TEXAS INSTRUMENTS **SOLID STATE SOFTWARE™ CARTRIDGE**

ADVANCED ELECTRICAL ENGINEERING

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IMPORTANT NOTICE REGARDING PROGRAMS AND BOOK MATERIALS

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Introduction

The Electrical Engineering Library is an interchangeable *Solid State Software*™ cartridge that contains nine professionally-written, easy-to-use programs chosen to serve a broad range of mathematical applications. The nine programs require little or no programming knowledge or experience to use, and allow you to begin taking advantage of the power of your computer immediately. Other *Solid State Software* cartridges are available and can be obtained from most TI retailers or ordered directly from Texas Instruments.

Using this Manual

One section of this manual is devoted to each library program. The most important part of each section is the User Instructions which explain the operation of the program. The User Instructions have a special format designed to provide a maximum of information with a minimum of words. The first few times that you run a library program, you may wish to follow the User Instructions step-by-step. Once you are familiar with a program, you may only need to use these instructions as a reference. The extensive self-explanatory prompting built into the programs minimizes the need to carry instructions with the computer.

Examples are given for each program to illustrate its capabilities and requirements. The examples also allow you to check your cartridge by comparing your answers to those shown in this manual. Where more than one example is given in a section, it is a good practice to work the examples consecutively.

There is an appendix in the back of this manual which lists the user accessible subprograms found within the programs of this library. They contain many of the common and useful routines which may be very useful to you when writing your own programs.

Using Library Programs

The following sections discuss the Directory/Contents program and a few general guidelines for running the programs in this library.

Directory Program

The names of the programs in this library are listed in the Directory program. It is accessed by entering **RUN "CONTENTS"**. The program displays two names for each program—the long name which is the descriptive title of the program and the short name which is used to call the program for execution. For example, the long name for the first program in this library is ACTIVE FILTERS and its short name is "ACTIVE". To run this program, type **RUN "ACTIVE"** and press **[ENTER]**.

There are four editing keys used to display the names in the directory.

UP arrow — displays the previous long name in the directory. If the first program name is being displayed, the directory program is exited.

DOWN arrow — displays the next long name in the directory. If the last program name is being displayed, the directory program is exited.

RIGHT arrow — displays the short name of a program if the long name is in the display. If a short name is in the display, the key is ignored.

LEFT arrow — displays the long name of a program if the short name is in the display. If a long name is in the display, the key is ignored.

User Instructions—Directory/Contents

Select the Directory program by entering **RUN "CONTENTS"**.

Step	Display	Procedure/Comment	Goto
1.	ELECTRICAL ENGINEERING LIBRARY	Cartridge name.	2
2.	Use Printer?	a. Accept printer usage by entering **Y**.	3
		b. Reject printer usage by entering **N**.	4
3.	Enter Device Name:	Enter output device name.	4
4.	Long program name	Displays long program name.	5
5.		a. To see short name of same program, press right arrow.	6
		b. To see long name of previous program, press up arrow.	4
		c. To see long name of next program, press down arrow.	4
6.	Short program name	Displays short program name.	7
7.		a. To see long name of same program, press left arrow.	4
		b. To see long name of previous program, press up arrow.	4
		c. To see long name of next program, press down arrow.	4

General Guidelines

To simplify the use of *Solid State Software,* TI has implemented a few easily remembered rules for program prompts. You should closely follow the User Instructions the first time you execute a program. Thereafter, you should be able to execute the program by following these simple guidelines.

- Use of the term "enter" has a specific meaning in the User Instructions and examples within Compact Computer library programs. When you see this term, you are to key in the value or information which is indicated by the statement and then press **[ENTER]** to execute the entry. The **[ENTER]** key is also used to display consecutive outputs, to accept current values, and to continue the program following certain prompts.
- The procedure for beginning execution of library programs is explained immediately before the User Instructions of each program. This procedure involves entering the **[RUN]** command followed by the short name for the program in quotation marks and any other information which is necessary for the execution of the particular program.
- The first step in all Compact Computer libray programs is the display of the program name. The program name remains paused in the display for three seconds and then continues to the next prompt. Pressing **[ENTER]** or **[CLR]** causes the next prompt to be displayed immediately.
- Input prompts (prompts which indicate that a value must be entered) are always followed by colons. When applicable, default values are displayed immediately after the colon. You have the option of either entering a new value for the variable or accepting the current value by pressing **[ENTER]**. This feature is useful when editing input.
- When you enter a value which has less digits than the displayed value, space over the extra digits to insure that only the new value is entered.
- Prompts ending in a ? are questions requiring either yes or no responses. It is only necessary to enter a y or a n in either upper or lower case as a response.
- All commands and responses except yes and no must be entered exactly as they are presented in the User Instructions of this library. **Note:** Commands and responses in this library are represented with upper case letters. However, the Compact Computer makes no distinction between upper or lower case letters so they may be used interchangeably.

- Displayed messages such as instructions and output require you to press **[ENTER]** to proceed to the next message or prompt. Certain prompts are paused for three seconds before proceeding to the next prompt. Pressing **[ENTER]** after a paused prompt causes the next prompt to be displayed immediately.
- Any special handling of the response keys is described expressly in the User Instructions or by further prompting.
- You may use equations as numeric input in response to a prompt. For example, you may use PI/2 as an input value. When the computer is waiting for a response, you may perform arithmetical computations without affecting the program. However, the value which is in the display when **[ENTER]** is pressed is accepted as the input. This means that you may not use an equation which requires the use of **[ENTER]** in its computations.
- To halt a running program, press **[BREAK]**. Entering **CON** continues the program from the point where **[BREAK]** was pressed even if the computer is turned off after you press **[BREAK]**. If **[BREAK]** is pressed when a prompt is in the display, the prompt may not reappear after **CON** is entered although the computer is still waiting for a response to that prompt.

Using the Optional Printer

If a printer is connected to the Compact Computer and you have responded **YES** to the `Use Printer?` prompt, a printed record is produced which contains all of the information needed to duplicate a particular execution of a program (with the exception of subprograms which you enter) including: the name of the program you have chosen; the options selected; the pertinent input data; and the results.

Use of the printer is made possible by responding **YES** to the `Use Printer?` prompt and then entering the appropriate peripheral ID number in response to the `Enter Device Name:` prompt. See the peripheral *Owner's Manual* for the appropriate ID number.

The presence of the printer also alters normal program operation. Since a printed record of the results is produced, operation of the program is not stopped for viewing individual results. Instead, a continuous list of results is printed until the output is complete.

Information on connecting the printer may be found in the peripheral *Owner's Manual.*

Using the Optional *Wafertape*™ Digital Tape Drive

The *Wafertape*™ digital tape drive may be used as a means of inputting or recording large amounts of data or for recording information in order to reproduce an exact run of a program. Those programs which are designed for use with the *Wafertape* peripheral incorporate special prompts indicating when you need to input and record your data. The only information which you must provide is the device on which the data is recorded and the filename for that data.

The prompt for entry of this information is `Enter Device.Filename:`. The device must be entered as an integer from 1 through 7. The filename may be chosen by you and may contain any printable character (except control characters) but must be 12 characters or less in length.

Information on connecting the *Wafertape* peripheral may be found in the peripheral *Owner's Manual.*

Caring for Cartridges

Even though the cartridges for your Compact Computer are durable devices, you should handle them with care. Follow these precautions when handling the cartridges.

- **Be sure that your body is free of static electricity.** Prior to handling any cartridge, touch some metal object to discharge any static electricity you may be carrying.
- Keep the cartridge port cover secure on the computer to keep the cartridge port dust free.
- Keep the contact area of the cartridges clean. A buildup of debris or foreign particles on the contacts can impair their operation. Keep the cartridges stored either in the original container or in the computer's cartridge port.
- Use a cotton swab soaked in alcohol to clean the cartridge and cartridge port contacts when necessary. After the alcohol has dried, remove any remaining lint with a clean, soft-bristled brush.

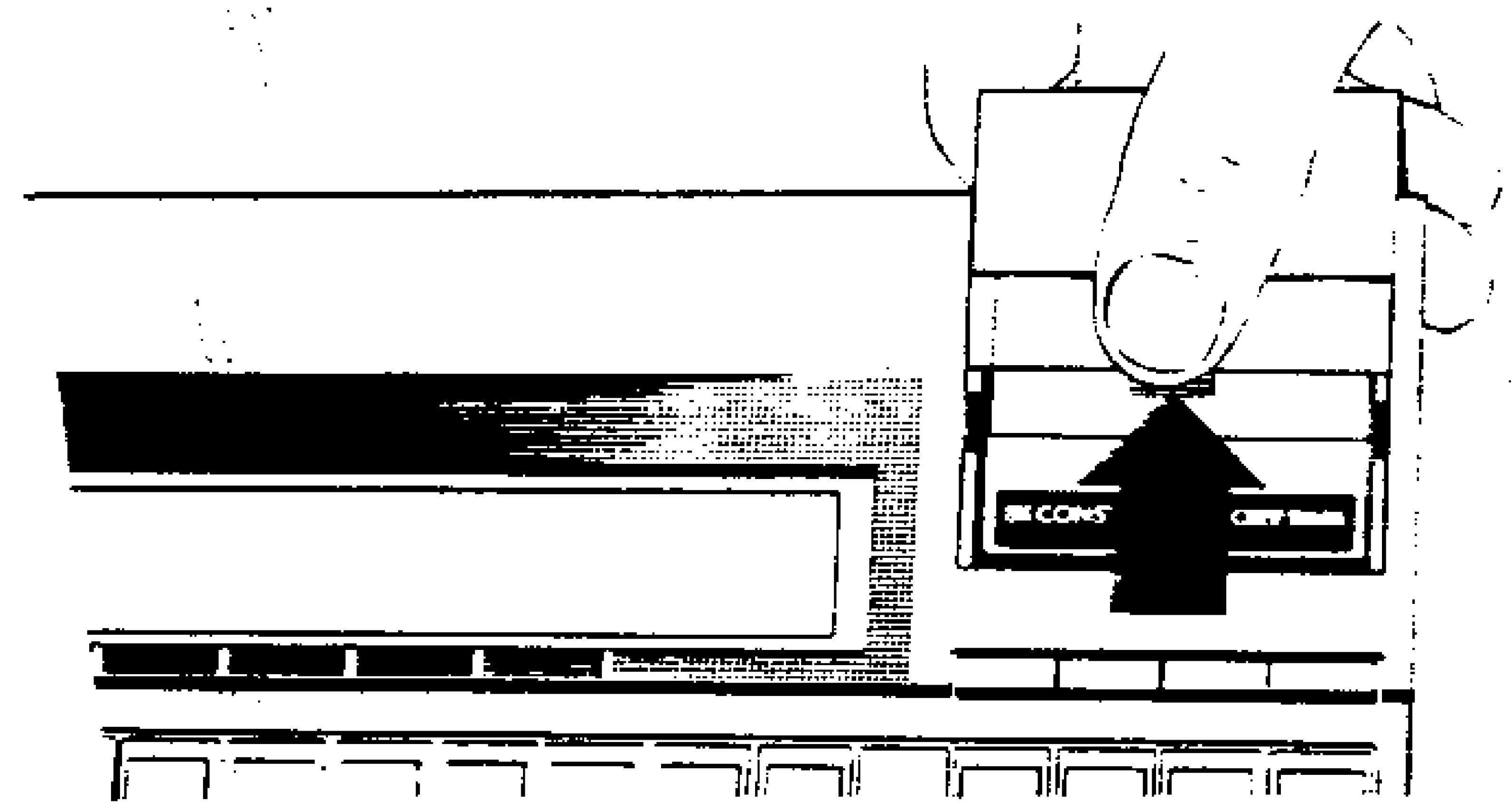
  CAUTION: Do not use any other liquid substance to clean the contacts.

Installing and Replacing Cartridges

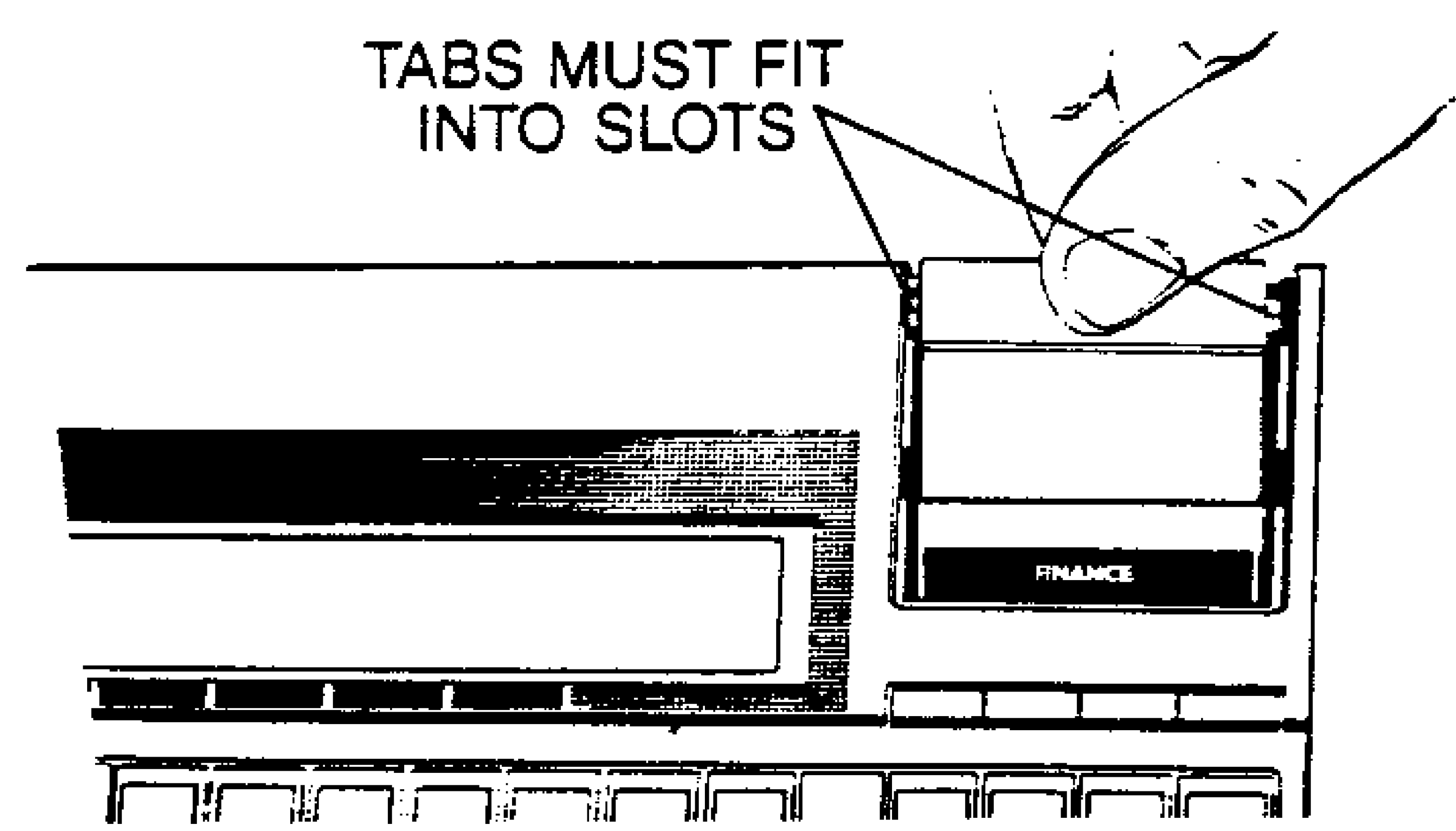
The Electrical Engineering Library cartridge can easily be installed or replaced. *Solid State Software* cartridges are installed in the cartridge port of the Compact Computer. Turn the computer off when installing or replacing a cartridge. Installing a cartridge while the computer is on may result in memory loss.

Use the following procedure when installing a cartridge.

1. Turn the computer off.
2. Slide the cartridge port cover back and remove it from the computer as shown in the diagram below.



