839	.190064410	-14.42198398
.151356125	.195690758	-14.16859369
.154881662	.201432308	-13.91741741
.158489319	.207290032	-13.66843164
.162181010	.213264895	-13.42161253
.165958691	.219357860	-13.17693599
.169824365	.225569880	-12.93437784
.173780083	.231901898	-12.69391394
.177827941	.238354846	-12.45552027
.181970086	.244929640	-12.21917313
.186208714	.251627174	-11.98484919
.190546072	.258448323	-11.75252563
.194984460	.265393931	-11.52218025
.199526231	.272464811	-11.29379158
.204173794	.279661737	-11.06733897
.208929613	.286985441	-10.84280268
.213796209	.294436604	-10.62016399
.218776162	.302015851	-10.39940526
.223872114	.309723743	-10.18051002
.229086765	.317560770	-9.96346306
.234422881	.325527345	-9.74825047
.239883292	.333623793	-9.53485969
.245470892	.341850342	-9.32327963
.251188643	.350207118	-9.11350063
.257039578	.358694131	-8.90551457
.263026799	.367311271	-8.69931489
.269153480	.376058293	-8.49489660
.275422870	.384934807	-8.29225633
.281838293	.393940274	-8.09139234

.288403150	.403073989	-7.89230453
.295120923	.412335073	-7.69499445
.301995172	.421722463	-7.49946531
.309029543	.431234900	-7.30572197
.316227766	.440870921	-7.11377092
.323593657	.450628844	-6.92362026
.331131121	.460506765	-6.73527971
.338844156	.470502541	-6.54876054
.346736850	.480613783	-6.36407558
.354813389	.490837847	-6.18123914
.363078055	.501171829	-6.00026698
.371535229	.511612547	-5.82117626
.380189396	.522156545	-5.64398548
.389045145	.532800077	-5.46871441
.398107170	.543539109	-5.29538404
.407380278	.554369305	-5.12401648
.416869383	.565286033	-4.95463489
.426579519	.576284356	-4.78726340
.436515832	.587359030	-4.62192701
.446683592	.598504508	-4.45865148
.457088189	.609714940	-4.29746327
.467735141	.620984171	-4.13838939
.478630092	.632305754	-3.98145732
.489778819	.643672946	-3.82669488
.501187233	.655078725	-3.67413010
.512861384	.666515791	-3.52379113
.524807460	.677976584	-3.37570611
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.549540874	.700937864	-3.08640958
.562341325	.712422036	-2.94525311
.575439937	.723897337	-2.80646041
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.602559586	.746786559	-2.53607015
.616595002	.758182713	-2.40452244
.630957344	.769534512	-2.27543796
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.660693448	.792068354	-2.02474676
.676082975	.803231918	-1.90318084
.691830971	.814314225	-1.78415957
.707945784	.825306027	-1.66769967
.724435960	.836198123	-1.55381623
.741310241	.846981391	-1.44252263
.758577575	.857646811	-1.33383046
.776247116	.868185497	-1.22774946
.794328234	.878588725	-1.12428748
.812830516	.888847959	-1.02345041
.831763771	.898954874	-.92524217
.851138038	.908901388	-.82966467
.870963590	.918679679	-.73671780
.891250938	.928282213	-.64639942
.912010839	.937701758	-.55870540
.933254300	.946931410	-.47362955
.954992586	.955964605	-.39116375

.977237221	.964795136	-.31129789
1.000000000	.973417168	-.23401997
1.023292992	.981825246	-.15931610
1.047128548	.990014306	-.08717060
1.071519305	.997979682	-.01756601
1.096478196	1.005717114	.04951681
1.122018454	1.013222746	.11409862
1.148153621	1.020493134	.17620174
1.174897554	1.027525239	.23584996
1.202264434	1.034316431	.29306848
1.230268770	1.040864485	.34788381
1.258925411	1.047167573	.40032371
1.288249551	1.053224264	.45041711
1.318256738	1.059033509	.49819404
1.348962882	1.064594642	.54368553
1.380384264	1.069907367	.58692356
1.412537544	1.074971747	.62794100
1.445439770	1.079788200	.66677154
1.479108388	1.084357481	.70344960
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1.621810097	1.100189426	.82934933
1.659586907	1.103545442	.85580443
1.698243652	1.106665420	.88032680
1.737800828	1.109552216	.90295490
1.778279409	1.112208945	.92372768
1.819700858	1.114638973	.94268448
1.862087136	1.116845903	.95986511
1.905460717	1.118833572	.97530979
1.949844599	1.120606039	.98905917
1.995262314	1.122167575	1.00115432
2.041737944	1.123522658	1.01163671
2.089296130	1.124675961	1.02054825
2.137962089	1.125632346	1.02793129
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2.238721138	1.126974695	1.03828329
2.290867652	1.127371247	1.04133908
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2.454708915	1.127529136	1.04255546
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2.630267991	1.126262461	1.03279218
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7.413102408	1.043703510	.37154288
7.585775745	1.042124414	.35839141
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8.128305156	1.037642293	.32095330
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Thesis
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Computer analysis and design of electrical circuits using the IBM 360/67 and the XDS 9300 Computer and the AGT/10 Display Unit.