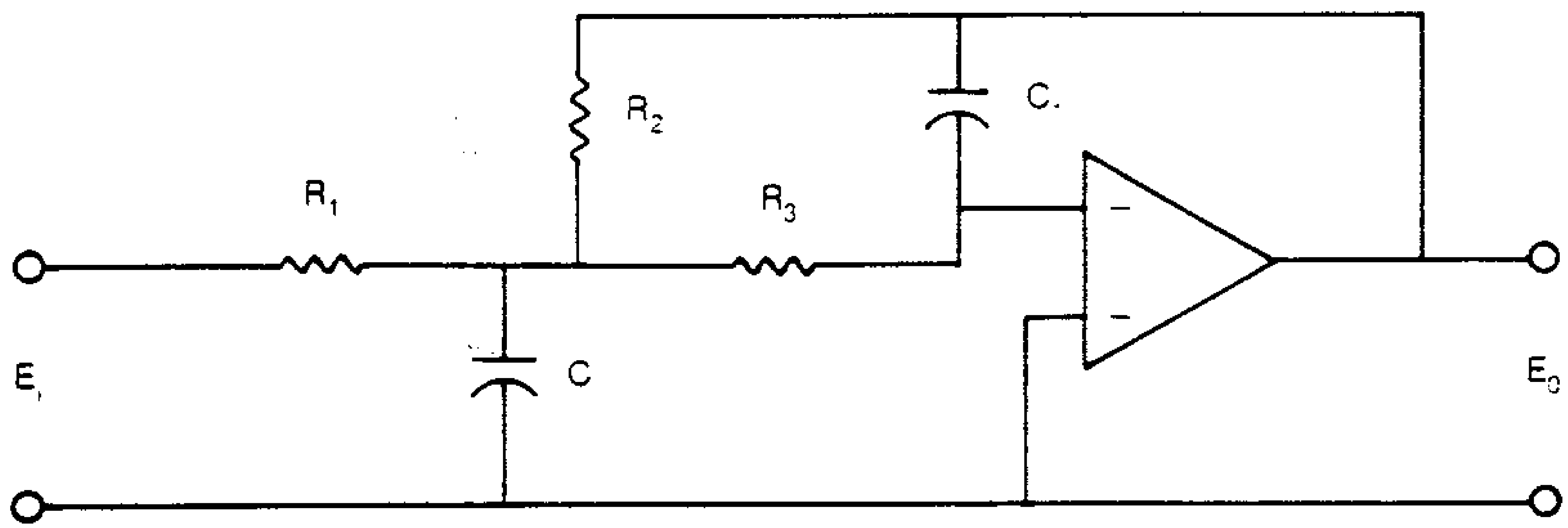
3. If a cartridge is already installed, remove it by pushing the cartridge away from the keyboard until it is released. Lift the cartridge from the cartridge port.
4. Lay the cartridge to be installed in the cartridge port, with the cartridge name facing up and toward the keyboard.
5. Press firmly on the back of the cartridge and slide it toward the keyboard until the tabs on the cartridge enter the slots provided and the cartridge locks into place. Replace the cartridge port cover and check that its tabs also fit into the slots.



Active LP, HP, and BP Filters—"ACTIVE"

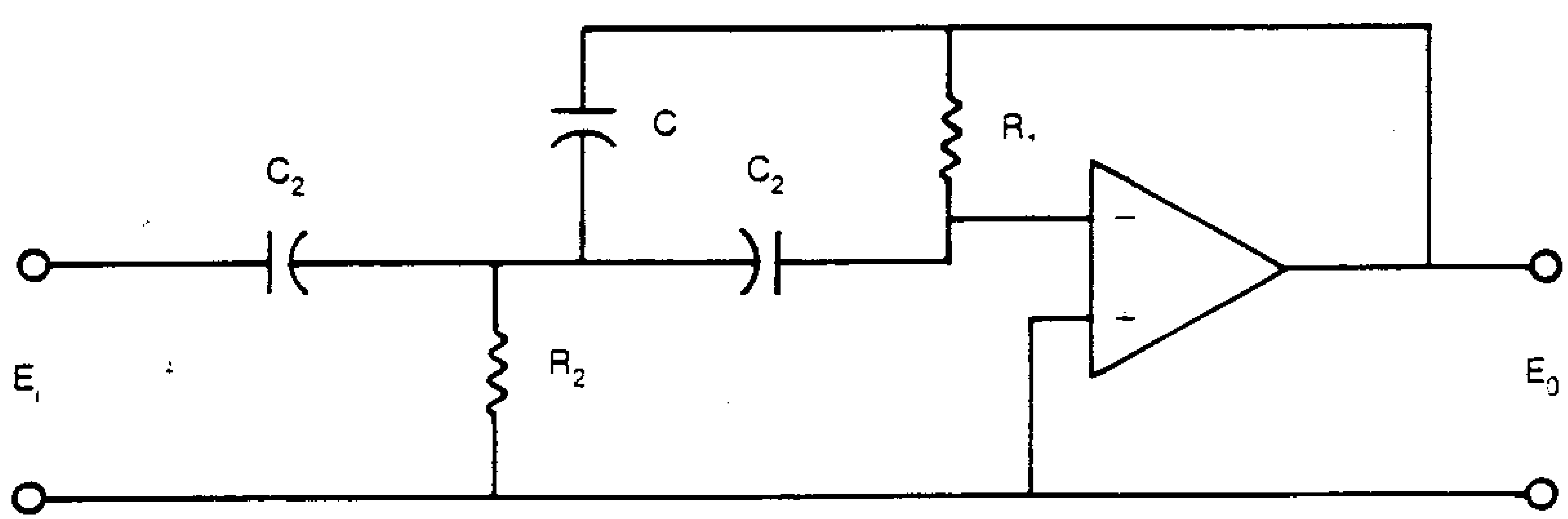
This program computes the necessary component values for use in the design of active lowpass, highpass, and bandpass filters as illustrated.

Active Lowpass Filter



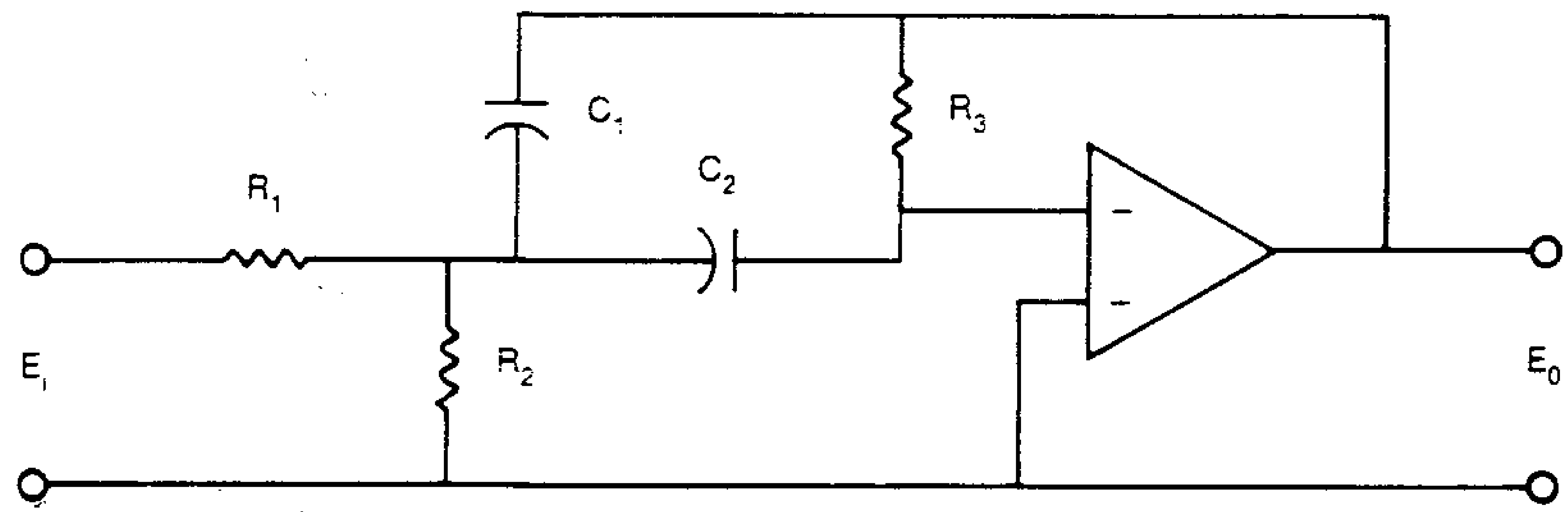
Given the peaking factor, the passband voltage gain in dB, the cutoff frequency in Hertz, and C_1 in farads, the program calculates values of C, R_1, R_2, and R_3. Rolloff is 12 dB per octave.

Active Highpass Filter



Given the peaking factor, the passband voltage gain in dB, the cutoff frequency in Hertz, and C_2 in farads, the program calculates values for C, R_1, and R_2. Rolloff is 12 dB per octave.

Active Bandpass Filter

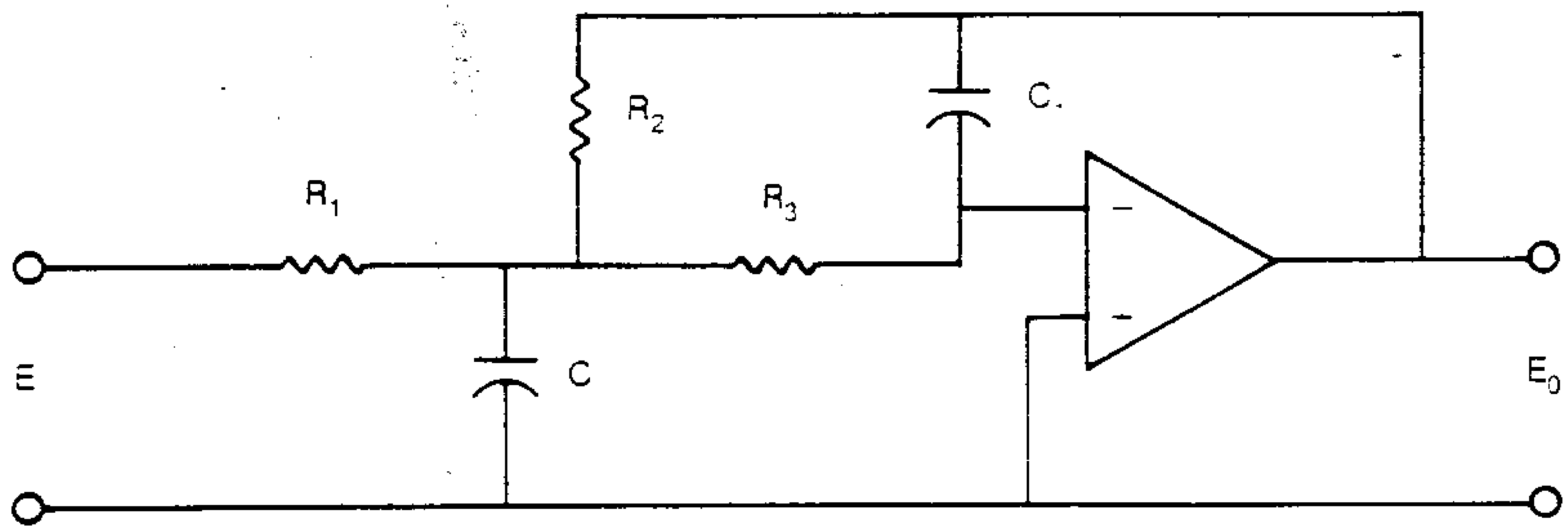


Given the 3-dB bandwidth in Hertz, the midband voltage gain in dB, the center frequency in Hertz, and C_1 and C_2 in farads, the program computes values for R_1, R_2, and R_3. The calculated value of R_1 includes source resistance.

If $Q \leq (H_0/2)^{1/2}$, program execution stops. To insure that all resistances are greater than zero, either Q = FTB, or H_0 should be adjusted so that $Q > (H_0/2)^{1/2}$.

Method Used—Active LP, HP, BP Filters

Active Lowpass Filter



The voltage transfer function is

$$\frac{E_o}{E_i}(s) = \frac{-1/R_1R_3C\,C_1}{s^2 + \left(\frac{1}{R_1} + \frac{1}{R_3} + \frac{1}{R_2}\right)\left(\frac{1}{C}\right)s + \frac{1}{R_2R_3C\,C_1}}$$

The corresponding lowpass network function is

$$H(s) = \frac{-H_0\omega_0^2}{s^2 + \alpha\omega_0 s + \omega_0^2}$$

where

$H_0 = 10^{A/20}$, A = passband gain in dB

$\omega_0 = 2\pi F$

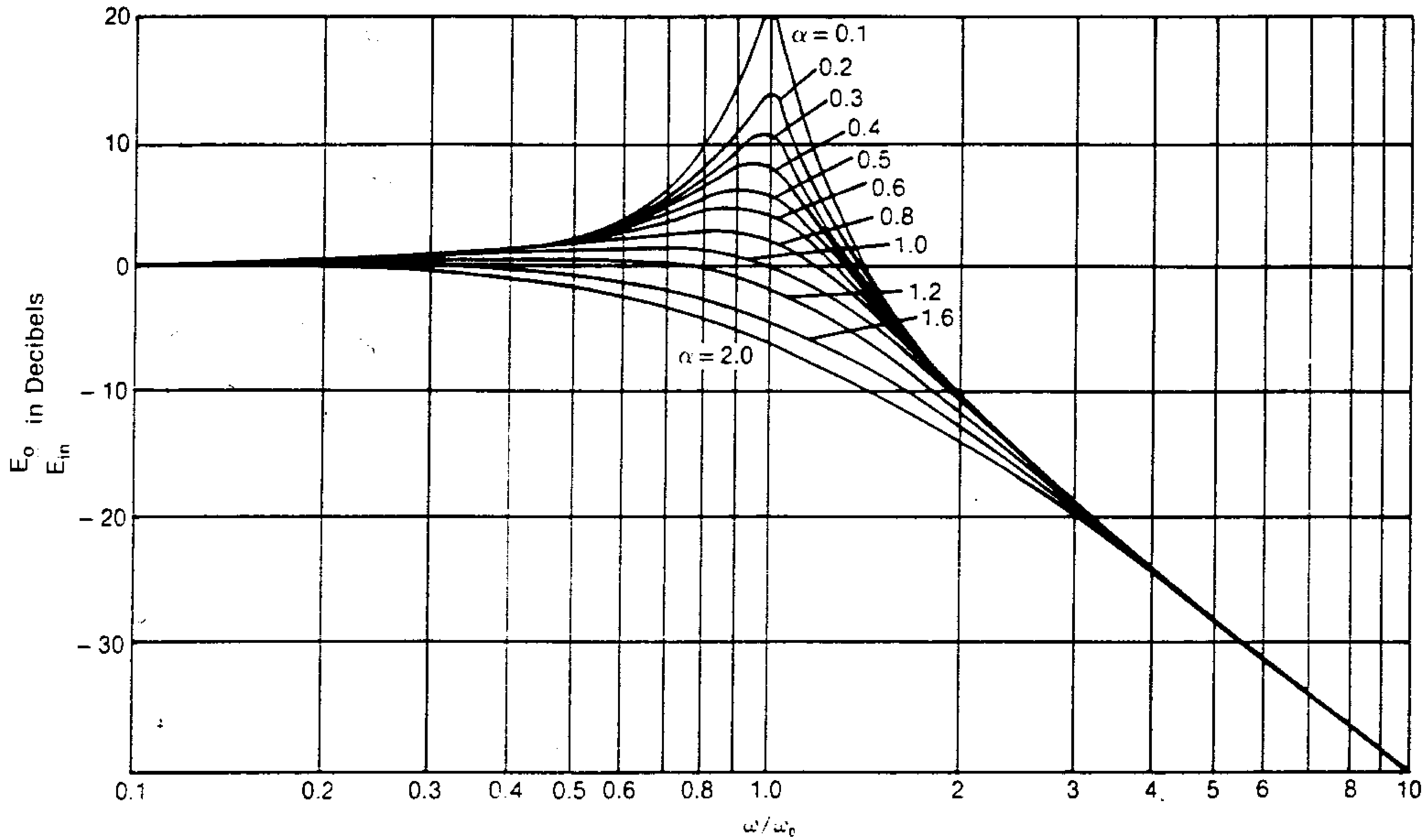
F = cutoff frequency in hertz

α = peaking factor $= 2\zeta$

ζ = damping ratio

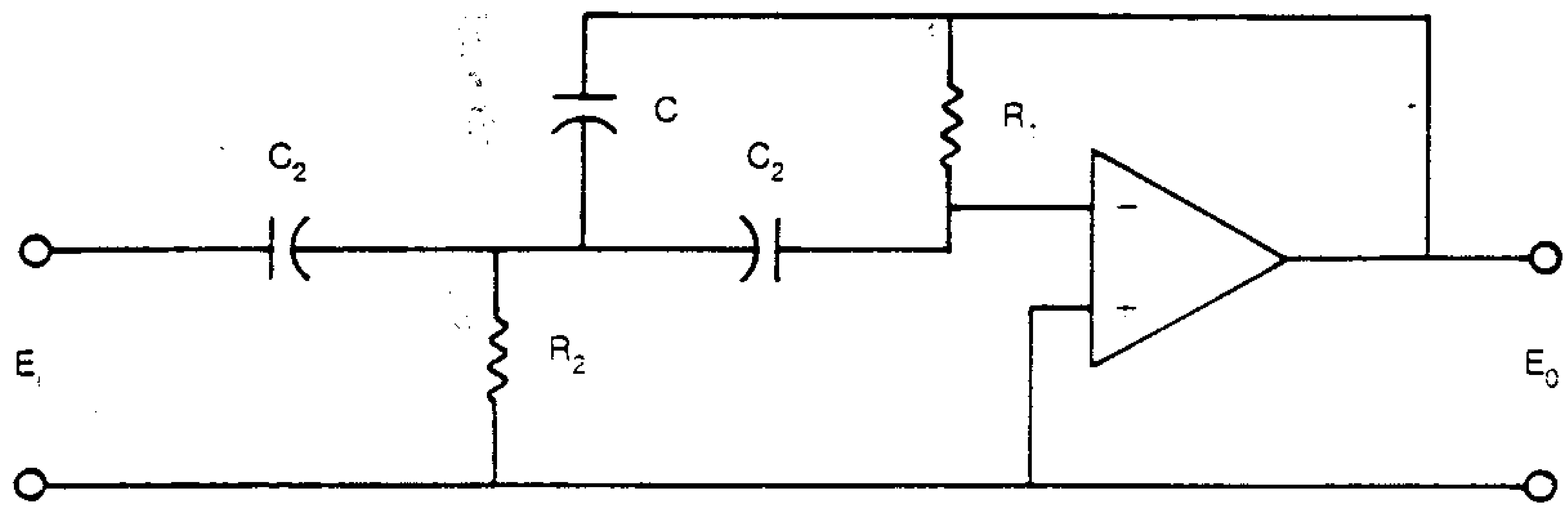
Given A, f, a, and C1 in farads, the program calculates R1, R2, R3 and C using the following equations.

$$C = \frac{4(1 + H_0)C_1}{\alpha^2} \qquad R_1 = \frac{R_2}{H_0} \qquad R_2 = \frac{\alpha}{4\pi F\, C_1} \qquad R_3 = \frac{R_2}{H_0 + 1}$$



Magnitude response of second-order lowpass filters for several values of a ≤ 2.

Active Highpass Filters



The voltage transfer function is

$$\frac{E_o}{E_i}(s) = \frac{-(C_2/C)s^2}{s^2 + \left(\frac{2}{C} + \frac{1}{C_2}\right)\left(\frac{1}{R_1}\right)s + \frac{1}{R_1R_2C_2C}}$$

The corresponding highpass network function is

$$H(s) = \frac{-H_0s^2}{s^2 + \alpha\omega_0 s + \omega_0^2}$$

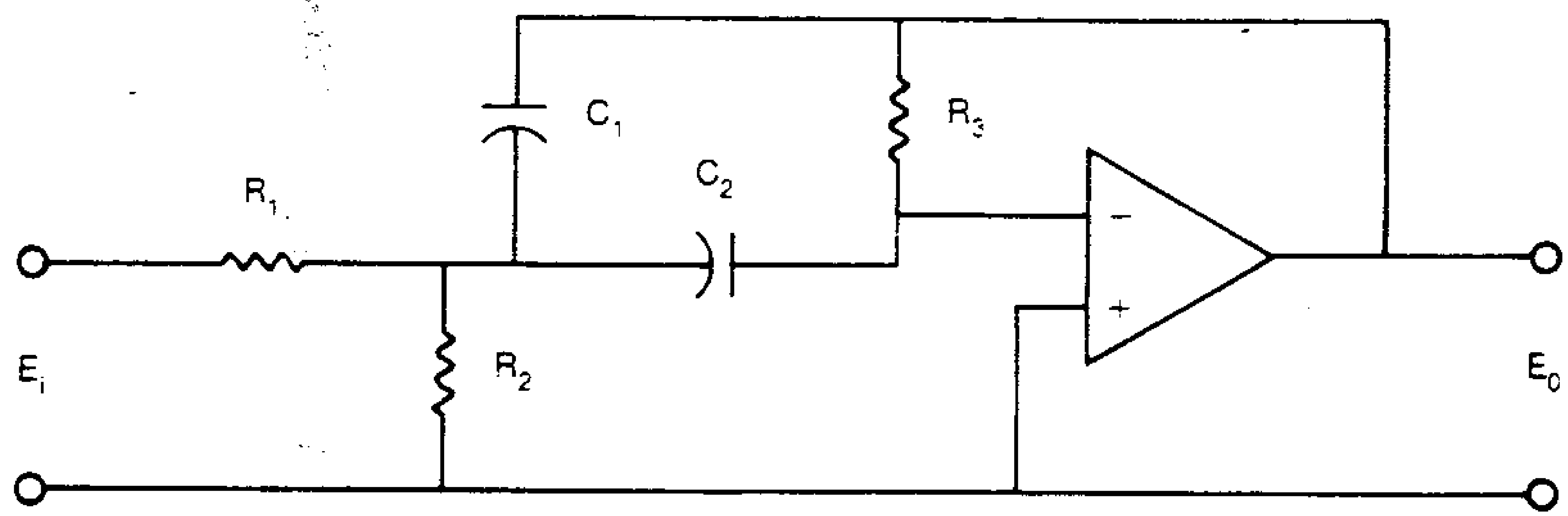
where

$H_0 = 10^{A/20}$, A = passband gain in dB
$\omega_0 = 2\pi F$
F = cutoff frequency in Hertz
α = peaking factor = 2ζ
ζ = damping ratio

Given A, f, a, and C2 in farads, the program calculates R1, R2, and C using the following equations.

$$C = \frac{C_2}{H_0} \qquad R_1 = \frac{2H_0 + 1}{2\pi F\alpha C_2} \qquad R_2 = \frac{\alpha}{2\pi F\, C_2(2 + 1/H_0)}$$

Active Bandpass Filters



The voltage transfer function is

$$\frac{E_o}{E_i}(s) = \frac{-(1R_1C_1)s}{s^2 + \left(\frac{C_1 + C_2}{R_3C_1C_2}\right)s + \frac{R_1 + R_2}{R_1R_2R_3C_1C_2}}$$

The corresponding bandpass network function is

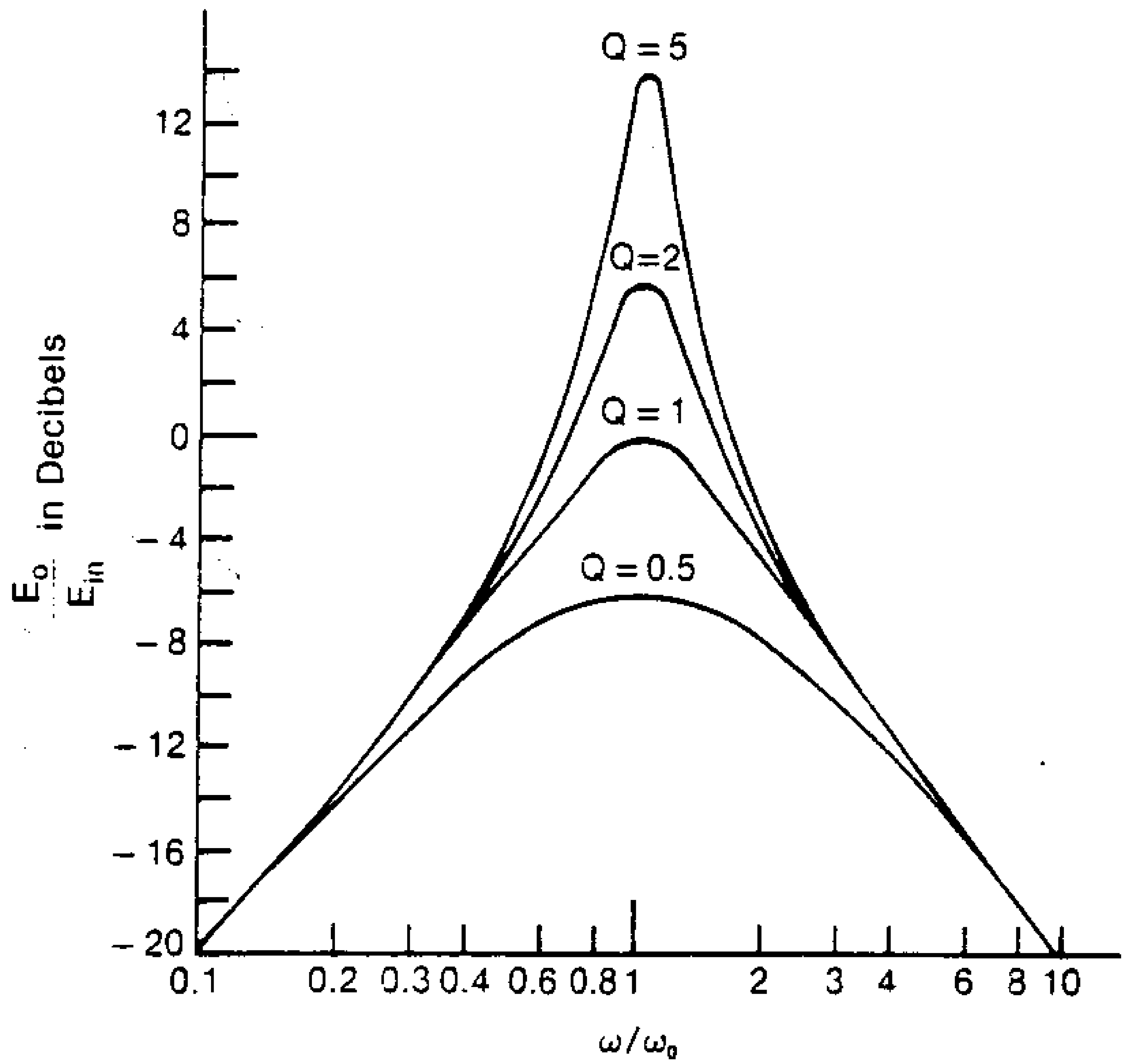
$$H(s) = \frac{-H_0\alpha\omega_0 s}{s^2 + \alpha\omega_0 s + \omega_0^2}$$

where

$H_0 = 10^{A/20}$, A = midband voltage gain in dB
$\alpha = 1/Q$
$Q = F/B$, quality factor measure of selectivity of filter
F = Center frequency of passband in Hertz
B = 3-dB bandwidth in Hertz
$\omega_0 = 1\pi F$

Given B, A, f, C1 and C2 in farads, the program calculates R1, R2, and R3 using the following equations.

$$R_1 = \frac{Q}{2\pi F H_0 C_1} \qquad R_2 = [Q(C_1 + C_2)2\pi F - (1/R_1)]^{-1} \qquad R_3 = \frac{Q}{2\pi F}\left(\frac{1}{C_1} + \frac{1}{C_2}\right)$$



Magnitude response of second order bandpass filter showing effect of Q on network voltage transfer function.

References: *Operational Amplifiers Design and Applications*, Graeme, Tobey and Huelsman, McGraw-Hill, 1971.
Theory and Design of Active RC Circuits, Huelsman, McGraw-Hill, 1968.
Electronics, pp. 86-89, June 7, 1971.

User Instructions—Active LP, HP, and BP Filters

Select the Active LP, HP, BP Filters program by entering **RUN "ACTIVE"**.

Step	Display	Procedure/Comment	Goto
1.	ACTIVE FILTERS	Program name.	2
2.	Use Printer?	a. Accept printer usage by entering **Y.**	3
		b. Reject printer usage by entering **N.**	4
3.	Enter Device Name:	Enter the output device name.	4
4.	Lowpass Filters?	a. Select lowpass filters option by entering **Y.**[3,4]	5
		b. Display next option by entering **N.**	14
5.	Enter frequency:	Enter the cutoff frequency in Hertz.[1]	6
6.	Enter Gain (dB):	Enter the passband gain in dB.	7
7.	Enter Pf:	Enter the peaking factor.[1]	8
8.	Enter C1:	Enter C1 in farads.[1]	9
9.	Edit?	a. Edit data by entering **Y.**	5
		b. Accept data by entering **N.**	10
10.	R1=	Displays R1 in ohms. Proceed by pressing **[ENTER]**.	11
11.	R2=	Displays R2 in ohms. Proceed by pressing **[ENTER]**.	12
12.	R3=	Displays R3 in ohms. Proceed by pressing **[ENTER]**.	13
13.	C=	Displays C in farads. Proceed by pressing **[ENTER]**.	33
14.	Highpass Filters?	a. Select highpass filters option by entering **Y.**[3]	15
		b. Display next option by entering **N.**	23
15.	Enter frequency:	Enter the cutoff frequency in Hertz.[1]	16
16.	Enter Gain (dB):	Enter the passband gain in dB.	17
17.	Enter Pf:	Enter the peaking factor.[1]	18

(continued)

(continued)

Step	Display	Procedure/Comment	Goto
18.	Enter C2:	Enter C2 in farads.[1]	19
19.	Edit?	a. Edit data by entering **Y.**	15
		b. Accept data by entering **N.**	20
20.	R1=	Displays R1 in ohms. Proceed by pressing **[ENTER].**	21
21.	R2=	Displays R2 in ohms. Proceed by pressing **[ENTER].**	22
22.	C=	Displays C in farads. Proceed by pressing **[ENTER].**	33
23.	Bandpass Filters?	a. Select bandpass filters option by entering **Y.**[2,4]	24
		b. Display next option by entering **N.**	33
24.	Enter frequency:	Enter the cutoff frequency in Hertz.[1]	25
25.	Enter Gain (dB):	Enter the passband gain in dB.	26
26.	Enter C1:	Enter C1 in farads.[1]	27
27.	Enter C2:	Enter C2 in farads.[1]	28
28.	Enter B:	Enter 3-dB bandwidth in Hertz.	29
29.	Edit?	a. Edit data by entering **Y.**	24
		b. Accept data by entering **N.**	30
30.	R1=	Displays R1 in ohms. Proceed by pressing **[ENTER].**	31
31.	R2=	Displays R2 in ohms. Proceed by pressing **[ENTER].**	32
32.	R3=	Displays R3 in ohms. Proceed by pressing **[ENTER].**	33
33.	Exit Program?	a. Exit program by entering **Y.**	STOP
		b. Continue program by entering **N.**	4

Notes

1. Input value must be greater than zero.
2. If SQR(H_0/2) ≥ Q then an error message is given and all values must be adjusted so that all resistances are greater than zero. This can be done by assuring that Q = f/B or H_0 should be adjusted so that Q > SQR(H_0/2).
3. A 12-dB per octave roll-off exists in the lowpass and highpass cases.
4. The calculated value of R1 includes source resistance, i.e., Actual R1 = Calculated R1 − Source R.
5. Because operations amplifiers are non-ideal, gain should be chosen to insure that H_0 is less than 10 when S is about 0.1. H_0 may be increased if Pf is also increased. A maximum H_0 of 100 is acceptable with Pf = 1 for an operational amplifier with an open-loop gain of at least 80 dB.

Example 1

Find the component values for an active lowpass filter with a peaking factor of $\sqrt{2}$, passband gain of 20dB, cutoff frequency of 1000 Hertz, and C1 of 0.02 microfarads.

Select the Active LP, HP, BP Filters program by entering **RUN "ACTIVE"**.

Step	Display	Procedure/Comment
1.	ACTIVE FILTERS	Program name.
2.	Use Printer?	Enter **N.**
3.	Lowpass Filters?	Enter **Y.**
4.	Enter frequency: 0	Enter **1000.**
5.	Enter Gain (dB): 0	Enter **20.**
6.	Enter Pf: 0	Enter **SQR(2).**
7.	Enter C1:0	Enter **2E−8.**
8.	Edit?	Enter **N.**
9.	R1=562.6976976 R2=5626.976976 R3=511.5433615 C =.00000044	Displays all requested values. Proceed after each output by pressing **[ENTER]**.
10.	Exit Program?	Enter **Y.**

Example 2

Find the component values for an active highpass filter with a peaking factor of .5, a passband gain of 6 dB, a cutoff frequency of 400 Hertz, and C2 of 0.047 microfarads.

Select the Active LP, HP, BP Filters program by entering **RUN "ACTIVE"**.

Step	Display	Procedure/Comment
1.	ACTIVE FILTERS	Program name.
2.	Use Printer?	Enter **N.**
3.	Lowpass Filters?	Enter **N.**
4.	Highpass Filters?	Enter **Y.**
5.	Enter frequency: 0	Enter **400.**
6.	Enter Gain (dB): 0	Enter **.5.**
7.	Enter Pf: 0	Enter **6.**
8.	Enter C2= 0	Enter **.047E – 6.**
9.	Edit?	Enter **Y.**
10.	Enter frequency: 400	Accept current value by pressing **[ENTER]**.
11.	Enter Gain (dB): .5	Enter **6.**
12.	Enter Pf: 6	Enter **.5.**
13.	Enter C2: .000000047	Accept current value by pressing **[ENTER]**.
14.	Edit?	Enter **N.**
15.	R1= 84496.45356	Displays R1 in ohms. Proceed by pressing **[ENTER]**.
16.	R2= 1692.334014	Displays R2 in ohms. Proceed by pressing **[ENTER]**.
17.	C1= 2.35558E-08	Displays C in farads. Proceed by pressing **[ENTER]**.
18.	Exit Program?	Enter **Y.**

Example 3

Find the component values for an active bandpass filter with passband gain of 30 dB, center frequency of 150 Hertz, C1 of .1 microfarad, C2 of .1 microfarad, and a 3-dB bandwidth of 16 Hertz.

Select the Active LP, HP, BP Filters program by entering **RUN "ACTIVE"**.

Step	Display	Procedure/Comment
1.	ACTIVE FILTERS	Program name.
2.	Use Printer?	Enter **N.**
3.	Lowpass Filters?	Enter **N.**
4.	Highpass Filters?	Enter **N.**
5.	Bandpass Filters?	Enter **Y.**
6.	Enter frequency: 0	Enter **150.**
7.	Enter Gain (dB): 0	Enter **30.**
8.	Enter C1: 0	Enter **1E-7.**
9.	Enter C2: 0	Enter **1E-7.**
10.	Enter B: 0	Enter **16.**
11.	Edit?	Enter **N.**
12.	R1= 3145.575757	Displays R1 in ohms. Proceed by pressing **[ENTER]**.
13.	R2= 690.017292	Displays R2 in ohms. Proceed by pressing **[ENTER]**.
14.	R3= 198943.6789	Displays R3 in ohms. Proceed by pressing **[ENTER]**.
15.	Exit Program?	Enter **Y.**

Bode/Nyquist Calculations—"BODE"

Given a transfer function or immittance function as a ratio of polynomials, this program calculates the data needed for Bode and Nyquist plots for specified frequency values. Up to 20 elements may be entered in this program regardless of the memory capacity of the computer.

Given the transfer function or immittance function

$$H(s) = \frac{b_0 + b_1 s + \ldots b_n s^m}{a_0 + a_1 s + \ldots a_n s^n} \quad m < n < 20$$

the program calculates the Bode-plot data

$H_{dB} = 20 \log_{10}[H(jw)]$
angle $H = \arg [H(jw)]$ (degrees)

and the rectangular and polar Nyquist-plot data

$H_r = \mathrm{Re}\,[H(jw)]$ $[H] = [H(jw)]$
$H_r = \mathrm{Im}\,[H(jw)]$ angle $H = \arg [H(jw)]$ (degrees)

Data may be calculated at a single frequency (w) or at multiple frequencies ($w = w_o + n\ w$). The method used is to substitute jw in H(s), giving

$$H(j\omega) = \frac{b_0 + b_1(j\omega) + \ \dots\ b_n(j\omega)^m}{a_0 + a_1(j\omega) + \ \dots\ a_n(j\omega)^n} \quad m \leq n \leq 20$$

The real and imaginary parts of the numerator are

$$N_r = b_0 - b_2\omega^2 + b_4\omega^4 - b_6\omega^6 + \ \dots\ + b_{20}\omega^{20}$$

$$N_i = \omega(b_1 - b_3\omega^2 + b_5\omega^4 - b_7\omega^6 + \ \dots\ - b_{19}\omega^{18})$$

For the denominator the real and imaginary parts are

$$D_r = a_0 - a_2\omega^2 + a_4\omega^4 - a_6\omega^6 + \ \dots\ + a_{20}\omega^{20}$$

$$D_i = \omega(a_1 - a_3\omega^2 + a_5\omega^4 - a_7\omega^6 + \ \dots\ - a_{19}\omega^{18})$$

By substitution

$$H(j\omega) = \frac{N_r + jN_i}{D_r + jD_i}$$

where $b_7 = 0$ if $m < 7$, etc.

Multiplying by the complex conjugate.

$$H(j\omega) = \frac{N_r + jN_i}{D_r + jD_i}\left[\frac{D_r - jD_i}{D_r - jD_i}\right]$$

gives

$$H_r = \frac{D_rN_r + D_iN_i}{D_r^2 + D_i^2} \quad \text{and} \quad H_i = \frac{D_rN_i - D_iN_r}{D_r^2 + D_i^2}$$

The magnitude and angle of H are calculated by rectangular to polar conversion.

User Instructions—Bode/Nyquist Calculations

Select the Bode/Nyquist Calculations program by entering **RUN "BODE"**.

Step	Display	Procedure/Comment	Goto
1.	BODE/NYQUIST CALCULATIONS	Program name.	2
2.	Use Printer?	a. Accept printer usage by entering **Y**.	3
		b. Reject printer usage by entering **N**.	4
3.	Enter Device Name:	Enter output device name.	4
4.	Denominator Coeff. Enter "E" to end input	Displays prompt. Proceed by pressing **[ENTER]**.	5
5.	Enter D(#):	a. Enter a denominator value.	5
		b. End input by entering **E**.	6
6.	Edit?	a. Edit data by entering **Y**.	7
		b. Accept data by entering **N**.	11
7.	Edit all Data?	a. Edit all data by entering **Y**.	5
		b. Edit single elements by entering **N**.	8
8.	Enter element to be edited:	Enter element number to be edited.	9
9.	Enter D(#):	Enter a denominator value.	10
10.	Edit more elements?	a. Edit more elements by entering **Y**.	8
		b. Accept data by entering **N**.	11
11.	Numerator Coeff. Enter "E" to end input	Displays prompt. Proceed by pressing **[ENTER]**.	12
12.	Enter N(#):	a. Enter a numerator value.	12
		b. End input by entering **E**.	13
13.	Edit?	a. Edit data by entering **Y**.	14
		b. Accept data by entering **N**.	18
14.	Edit all Data?	a. Edit all data by entering **Y**.	12
		b. Edit single elements by entering **N**.	15

(continued)

(continued)

Step	Display	Procedure/Comment	Goto
15.	Enter element to be edited:	Enter element number to be edited.	16
16.	Enter N(#):	Enter a numerator value.	17
17.	Edit more elements?	a. Edit more elements by entering **Y**. b. Accept data by entering **N**.	15 18
18.	Enter Starting frequency:	Enter the starting frequency.	19
19.	Enter Ending frequency:	Enter the ending frequency.	20
20.	Enter No. of Intervals:	Enter the number of intervals.	21
21.	Linear Sweep?	a. Select linear sweep option by entering **Y**. b. Display next option by entering **N**.	23 22
22.	Log Sweep?	a. Select log sweep option by entering **Y**. b. Display next option by entering **N**.	23 21
23.	Edit?	a. Edit data by entering **Y**. b. Accept data by entering **N**.	18 24
24.	frequency=	Displays the frequency. Proceed by pressing **[ENTER]**.	25
25.	H(re)=	Displays real H(jw). Proceed by pressing **[ENTER]**.	26
26.	H(im)=	Displays imaginary H(jw). Proceed by pressing **[ENTER]**.	27
27.	Magnitude=	Displays H(jw). Proceed by pressing **[ENTER]**.	28
28.	dB=	Displays 20*LOG(H(jw)). Proceed by pressing **[ENTER]**.	29
29.	Angle=	Displays angle H(jw). Proceed by pressing **[ENTER]**.	30
30.		a. If output is incomplete. b. If output is complete.	24 31
31.	Exit Program?	a. Exit program by entering **Y**. b. Continue program by entering **N**.	STOP 4

Example

Determine the Bode plot for the transfer function (100) / ($s^2 + 5s + 100$).

Select the Bode/Nyquist Calculations program by entering **RUN "BODE"**.

Step	Display	Procedure/Comment
1.	BODE/NYQUIST CALCULATIONS	Program name.
2.	Use Printer?	Enter **N**.
3.	Denominator Coeff. Enter "E" to end input	Proceed by pressing **[ENTER]**.
4.	Enter D(0): 0	Enter **100**.
5.	Enter D(1): 0	Enter **5**.
6.	Enter D(2): 0	Enter **1**.
7.	Enter D(3): 0	Enter **E**.
8.	Edit?	Enter **N**.
9.	Numerator Coeff. Enter "E" to end input	Proceed by pressing **[ENTER]**.
10.	Enter N(0): 0	Enter **100**.
11.	Enter N(1): 0	Enter **E**.
12.	Edit?	Enter **N**.
13.	Enter Starting frequency: 0	Enter **1.273239545**.
14.	Enter Ending frequency: 0	Enter **2.228169203**.
15.	Enter No. of Intervals: 0	Enter **3**.
16.	Linear Sweep?	Enter **Y**.
17.	Edit?	Enter **N**.

(continued)

(continued)

Step	Display		Procedure/Comment
18.	frequency=	1.273239545	Displays all requested values. Proceed after each output by pressing **[ENTER]**.
	H(re)=	1.243093922	
	H(im)=	-1.38121547	
	Magnitude=	1.858235366	
	dB=	5.382014427	
	Angle=	-48.01278753	
	frequency=	1.591549431	
	H(re)=	-4.08E-10	
	H(im)=	-2.	
	Magnitude=	2.	
	dB=	6.020599913	
	Angle=	-90.00000001	
	frequency=	1.909859317	
	H(re)=	-.7947976878	
	H(im)=	-1.083815029	
	Magnitude=	1.344008327	
	dB=	2.568039187	
	Angle=	-126.2538377	
	frequency=	2.228169203	
	H(re)=	-.6800793428	
	H(im)=	-.4958911876	
	Magnitude=	.841674511	
	dB=	-1.497116494	
	Angle=	-143.901716	
19.	Change Frequencies?		Enter **N.**
20.	Exit Program?		Enter **Y.**

Roots of a Polynomial—"COMPLEX"

The general form of a polynomial of degree n is

$$P_n(x) = a_0 + a_1x + \ ... \ + a_{n-1}x^{n-1} + a_nx^n$$

This program uses the Lin-Bairstow method to find all roots, real and complex, of up to a 100th degree polynomial in one variable with real coefficients when using a 6K byte memory capacity computer. This method is based on the fact that the polynomial can be represented as a product of quadratic and linear factors. An initial guess is made of a trial quadratic factor which, for purposes of convergence, is hopefully near the desired factor of the polynomial. The trial factor is divided into the polynomial and a remainder results which is generally non-zero, assuming the initial guess is not an exact factor. The trial factor is transformed into an "exact" factor of the polynomial by an iterative process which modifies the coefficients of the quadratic term to make the remainder less than or equal to ϵ (error factor). The resulting roots can be found by using the quadratic formula. The original polynomial can be reduced by dividing out the quadratic factor. The remaining roots of the reduced polynomial are computed in the same manner as above, with the program using the exact quadratic factor which was found as the new guess or allowing you to enter a quadratic factor for the new guess. If, in the course of finding the root pairs by dividing out the quadratic factors, the reduced polynomial has degree = 2, the remaining roots are found using the quadratic formula; if degree = 1, the obvious root is computed.

Notes

1. An initial estimate of 0 for u and v is recommended in searching for all roots. In general, there is no advantage in using previously computed values of u and v.
2. A plot of f(x) may be used to find the approximate location of real roots. The order of f(x) may then be lowered by dividing f(x) by factors of the form $(x - R_i)$ where R_i are the real roots.
3. If f(x) has multiple sets of equal roots, Δ u and Δ v will appear to be converging but then may never get smaller than the stated Δ. The solution to this case is to define a larger Δ and thus accept a less precise approximation of the equal roots.
4. Do not assume divergence of Δ u and Δ v simply because monotonic convergence does not occur. Δ u and Δ v often oscillate with large amplitude prior to convergence.

Method Used—Roots of a Polynomial

The following is an outline of the Lin-Bairstow method.

Given a polynomial of degree n: $Pn(x) = A0 + A1x + A2x^2 + \ldots + An - rx^{(n-1)} + Anx^n$ and trial quadratic factor: $x^2 - ux - v$

Equation 1:

$$Pn(x) = (x^2 - ux - v)Qn - 2\ (x) + \text{remainder}$$
$$= (x^2 - ux - v)(Bnx^{(n-2)} + Bn - 1x^{(n-3)} + \ldots + B3x + B2) + B1(x - u) + B0$$

Multiplying out and equating coefficients of like powers of x:

$Ai = Bi \quad Bi = Ai$

$Ai - 1 = Bi - 1 - uBi - 2$	$Bi - 1 = Ai - 1 + uBi$
$Ai - 2 = Bi - 2 - uBi - 1 - vBi$	$Bi - 2 = Ai - 2 + uBi - 1 + vBi$
$Ai - 3 = Bi - 3 - uBi - 2 - vBi - 1$	$Bi - 3 = Ai - 3 + uBi - 2 + vBi - 1$
⋮ OR	⋮
$A1 = B3 - uB2 - vB1$	$B1 = A3 + uB2 + vB1$
$A0 = B2 - uB1 - vB0$	$B0 = A3 + uB1 + vB0$
for $i = 3, \ldots, n$	for $i = 3, \ldots, n$

Note: The remainder term from equation (1) is $Bn\ (x - u) + Bn + 1$. If Bn and $Bn + 1$ are both zero it implies that $(x^2 - ux - v)$ is an exact quadratic factor. Normally, this is not the case. Thus, values of u and v must be modified so that Bn and $Bn + 1$ both approach zero.

Since Bn and $Bn + 1$ are functions of parameters u and v, $Bn(u,v)$ and $Bn + 1\ (u,v)$ can be expanded as Taylor series for a function of two variables in terms of $(u^* - u) = \Delta u$ and $(v^* - v) = \Delta v$ where Δu and Δv are presumed small so that terms of higher order than the first are negligible.

$$Bn(u^*,v^*) = B(n)\ (u,v) + pd(Bn\ /\ u)\ \Delta u + pd(Bn\ /\ v)\ \Delta v + \ldots$$
$$Bn + 1(u^*,v^*) = B(n + 1)(u,v) + pd(B(n + 1)\ /\ u)\ \Delta u + pd(B(n + 1)\ /\ v)\ \Delta v \ldots$$

Taking (u^*,v^*) as the point where the remainder is zero, (Δu and Δv being the increments added to the orginal u and v to get the new values u^* and v^*),

Equation 2:

$$Bn(u^*,v^*) = 0 = Bn + pd(Bn/u)\ \Delta u + pd(Bn/v)\ \Delta v$$

Equation 3:

$$B(n+1)\ (u^*,v^*) = 0 = B(n+1) + pd(B(n+1)/u)\ \Delta u + pd(B(n+1)/v)\ \Delta v$$

The problem now is to solve equations (2) and (3) simultaneously for Δu and Δv. Bairstow showed that the required partial derivatives can be obtained from the B's in the same way that the B's were obtained from the A's.

Define a set of C's as follows.

$Ci = Bi$	$pd(B1/u) = pd(A1/u) = 0$	
$Ci-1 = Bi-1 + uCi$	$pd(B2/u) = pd(B1/u)\ u + B1 = B1 = C1$	$pd(B2/v) = pd(A2/v) + pd(B1/v)\ u = 0$
$Ci-2 = Bi-2 + uCi-1 + vCi$	$pd(B3/u) = pd(B2/u)\ u + B2 = C2$	$pd(B3/v) = pd(B2/v)\ u + pd(B1/v)\ v + B1 = B1 = C1$
$Ci-3 = Bi-3 + uCi-2 + vCi-1$		

The above three columns can be generalized by the following recurrence relation.

$$Ci = Bi + uCi+1 + vCi+2$$

for $i = 1,n$

where $pd(Bi/u) = pd(Bi+1/v) = Ci-1$

Equations (2) and (3) can be rewritten as

$$-Bn = Cn-1\ \Delta u + Cn-2\ \Delta v$$

$$-Bn+1 = Cn\ \Delta u + Cn-1\ \Delta v$$

Then, using Cramer's rule:

$$\text{Delta u} = \frac{\begin{vmatrix} -B1 & C3 \\ -B0 & C2 \end{vmatrix}}{\begin{vmatrix} C2 & C3 \\ C1 & C2 \end{vmatrix}} \qquad \text{Delta v} = \frac{\begin{vmatrix} C2 & -B1 \\ C1 & -B0 \end{vmatrix}}{\begin{vmatrix} C2 & C3 \\ C1 & C2 \end{vmatrix}}$$

If the denominator = 0, $\Delta u = 1 + \Delta u'$, $\Delta v = 1 +$ delta v' where $\Delta u'$ and $\Delta v'$ are values of Δu and Δv computed from the previous iteration.

If Δu is less than or equal to epsilon and Δv is less than or equal to epsilon where epsilon is the allowable error factor, then $(x^2 - ux - v)$ is a factor of P(x). Roots of $(x^2 - ux - v)$ are found by using the quadratic formula.

$$\frac{Pn(x)}{(x^2 - ux - v)} = Qn - 2(x)$$, the reduced polynomial used to find the remaining roots.

Reference: *Applied Numerical Analysis*, Curtis F. Gerald, Addison-Wesley, 1970.

User Instructions—Roots of a Polynomial

Select the Roots of a Polynomial program by entering **RUN "COMPLEX"**.

Step	Display	Procedure/Comment	Goto
1.	ROOTS OF A POLYNOMIAL	Program name.	2
2.	Use Printer?	a. Accept printer usage by entering **Y**.	3
		b. Reject printer usage by entering **N**.	4
3.	Enter Device Name:	Enter the output device name.	4
4.	Enter Degree:	Enter the degree of the polynomial.	5
5.	Enter X(#):	Enter the coefficient of X(n).[1]	6
6.		a. If there are more coefficients to be entered.	5
		b. If there are no more coefficients to be entered.	7

(continued)

(continued)

Step	Display	Procedure/Comment	Goto
7.	`Enter u:`	Enter initial estimate of u.	8
8.	`Enter v:`	Enter initial estimate of v.	9
9.	`Enter Accuracy:`	Enter allowable error.	10
10.	`Enter Max. its:`	Enter the maximum number of iterations the program should calculate to try to find the roots.	11
11.	`Edit?`	a. Edit data by entering **Y.**	4
		b. Accept data by entering **N.**	12
12.	`Print successive values of...`	Displays prompt. Proceed by pressing **[ENTER].**	13
13.	`Delta u and Delta v?`	a. Print out the Delta u and Delta v values and the roots for each iteration by entering **Y.**	14
		b. Print out just the roots by entering **N.**	24
14.	`Delta u=`	Displays Delta u. Proceed by pressing **[ENTER].**	15
15.	`Delta v=`	Displays Delta v. Proceed by pressing **[ENTER].**	16
16.		a. Compute and print Delta u and Delta v values until a set of roots are found.	14
		b. Set of roots are found.	24
		c. Maximum iterations have been completed.	17
17.	`Doesn't converge after ## its`	The roots where not found in the maximum number of iterations given the program to find all of the roots. Proceed by pressing **[ENTER].**	18
18.	`Continue?`	a. Continue looking for the roots for this problem by entering **Y.**	19
		b. Stop looking for the roots for this problem by entering **N.**	23

(continued)

(continued)

Step	Display	Procedure/Comment	Goto
19.	Enter Max. its:	Enter how many additional iterations to compute.	20
20.	Change u and v?	a. Change u and v by entering **Y**.	21
		b. Continue with the current values of u and v by entering **N**.	23
21.	Enter u:	Enter new estimate of u.	22
22.	Enter v:	Enter new estimate of v.	23
23.		a. If printing Delta u and Delta v.	14
		b. If not printing Delta u and Delta v.	24
24.	Degree=	Displays the degree of the current polynomial. Proceed by pressing **[ENTER]**.	25
25.	Re/IM*=	Displays the first root. Proceed by pressing **[ENTER]**.	26
26.		a. If the degree of the current polynomial is one.	28
		b. If the degree of the current polynomial is greater than one.	27
27.	Re/IM*=	Displays the second root. Proceed by pressing **[ENTER]**.	28
28.		a. If the degree of the current polynomial is one or two.	29
		b. If there are more roots to be found and if printing the succesive Delta u and Delta v's.	14
		c. If there are more roots to be found and if just the roots are being printed.	24
29.	Exit Program?	a. Exit program by entering **Y**.	STOP
		b. Continue program by entering **N**.	4

Notes

RE/IM* – RE or IM is displayed with the root depending on the case.

1. All coefficients must be entered, starting with the coefficient of the X(n) term.

Example 1

Find the roots of the polynomial

$$x^5 - 17.8x^4 + 99.41x^3 - 261.218x^2 + 352.611x - 134.106 = 0$$

Use 0 for initial estimates of u and v. Give the program 50 iterations to find the roots. Enter an epsilon of .00001.

Select the Roots of a Polynomial program by entering **RUN "COMPLEX"**.

Step	Display	Procedure/Comment
1.	ROOTS OF A POLYNOMIAL	Program name.
2.	Use Printer?	Enter **N**.
3.	Enter Degree: 0	Enter **5**.
4.	Enter X(5): 0	Enter **1**.
5.	Enter X(4): 0	Enter **–17.8**.
6.	Enter X(3): 0	Enter **99.41**.
7.	Enter X(2): 0	Enter **–261.218**.
8.	Enter X(1): 0	Enter **352.611**.
9.	Enter X(0): 0	Enter **–134.106**.
10.	Enter u: 0	Accept current value by pressing **[ENTER]**.
11.	Enter v: 0	Accept current value by pressing **[ENTER]**.
12.	Enter Accuracy: 0	Enter **.00001**.
13.	Enter Max. its: 50	Accept current value by pressing **[ENTER]**.
14.	Edit?	Enter **N**.

(continued)

(continued)

Step	Display	Procedure/Comment
15.	Print successive values of...	Proceed by pressing **[ENTER]**.
16.	Delta u and Delta v?	Enter **N**.
17.	Degree= 5	Displays the degree of present polynomial. Proceed by pressing **[ENTER]**.
18.	Re= 3.619868415	Displays a root. Proceed by pressing **[ENTER]**.
19.	Re= .5801315846	Displays another root. Proceed by pressing **[ENTER]**.
20.	Change u and v?	Enter **N**.
21.	Degree= 3 Re= 1.65 Im= 1.86480562 Degree= 1 Re= 10.3	Displays all requested values. Proceed after each output by pressing **[ENTER]**.
22.	Exit Program?	Enter **Y**.

Example 2

Find the roots of the polynomial

$$x^4 - 34x^3 + 431x^2 - 2414x + 5040 = 0$$

Use 12 for an initial estimate of u and 6 for an initial estimate of v. Give the program 50 iterations to find the roots, and enter an epsilon of .00001. Print the Δu and Δv values.

Select the Roots of a Polynomial program by entering **RUN "COMPLEX"**.

Step	Display	Procedure/Comment
1.	ROOTS OF A POLYNOMIAL	Program name.
2.	Use Printer?	Enter **N**.
3.	Enter Degree: 0	Enter **4**.
4.	Enter X(4): 0	Enter **1**.
5.	Enter X(3): 0	Enter **−34**.
6.	Enter X(2): 0	Enter **431**.
7.	Enter X(1): 0	Enter **2414**.
8.	Enter X(0): 0	Enter **4050**.
9.	Enter u: 0	Enter **12**.
10.	Enter v: 0	Enter **6**.
11.	Enter Accuracy: 0	Enter **.00001**.
12.	Enter Max. its: 50	Accept current value by pressing **[ENTER]**.
13.	Edit?	Enter **Y**.
14.	Enter Degree: 4	Accept current value by pressing **[ENTER]**.
15.	Enter X(4): 1	Accept current value by pressing **[ENTER]**.
16.	Enter X(3): -34	Accept current value by pressing **[ENTER]**.
17.	Enter X(2): 431	Accept current value by pressing **[ENTER]**.
18.	Enter X(1): 2414	Enter **−2414**.
19.	Enter X(0): 4050	Enter **5040**.
20.	Enter u: 12	Accept current value by pressing **[ENTER]**.
21.	Enter v: 6	Accept current value by pressing **[ENTER]**.
22.	Enter accuracy: .00001	Accept current value by pressing **[ENTER]**.
23.	Enter Max. its: 50	Accept current value by pressing **[ENTER]**.

(continued)

(continued)

Step	Display	Procedure/Comment
24.	Edit?	Enter **N**.
25.	Print successive values of...	Proceed by pressing **[ENTER]**.
26.	Delta u and Delta v?	Enter **Y**.
27.	Delta u= 4.438319711 Delta v= -20.8139137 Delta u= .2826726504 Delta v= -27.86047113 Delta u= .1401297406 Delta v= -14.09017973 Delta u= .0699490743 Delta v= -7.069172312 Delta u= .0352853349 Delta v= -3.510466384 Delta u= .0183089239 Delta v= -1.691221263 Delta u= .0099474054 Delta v= -.7288224444 Delta u= .0045959261 Delta v= -.2138171346 Delta u= .0007794675 Delta v= -.0217206452 Delta u= 1.176474E-05 Delta v= -.0002152342 Delta u= .000000001 Delta v= -.0000000171	Display all requested values. Proceed after each output by pressing **[ENTER]**.

(continued)

(continued)

Step	Display		Procedure/Comment
	Degree=	4	
	Re=	10.	
	Re=	7.	
	Degree=	2	
	Re=	8.999999992	
	Re=	8.000000009	
28.	Exit Program?		Enter Y.

Discrete Fourier Transform—"DFT"

This program transforms a complex time series to the frequency domain (DFT) and performs the inverse transform (IDFT) from the frequency domain back to the time domain. The frequency representation of the transform is given in terms of magnitude in dB and phase in degrees. (Angles input in this program must be in degrees with decimal format.) With a 6K byte memory capacity computer, the program allows a DFT sampling rate of up to 64 points using the 2N point transform option. For IDFT's, you can generate a time-domain image of a signal by taking up to a 64-point sample of its symmetric frequency domain representation. It is assumed that the time series reflects a periodic function over some finite interval so that the frequency domain behavior can also be expressed as a discrete series representing a periodic function. The following equations are used in this program.

Discrete Fourier Transform (DFT)

$$F_{re}(X) = \sum_{n=0}^{N-1} f(n) \cos\left(\frac{2\pi nX}{N}\right)$$

$$F_{im}(X) = -\sum_{n=0}^{N-1} f(n) \sin\left(\frac{2\pi nX}{N}\right) \qquad X = 0, 1, 2, \ldots, N-1$$

$$|F(X)| = \sqrt{[F_{re}(X)]^2 + [F_{im}(X)]^2}$$

magnitude in dB $= 20 \log |F(X)|$

phase in degrees, $\angle F(X) = \tan^{-1}\left[\frac{F_{im}(X)}{F_{re}(X)}\right], -90° \le \angle F(X) < 270°$

where

$F(X) = F_{re}(X) + jF_{im}(X)$ is the transform of the sample at X.
$F_{re}(X)$ = real part of the transform
$F_{im}(X)$ = imaginary part of the transform
$f(n)$ = value of the waveform sampled at n
N = total number of samples

Inverse Discrete Fourier Transform (IDFT)

$$f(X) = \frac{1}{N} \sum_{n=0}^{N-1} F_{re}(n) \cos\left(\frac{2\pi nX}{N}\right) - F_{im}(n) \sin\left(\frac{2\pi nX}{N}\right)$$

where

$f(X)$ = the value of the waveform sampled at X
$F_{re}(n)$ = real part of the transform at sample n
$F_{im}(n)$ = imaginary part of the transform at sample n
N = total number of samples

The program assumes that the time function (f) and the frequency function (F) are approximated by N equally spaced samples at intervals of Δ T(DFT) or 1/ Δ T(IDFT). These N samples define the Discrete Fourier Transform pair f $\neq$ F because the N time and frequency values give a discrete representation of the time and frequency domain waveforms, respectively. To minimize the effects of aliasing, choose N such that the DFT sample interval is $\Delta T \leq 1/2f_c$ where f_c is the highest frequency component of the transform and the IDFT sample interval is $1/\Delta T \leq 2f_c$ which is the Nyquist sampling rate.

Six Windowing Techniques are available for use in sidelobe suppression.

1. Hamming
2. Hanning
3. Blackman
4. Bartlett

5. Dolph-Tchebycheff*
6. Dolph-Tchebycheff(normalized)*

Data input may be simplified by the following options.

1. Transforming 2 real time series simultaneously.
2. Transforming a 2N point transform using an N point transform.

Notes

1. The DFT of a real series may be computed by entering the series values for the real part of the samples and zero for the imaginary part.
2. The algorithm requires that the sample length $N = 2^m$ where m is a positive integer > 0.
3. Since the DFT of 2 real series simultaneously requires the use of a complex input sequence, series 1 is input as real data and series 2 is input as imaginary data. The algorithm requires that the sample length be 2N for a 2N point transform.

References: *The Fast Fourier Transform,* E. Oran Brigham. Prentice Hall, 1974.
An Introduction to Discrete Systems, Kenneth Steiglitz, John Wiley and Sons, 1974.
Digital Signal Processing, Alan V. Oppenheim, Ronald Schokr. Prentice Hall, 1975.
"Properties of Dolph-Tchebycheff Weighting Functions," H.R. Wood, IEEE Transactions on Aerospace and Electronic Systems, September 1973, pp. 785-789.

User Instructions—Discrete Fourier Transform

Select the Discrete Fourier Transform program by entering **RUN "DFT"**.

Step	Display	Procedure/Comment	Goto
1.	`DFT`	Program name.	2
2.	`Use Printer?`	a. Accept printer usage by entering **Y**. b. Reject printer usage by entering **N**.	3 4
3.	`Enter Device Name:`	Enter the output device name.	4
4.	`Enter No. of Samples:`	Enter the number of samples to be input.	5
5.	`a+bj Form?`	a. Select a + bj form by entering **Y**. b. Display next option by entering **N**.	6 17

(continued)

(continued)

Step	Display	Procedure/Comment	Goto
6.	Enter Data From Keyboard?	a. Enter the samples from the keyboard by entering **Y**.	7
		b. Display next option by entering **N**.	10
7.	Enter Real(#):	Enter the real part of sample.	8
8.	Enter Imag(#):	Enter the imaginary part of sample.	9
9.		a. If input is incomplete.	7
		b. If input is complete.	12
10.	Enter Data From Media?	a. Enter the samples from media by entering **Y**.	11
		b. Continue program by entering **N**.	64
11.	Enter Device.Filename:	Enter the device and filename in the form Device.Filename.	12
12.	Edit?	a. Edit data by entering **Y**.	13
		b. Accept data by entering **N**.	29
13.	Enter element to be edited:	Enter the element number to be edited.	14
14.	Enter Real(#):	Enter the real part of sample.	15
15.	Enter Imag(#):	Enter the imaginary part of sample.	16
16.	Edit more elements?	a. Edit more data elements by entering **Y**.	13
		b. Accept data by entering **N**.	29
17.	(r,e) Form?	a. Select (r,e) form by entering **Y**.	18
		b. Display next option by entering **N**.	5
18.	Enter Data From Keyboard?	a. Enter the samples from the keyboard by entering **Y**.	19
		b. Display next option by entering **N**.	22
19.	Enter r(#):	Enter the magnitude part of sample.	20

(continued)

(continued)

Step	Display	Procedure/Comment	Goto
20.	`Enter e(#):`	Enter the angle part of sample.	21
21.		a. If input is incomplete. b. If input is complete.	19 24
22.	`Enter Data From Media?`	a. Enter the samples from media by entering **Y.** b. Continue program by entering **N.**	23 64
23.	`Enter Device.Filename:`	Enter the device and filename in the form Device.Filename.	24
24.	`Edit?`	a. Edit data by entering **Y.** b. Accept data by entering **N.**	25 29
25.	`Enter element to be edited:`	Enter the element number to be edited.	26
26.	`Enter r(#):`	Enter the magnitude part of sample.	27
27.	`Enter e(#):`	Enter the angle part of sample.	28
28.	`Edit more elements?`	a. Edit more data elements by entering **Y.** b. Accept data by entering **N.**	25 29
29.	`Save Data on Media?`	a. Save data on media by entering **Y.** b. Continue program by entering **N.**	30 31
30.	`Enter Device.Filename:`	Enter the device and filename in the form Device.Filename.	31
31.	`Window Data?`	a. Window data by entering **Y.** b. Continue program by entering **N.**	32 34

32.	`0-MENU 1-HANNING...`
	`2-HAMMING 3-BLACKMAN...`
	`4-BARTLETT 5-D-T...`
	`6-D-T NORM.`
		Displays Menu. Proceed after each line by pressing **[ENTER]**.	33

(continued)

(continued)

Step	Display	Procedure/Comment	Goto
33.	`Enter Window Option:`	Enter the window option from the choices given.	
		0-Repeat menu.	32
		1-Perform Hanning window on data.	37
		2-Perform Hamming window on data.	37
		3-Perform Blackman window on data.	37
		4-Perform Bartlett window on data.	37
		5-Perform Dolph-Tchebycheff window on data.	34
		6-Perform Dolph-Tchebycheff (normalized) window on data.	34
34.	`Enter Side Lobe Ratio in dB:`	Enter the side lobe ratio in dB.	35
35.	`Signal-to-Noise Loss=`	Displays signal-to-noise loss. Proceed by pressing **[ENTER]**.	37
36.	`Compute?`	a. Compute without windowing the data by entering **Y**.	37
		b. Display next option by entering **N**.	64

37.	`0-MENU 1-DFT...`
	`2-DFT(SIMO) 3-DFT(2N)...`
	`4-IDFT.`
		Displays Menu. Proceed after each line by pressing **[ENTER]**.	38

38.	`Enter Option:`	Enter the compute option from the choices given.	
		0-Repeat menu.	37
		1-Perform DFT calculations, and display results.	39
		2-Perform DFT(SIMO) calculations, and display results.	45
		3-Perform DFT(2N) calculations, and display results.	56
		4-Perform IDFT calculations, and display results.	39

(continued)

(continued)

Step	Display	Procedure/Comment	Goto
39.	Real(#)=	Displays real part of the transform. Proceed by pressing **[ENTER]**.	40
40.	Imag(#)=	Displays imaginary part of the transform. Proceed by pressing **[ENTER]**.	41
41.	Mag=	Displays the magnitude of the transform. Proceed by pressing **[ENTER]**.	42
42.	dB=	Displays the magnitude in dB of the transform. Proceed by pressing **[ENTER]**.	43
43.	Ang=	Displays the angle in degrees of the transform. Proceed by pressing **[ENTER]**.	44
44.		a. If output is incomplete. b. If output is complete.	39 62
45.	Re1(#)=	Displays real part of the transform. Proceed by pressing **[ENTER]**.	46
46.	Im1(#)=	Displays imaginary part of the transform. Proceed by pressing **[ENTER]**.	47
47.	Mag1=	Displays the magnitude of the transform. Proceed by pressing **[ENTER]**.	48
48.	dB1=	Displays the magnitude in dB of the transform. Proceed by pressing **[ENTER]**.	49
49.	Ang1=	Displays the angle in degrees of the transform. Proceed by pressing **[ENTER]**.	50
50.	Re2(#)=	Displays real part of the transform. Proceed by pressing **[ENTER]**.	51
51.	Im2(#)=	Displays imaginary part of the transform. Proceed by pressing **[ENTER]**.	52

(continued)

(continued)

Step	Display	Procedure/Comment	Goto
52.	Mag2=	Displays the magnitude of the transform. Proceed by pressing **[ENTER]**.	53
53.	dB2=	Displays the magnitude in dB of the transform. Proceed by pressing **[ENTER]**.	54
54.	Ang2=	Displays the angle in degrees of the transform. Proceed by pressing **[ENTER]**.	55
55.		a. If output is incomplete.	45
		b. If output is complete.	62
56.	Real(#)=	Displays real part of the transform. Proceed by pressing **[ENTER]**.	57
57.	Imag(#)=	Displays imaginary part of the transform. Proceed by pressing **[ENTER]**.	58
58.	Mag=	Displays the magnitude of the transform. Proceed by pressing **[ENTER]**.	59
59.	dB=	Displays the magnitude in dB of the transform. Proceed by pressing **[ENTER]**.	60
60.	Ang=	Displays the angle in degrees of the transform. Proceed by pressing **[ENTER]**.	61
61.		a. If output is incomplete.	56
		b. If output is complete.	62
62.	Save Data on Media?	a. Save data on media by entering **Y**.	63
		b. Continue program by entering **N**.	64
63.	Enter Device.Filename:	Enter the device and filename in the form Device.Filename.	64
64.	Exit Program?	a. Exit program by entering **Y**.	STOP
		b. Continue program by entering **N**.	4

Example

Find the Discrete Fourier Transform of a sampled pulse with a period of 8 seconds and a duration of 4 seconds.

Select the Discrete Fourier Transform program by entering **RUN "DFT"**.

Step	Display	Procedure/Comment
1.	DFT	Program name.
2.	Use Printer?	Enter **N**.
3.	Enter No. of Samples: 0	Enter **8**.
4.	a+bj Form?	Enter **N**.
5.	(r,e) Form?	Enter **Y**.
6.	Enter Data From Keyboard?	Enter **Y**.
7.	Enter r(1): 0	Enter **1**.
8.	Enter e(1): 0	Accept current value by pressing **[ENTER]**.
9.	Enter r(2): 0	Enter **1**.
10.	Enter e(2): 0	Accept current value by pressing **[ENTER]**.
11.	Enter r(3): 0	Enter **1**.
12.	Enter e(3): 0	Accept current value by pressing **[ENTER]**.
13.	Enter r(4): 0	Enter **1**.
14.	Enter e(4): 0	Accept current value by pressing **[ENTER]**.
15.	Enter r(5): 0	Enter **1**.
16.	Enter e(5): 0	Accept current value by pressing **[ENTER]**.
17.	Enter r(6): 0	Accept current value by pressing **[ENTER]**.
18.	Enter e(6): 0	Accept current value by pressing **[ENTER]**.
19.	Enter r(7): 0	Accept current value by pressing **[ENTER]**.
20.	Enter e(7): 0	Accept current value by pressing **[ENTER]**.

(continued)

(continued)

Step	Display	Procedure/Comment
21.	Enter r(8): 0	Accept current value by pressing **[ENTER]**.
22.	Enter e(8): 0	Accept current value by pressing **[ENTER]**.
23.	Edit?	Enter **N**.
24.	Save Data on Media?	Enter **N**.
25.	Window Data?	Enter **N**.
26.	Compute?	Enter **Y**.
27.	0-MENU 1-DFT... 2-DFT(SIMO) 3-DFT(2N)... 4-IDFT.	Displays Menu. Proceed after each line by pressing **[ENTER]**.
28.	Enter Option:	Enter **1**.
29.	Real(1)= 5 Imag(1)= 0 Mag= 5 dB= 13.97940009 Ang= 0 Real(2)= 0 Imag(2)= -2.414213562 Mag= 2.414213562 dB= 7.655513707 Ang= 270 Real(3)= 1 Imag(3)= 0 Mag= 1 dB= 0 Ang= 0	Displays all requested values. Proceed after each output by pressing **[ENTER]**.

(continued)

(continued)

Step	Display		Procedure/Comment
	Real(4)=	0	
	Imag(4)=	-.4142135624	
	Mag=	.4142135624	
	dB=	-7.655513707	
	Ang=	270	
	Real(5)=	1	
	Imag(5)=	0	
	Mag=	1	
	dB=	0	
	Ang=	0	
	Real(6)=	0	
	Imag(6)=	.4142135624	
	Mag=	.4142135624	
	dB=	-7.655513707	
	Ang=	90	
	Real(7)=	1	
	Imag(7)=	0	
	Mag=	1	
	dB=	0	
	Ang=	0	
	Real(8)=	0	
	Imag(8)=	2.414213562	
	Mag=	2.414213562	
	dB=	7.655513707	
	Ang=	90	
32.	Save Data on Media?		Enter **N.**
33.	Exit Program?		Enter **Y.**

Network Analysis—"NETWORK"

This program is designed for optimal use with a printer. The program computes the frequency response of a general linear network composed of resistors, capacitors, inductors, and voltage controlled dependent current sources. With a 6K byte memory capacity computer, you may enter a range of from 2 nodes and 200 components to 13 nodes and 13 components. The ratio of nodes to components within this range may be determined from the following table.

Nodes	Components
2	200
3	195
4	185
5	175
6	160
7	145
8	130
9	110
10	90
11	65
12	40
13	13

The program uses node analysis using the node admittance matrix [I] = [Y] [E], where I is the current entering any node, Y is the admittance to any node, and E is the voltage associated with any node with respect to ground. Program output is in the form of a log or linear frequency sweep which depends on starting frequency, ending frequency, and number of intervals specified. Printout consists of the frequency in Hertz, magnitude of the output voltage in dB, and the phase in degrees.

If the linear sweep is selected, the frequencies at which the circuit's response are computed are

$$f = fs + (n(fe - fs) \div INT)$$

where

n starts at 0 and increments until $f \geq fe$.

If INT = 0.5, fs is the starting frequency and 2fe − fs is the ending frequency.

If the logarithmic sweep is selected, the frequencies at which the circuit's response are computed are

$$f = 10^{(\log fs + (n(\log (fe \div fs) \div INT)))}$$

where

n starts at 0 and increments until $f \geq fe$.

If INT = 0.5, fs is the starting frequency and $10^{(\log(fe^2 \div fs))}$ is the ending frequency.

Program Assumptions

1. Phase output is always between −90° and 270°.
2. No independent current sources exist and all dependent sources are voltage controlled current sources.
3. Node zero is the reference or ground node, node one is the input node, and node two is the output node.
4. The output results from a one volt source connected between node one and node zero.
5. The from node is not zero when entering the node numbers between which a component (R, L, C, or gm) is connected.
6. A to node of nine or less must be entered in the second position from the decimal. From node one to node three is 1.03.

User Instructions—Network Analysis

Select the Network Analysis program by entering **RUN "NETWORK"**.

Step	Display	Procedure/Comment	Goto
1.	NETWORK ANALYSIS	Program name.	2
2.	Use Printer?	a. Accept printer usage by entering **Y**. b. Reject printer usage by entering **N**.	3 4
3.	Enter Device Name:	Enter the output device name.	4
4.	Enter No. of Nodes:	Enter the number of nodes.	5
5.	Enter No. of Elements:	Enter the number of elements.	6
6.	Enter Component ID... 1-gm 2-R 3-C 4-L:	Enter the Menu option.	7
7.	Enter Its Value:	Enter the component's value.	8
8.	Enter FF.TT:	Enter the from and to nodes in the format ff.tt.	9
9.		a. If in option 1. b. If in option 2, 3, or 4.	10 11
10.	Enter Cntrl V.(FF.TT):	Enter the control voltage.	11
11.		a. If input is incomplete. b. If input is complete.	6 12
12.	Enter Starting frequency:	Enter the starting frequency.	13
13.	Enter Ending frequency:	Enter the ending frequency.	14
14.	Enter No. of Intervals:	Enter the number of intervals.	15
15.	Linear Sweep?	a. Select linear sweep option by entering **Y**. b. Display next option by entering **N**.	17 16
16.	Log Sweep?	a. Select log sweep option by entering **Y**. b. Display next option by entering **N**.	17 15

(continued)

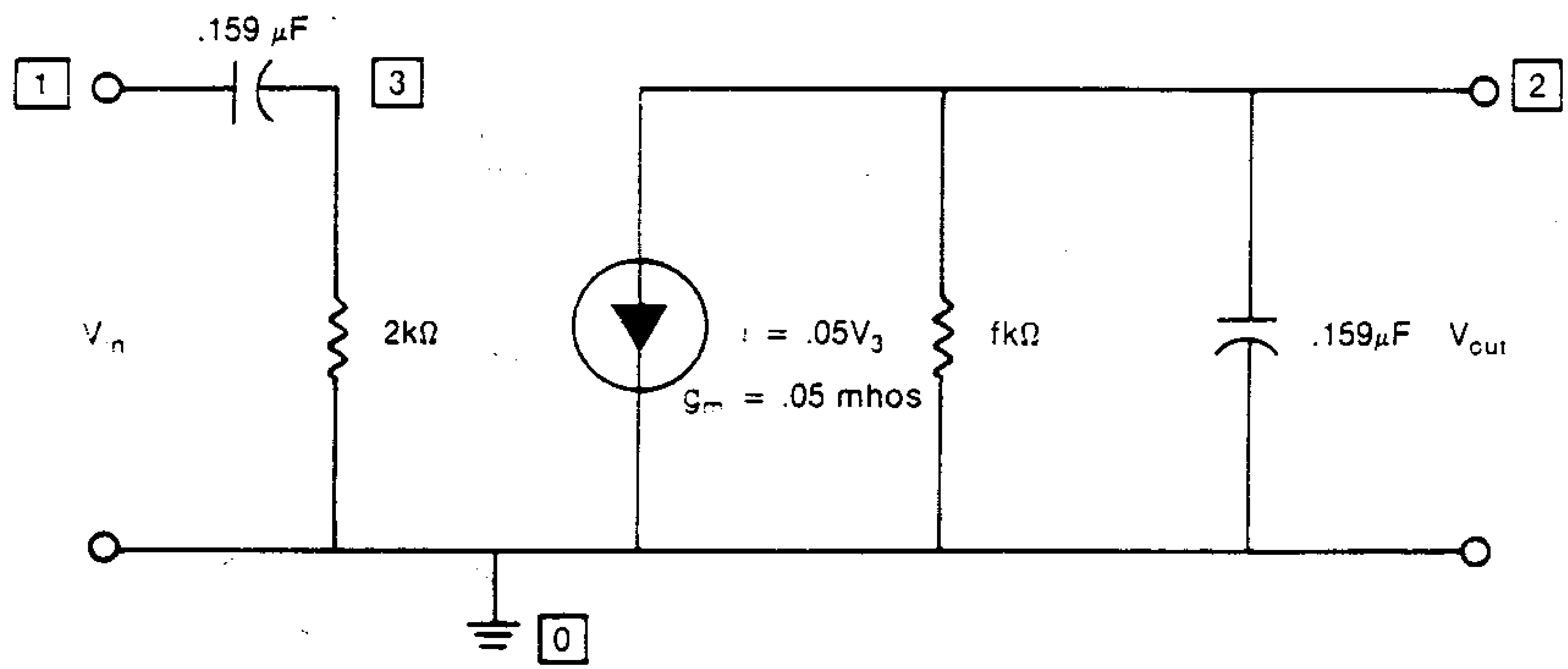
(continued)

Step	Display	Procedure/Comment	Goto
17.	`Edit?`	a. Edit data by entering **Y.**	4
		b. Accept data by entering **N.**	18
18.	`Frequency=`	Displays the frequency. Proceed by pressing **[ENTER].**	19
19.	`Magnitude(dB)=`	Displays the magnitude in dB. Proceed by pressing **[ENTER]**.	20
20.	`Phase(Degrees)=`	Displays the phase in degrees. Proceed by pressing **[ENTER]**.	21
21.		a. If output is incomplete.	18
		b. If output is complete.	22
22.	`Exit Program?`	a. Exit program by entering **Y.**	STOP
		b. Continue program by entering **N.**	4

Example

For the passive RC filter shown, determine the frequency response from 1 MHz to 10 MHz at 1 MHz increments.

COMMON-EMITTER AMPLIFIER (Equivalent Circuit Representation)



Select the Network Analysis program by entering **RUN "NETWORK"**.

Step	Display	Procedure/Comment
1.	NETWORK ANALYSIS	Program name.
2.	Use Printer?	Enter **N.**
3.	Enter No. of Nodes:	Enter **3.**
4.	Enter No. of Elements:	Enter **3.**
5.	Enter Component ID... 1-gm 2-R 3-C 4-L :	 Enter **2.**
6.	Enter Its Value:	Enter **50.**
7.	Enter FF.TT:	Enter **1.02.**
8.	Enter Component ID... 1-gm 2-R 3-C 4-L :	 Enter **3.**
9.	Enter Its Value:	Enter **1.59E – 09.**
10.	Enter FF.TT:	Enter **2.03.**
11.	Enter Component ID... 1-gm 2-R 3-C 4-L :	 Enter **2.**
12.	Enter Its Value:	Enter **20.**
13.	Enter FF.TT:	Enter **3.**
14.	Enter Starting frequency: 0	Enter **1000000.**
15.	Enter Ending frequency: 0	Enter **10000000.**
16.	Enter No. of Intervals: 0	Enter **10.**
17.	Linear Sweep?	Enter **Y.**
18.	Edit?	Enter **N.**
19.	Frequency= 1000000 Magnitude(dB)= -1.559073999 Phase(Degrees)= -23.66660142	Displays all requested values. Proceed after each output by pressing **[ENTER].**

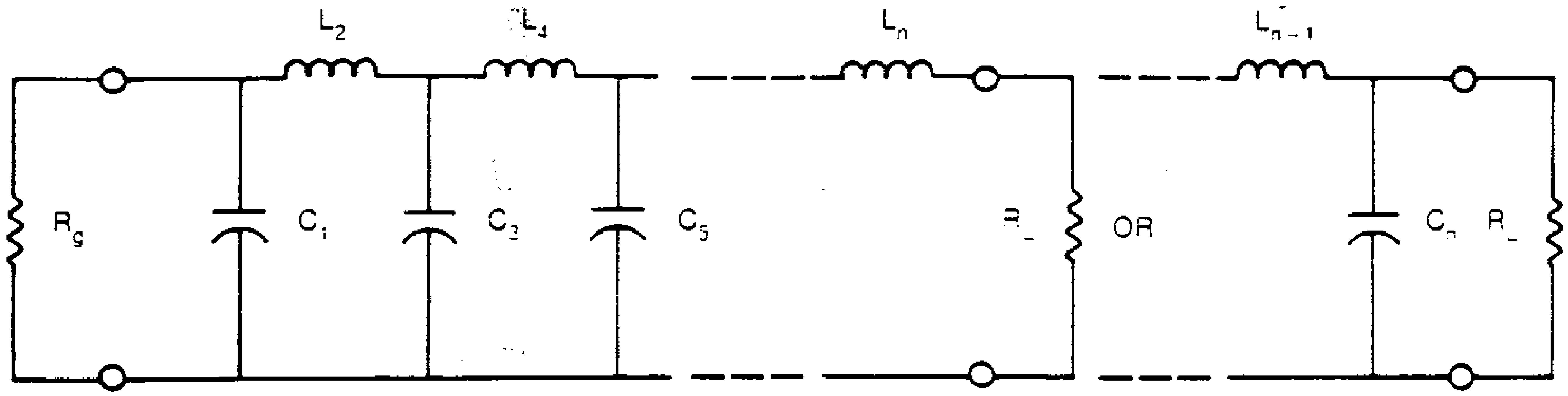
(continued)

(continued)

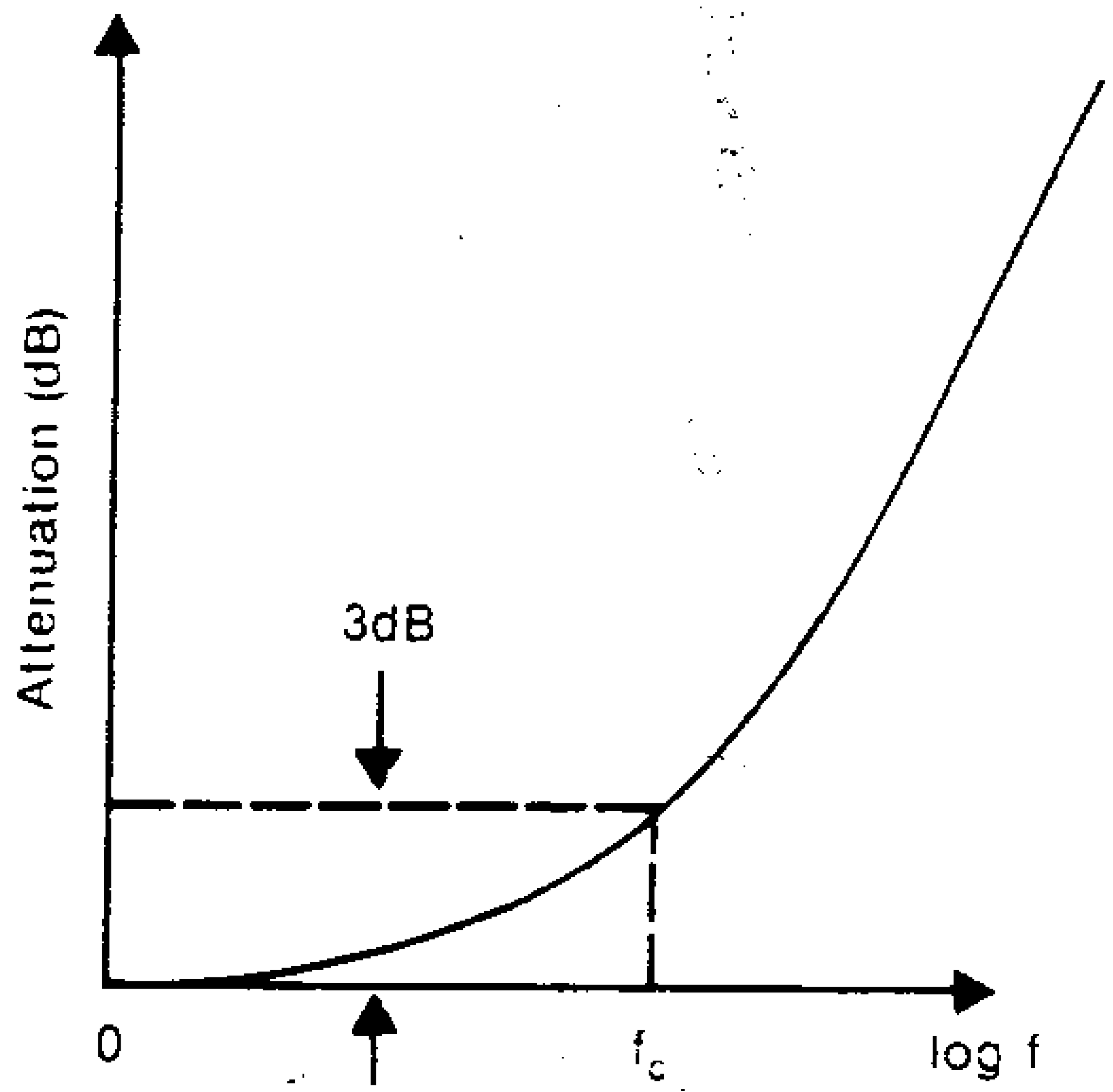
Step	Display		Procedure/Comment
	Frequency=	2000000	
	Magnitude(dB)=	-4.063903011	
	Phase(Degrees)=	-32.6537504	
	Frequency=	3000000	
	Magnitude(dB)=	-5.991926308	
	Phase(Degrees)=	-33.57584422	
	Frequency=	4000000	
	Magnitude(dB)=	-7.311881441	
	Phase(Degrees)=	-31.69590456	
	Frequency=	5000000	
	Magnitude(dB)=	-8.20826577	
	Phase(Degrees)=	-29.06775995	
	Frequency=	6000000	
	Magnitude(dB)=	-8.827545839	
	Phase(Degrees)=	-26.42794172	
	Frequency=	7000000	
	Magnitude(dB)=	-9.265698392	
	Phase(Degrees)=	-24.01851772	
	Frequency=	8000000	
	Magnitude(dB)=	-9.583468724	
	Phase(Degrees)=	-21.89613662	
	Frequency=	9000000	
	Magnitude(dB)=	-9.819429644	
	Phase(Degrees)=	-20.05033477	
	Frequency=	10000000	
	Magnitude(dB)=	-9.99847601[illegible]	
	Phase(Degrees)=	-18.44946143	
20.	Exit Program?		Enter Y.

Passive Lowpass Filters—"PASSIVE"

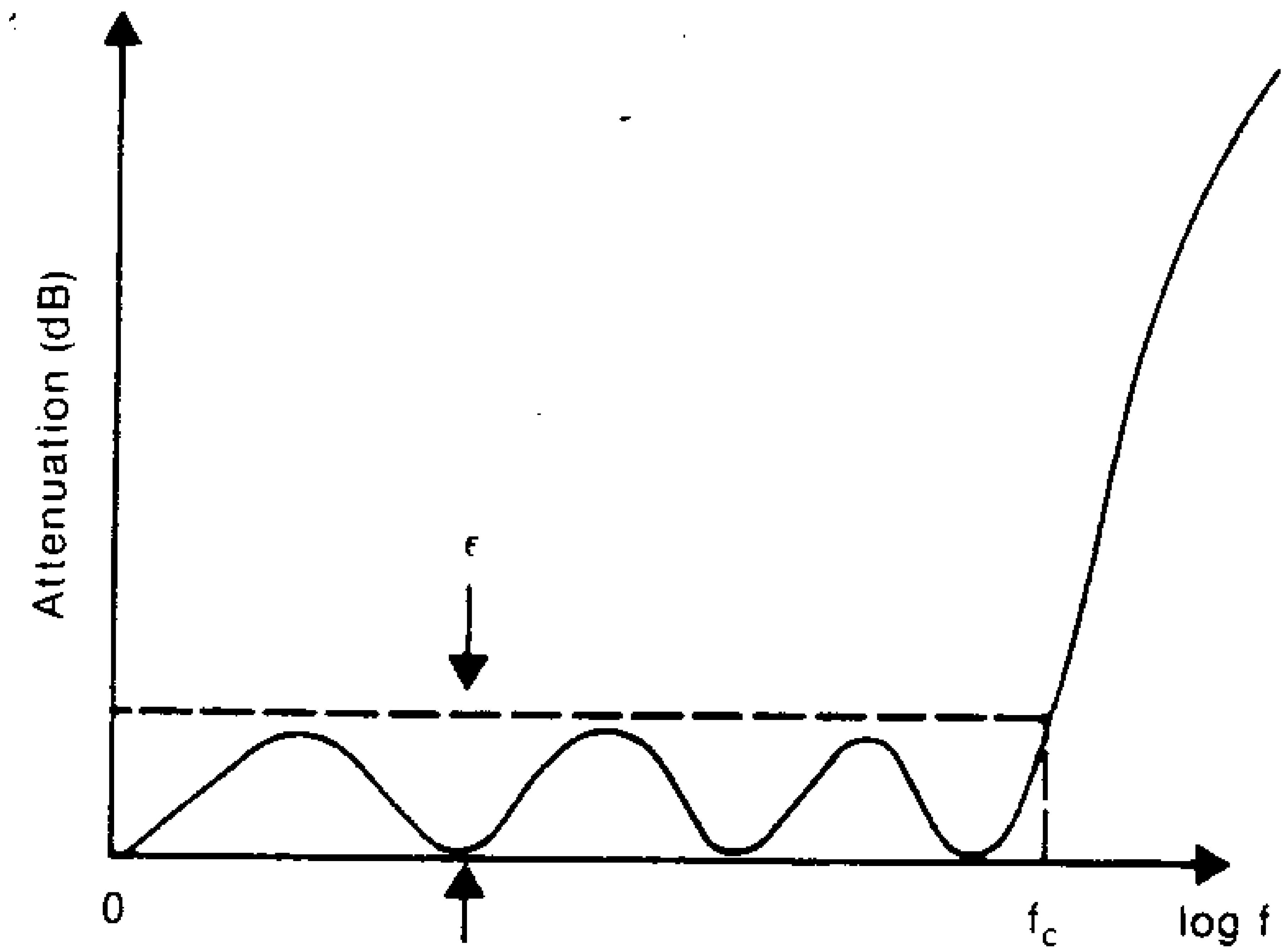
This program computes component values for passive lowpass Butterworth and Tchebycheff filters of the following form.



Required inputs are minimum stopband attenuation, A_{min} in dB, maximum passband attenuation, A_{max} in dB (A_{max} = allowable ripple for Tchebycheff filters), frequency where minimum stopband attenuation realized, f_{min} in Hertz, frequency where maximum passband attenuation realized, f_{max} in Hertz, and terminal resistance R in ohms. The program computes the filter order n which defines the number of reactive components.



Butterworth Lowpass Characteristic



Tchebycheff Lowpass Characteristic

For Butterworth filters with response of the form shown, the component values are computed as follows.

$$C_i = \frac{1}{\pi f_c R} \sin\left[\frac{(2i-1)\pi}{2n}\right] \qquad i = 1, 3, 5, \ldots$$

$$L_i = \frac{R}{\pi f_c} \sin\left[\frac{(2i-1)\pi}{2n}\right] \qquad i = 2, 4, 6, \ldots$$

For Tchebycheff filters with response of the form shown, the component values are computed as follows.

$$\beta = \ln\left[\coth\left(\frac{\epsilon}{40 \log e}\right)\right]$$

$$\gamma = \sinh\left(\frac{\beta}{2n}\right)$$

$$a_i = \sin\left[\frac{(2i-1)\pi}{2n}\right] \qquad i = 1, 2, 3, \ldots, n$$

$$b_i = \gamma^2 + \sin^2\left(\frac{i\pi}{n}\right) \qquad i = 1, 2, 3, \ldots, n$$

$$g_1 = \frac{2a_1}{\gamma}$$

$$g_i = \frac{4a_{i-1}a_i}{b_{i-1}\, g_{i-1}} \qquad i = 2, 3, 4, \ldots, n$$

$$C_i = \frac{g_i}{2\pi f_c R} \qquad i = 1, 3, 5, \ldots$$

$$L_i = \frac{Rg_i}{2\pi f_c} \qquad i = 2, 4, 6, \ldots$$

Note: This program assumes that the generator resistance Rg is equal to the load resistance R_L for Butterworth filters and odd-order Tchebycheff filters. Thus, the termination resistance $R = Rg = R_L$. In the case of even-order Tchebycheff filters, $R_L = Rg/\coth^2(\beta/4)$ which, for small ripple results in the generator resistance Rg being approximately equal to the load resistance R_L. Thus, the termination resistance $R = Rg \cong R_L$.

References: *Handbook of Filter Syntheses*, Zverev, John Wiley and Sons, 1967.
Microwave Filters, Impedance-Matching Networks, and Coupling Structures, Matthai, Young, Jones, McGraw-Hill, 1964.
Reference Data For Radio Engineers, 6th Edition 1977, Howard W. Sams & Co., Inc., ITT.

User Instructions—Passive Lowpass Filters

Select the Passive Lowpass Filters program by entering **RUN "PASSIVE"**.

Step	Display	Procedure/Comment	Goto
1.	PASSIVE LOWPASS FILTERS	Program name.	2
2.	Use Printer?	a. Accept printer usage by entering **Y.**	3
		b. Reject printer usage by entering **N.**	4
3.	Enter Device Name:	Enter the output device name.	4
4.	Enter R:	Enter the termination resistance in ohms.	5
5.	Enter A(max):	Enter the maximum attenuation of the passband in dB.	6
6.	Enter A(min):	Enter the minimum attenuation of the passband in dB.	7
7.	Enter f(max):	Enter the frequency of maximum attenuation in Hertz.	8
8.	Enter f(min):	Enter the frequency of minimun attenuation in Hertz.	9
9.	Edit?	a. Edit data by entering **Y.**	4
		b. Accept data by entering **N.**	10
10.	Butterworth?	a. Select Butterworth option by entering **Y.**	12
		b. Display next option by entering **N.**	11
11.	Tchebycheff?	a. Select Tchebycheff option by entering **Y.**	12
		b. Display next option by entering **N.**	10
12.	C(#)=	Displays the component value. Proceed by pressing **[ENTER]**.	13
13.	L(#)=	Displays next component value. Proceed by pressing **[ENTER]**.	14
14.		a. If component output is complete.	15
		b. If component output is incomplete.	12
15.	Exit Program?	a. Exit program by entering **Y.**	STOP
		b. Continue program by entering **N.**	4

Example 1

Compute the component values for a Butterworth filter having equal generator and load resistances of 2000 ohms. The filter must pass frequencies below 10 kilohertz(fc), with 3 dB as the maximum attenuation at 10 kilohertz. At least 30 dB attenuation must be provided at 15 kilohertz and above. The order of the filter is determined by the program.

Select the Passive Lowpass Filters program by entering **RUN "PASSIVE"**.

Step	Display	Procedure/Comment
1.	PASSIVE LOWPASS FILTERS	Program name.
2.	Use Printer?	Enter **N.**
3.	Enter R: 0	Enter **2000.**
4.	Enter A(max): 0	Enter **3.**
5.	Enter A(min): 0	Enter **30.**
6.	Enter f(max): 0	Enter **10000.**
7.	Enter f(min): 0	Enter **15000.**
8.	Edit?	Enter **N.**
9.	Butterworth?	Enter **Y.**
10.	C(1)= 2.763697E-09 L(2)= .0318309886 C(3)= 1.219198E-08 L(4)= .0598226902 C(5)= 1.591549E-08 L(6)= .0598226902 C(7)= 1.219198E-08 L(8)= .0318309886 C(9)= 2.763697E-09	Displays all requested values. Proceed after each output by pressing **[ENTER].**
11.	Exit Program?	Enter **Y.**

Example 2

Compute the component values for a Tchebycheff filter having equal generator and load resistances of 1000 ohms. The filter must pass frequencies below 3500 Hertz with an attenuation of 40 dB required at 5250 Hertz. The passband ripple is allowed to be .5 dB with 3500 Hertz being the cutoff frequency. The order of the filter is determined by the program.

Select the Passive Lowpass Filters program by entering **RUN "PASSIVE"**.

Step	Display	Procedure/Comment
1.	PASSIVE LOWPASS FILTERS	Program name.
2.	Use Printer?	Enter **N.**
3.	Enter R: 0	Enter **1000.**
4.	Enter A(max): 0	Enter **.5.**
5.	Enter A(min): 0	Enter **40.**
6.	Enter f(max): 0	Enter **5250.**
7.	Enter f(min): 0	Enter **3500.**
8.	Edit?	Enter **Y.**
9.	Enter R: 1000	Accept current value by pressing **[ENTER].**
10.	Enter A(max): .5	Accept current value by pressing **[ENTER].**
11.	Enter A(min): 40	Accept current value by pressing **[ENTER].**
12.	Enter f(max): 5250	Enter **3500.**
13.	Enter f(min): 3500	Enter **5250.**
14.	Edit?	Enter **N.**
15.	Butterworth?	Enter **N.**
16.	Tchebycheff?	Enter **Y.**

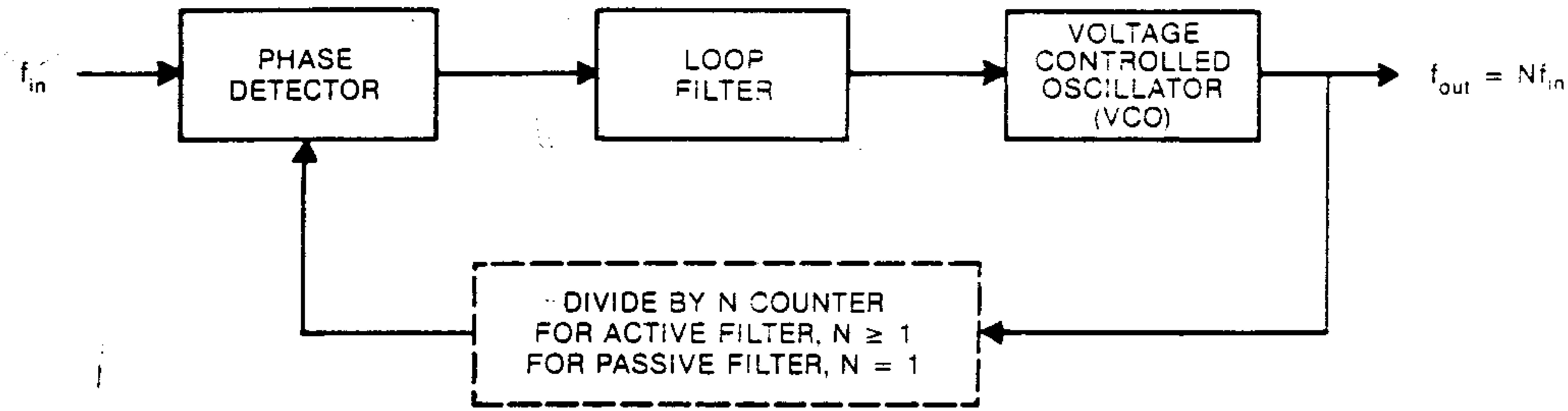
(continued)

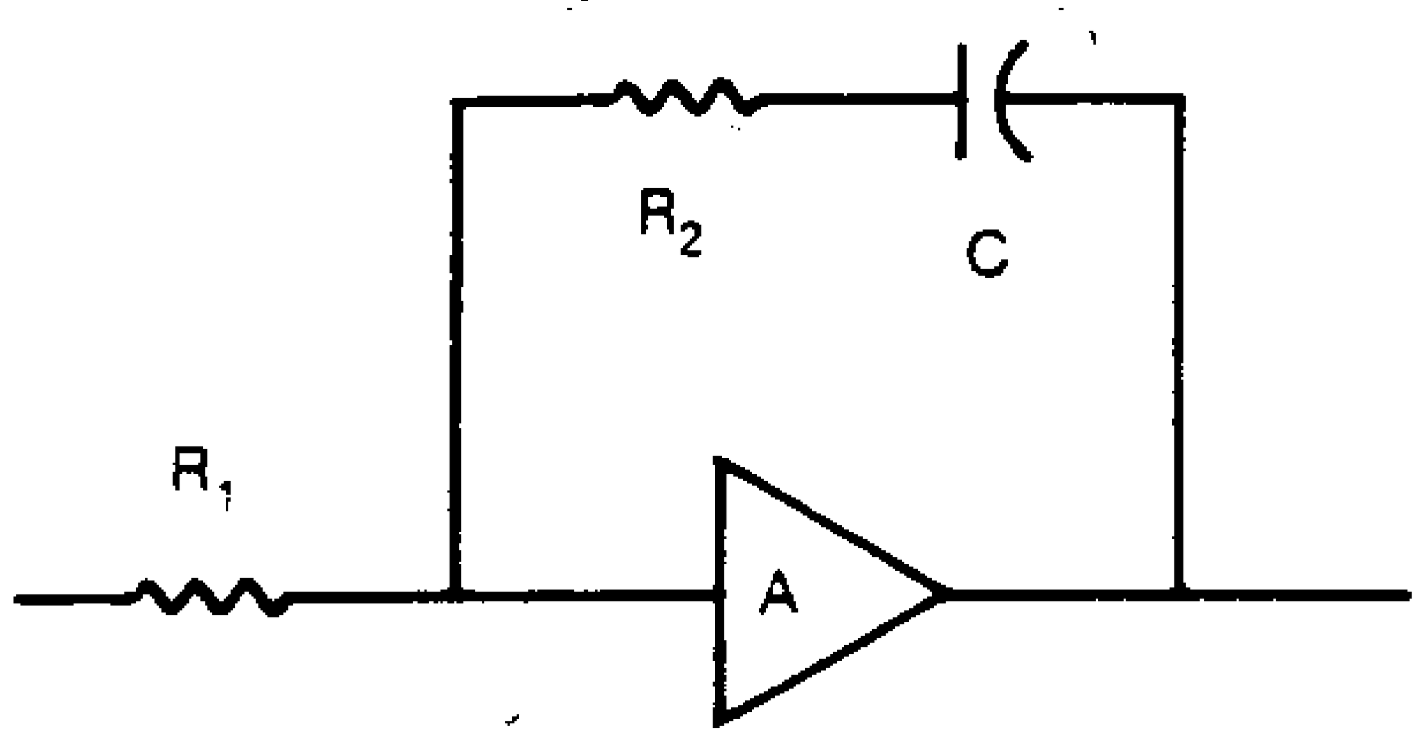
(continued)

Step	Display		Procedure/Comment
17.	C(1)=	7.899956E-08	Displays all requested values. Proceed after each output by pressing **[ENTER]**.
	L(2)=	.0572155871	
	C(3)=	1.199706E-07	
	L(4)=	.06113069	
	C(5)=	1.199706E-07	
	L(6)=	.0572155871	
	C(7)=	7.899956E-08	
18.	Exit Program?		Enter Y.

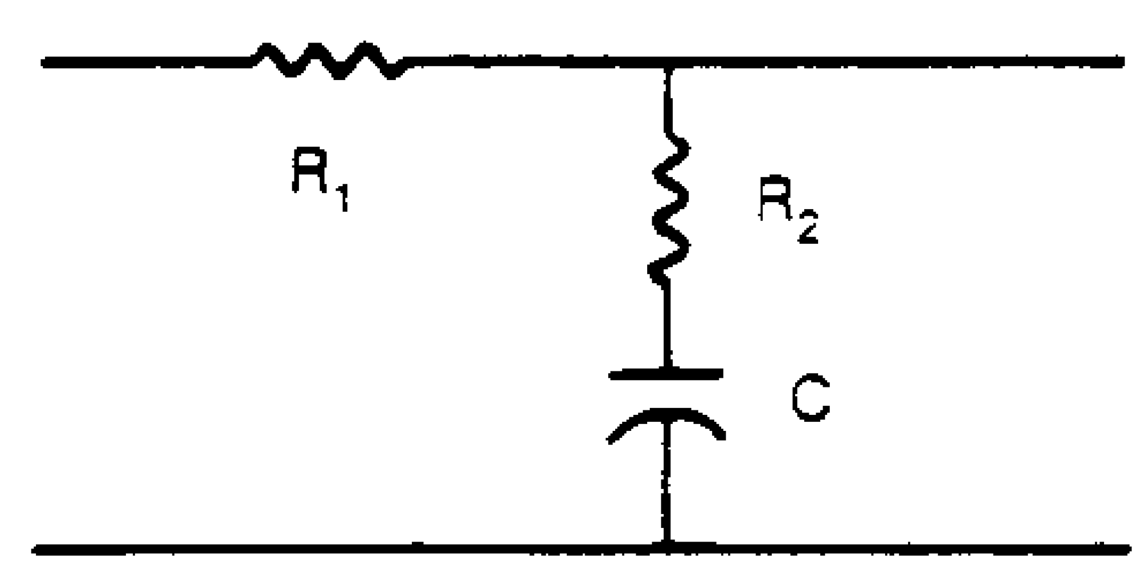
Phase-Locked Loop—"PLL"

Given the choice of an active or passive loop filter, this program computes the resulting design parameters for a basic phase-locked loop as illustrated below. A type-2, second-order loop is realized with an active filter while a type-1, second-order loop results with a passive filter.





ACTIVE FILTER



PASSIVE FILTER

The basic PLL transfer function is $\frac{\theta_o}{\theta_i}(S) = \frac{GF(S)}{S + GF(S)}$

where

- θ_i is the input phase
- θ_o is the output phase
- G is the loop gain
- F(S) is the transfer function of the loop filter.

$$G = K_p K_v$$

where

- K_p is the gain of the phase detector in volts/radian
- K_v is the gain of the VCO in radians/(second volt)

If the loop filter is active, a $(\div N)$ counter can be added to the loop, making the output frequency, f_{out}, an integral multiple of the input or reference frequency, f_{in}. In this case, N is an integer divisor ≥ 1 and $f_{out} = N\ f_{in}$. This technique is used for multiple frequency generation in frequency synthesizers. If the loop filter is passive, the program ignores the $(\div N)$ counter and in effect $N = 1$ making $f_{out} = f_{in}$.

In this program, you must input the loop gain G and a value for C in farads. If the loop filter chosen is active, then N is also required. At this point, you have the option of either inputting w_n, the natural angular frequency in radians/second and the damping factor and solving for the resistances R_1 and R_2 in ohms, or vice versa. With a passive loop filter, a test is made before computing R_1 and R_2 to insure that the resistance values are greater than zero. Finally, after completing the above computations, the loop-noise bandwidth can be computed.

Method Used—Phase Locked Loop

$F(S) = \dfrac{S\tau_2 + 1}{S\tau_1}$ for an active filter provided that the amplifier gain is very large and

$F(S) = \dfrac{S\tau_2 + 1}{S(\tau_1 + \tau_2) + 1}$ for a passive filter where $\tau_1 = R_1C$, $\tau_2 = R_2C$.

Using the transfer function representative F(S) for the passive filter. the basic PLL transfer function becomes

$$\frac{\theta_o}{\theta_i}(S) = \frac{G(S\tau_2 + 1)/(\tau_1 + \tau_2)}{S^2 + S(1 + G\tau_2)/(\tau_1 + \tau_2) + G/(\tau_1 + \tau_2)}$$

In order to preserve the analogy with second-order servo controls, one can substitute for the time constants τ_1 and τ_2, the parameters of ω_n, the natural angular frequency. and ζ, the damping factor. Making these substitutions,

$$\frac{\theta_o}{\theta_i}(S) = \frac{S\omega_n(2\zeta - \omega_n/G) + \omega_n^2}{S^2 + 2\zeta\omega_n S + \omega_n^2}$$

where, by definition

$$\omega_n = \sqrt{\frac{G}{\tau_1 + \tau_2}} \quad \text{and} \quad \zeta = \frac{\omega_n}{2}\left(\tau_2 + \frac{1}{G}\right)$$

A similar argument applies in the case where the loop filter is active except that the ($\div$ N) counter changes the form of the PLL transfer function,

$$\frac{\theta_o}{\theta_i}(S) = \frac{GF(S)/N}{S + G\,F(S)/N}$$

Using the transfer function representation F(S) for the active filter, the PLL transfer function becomes

$$\frac{\theta_o}{\theta_i}(S) = \frac{G(S\tau_2 + 1)/N\tau_1}{S^2 + S(G\tau_2/N\tau_1) + G/N\tau_1} \quad \text{or} \quad \frac{\theta_o}{\theta_i}(S) = \frac{2\zeta\omega_n S + \omega_n^2}{S^2 + 2\zeta\omega_n S + \omega_n^2}$$

where, by definition

$$\omega_n = \sqrt{\frac{G}{N\tau_1}} \text{ and } \zeta = \frac{\omega_n \tau_2}{2}$$

The loop filter components R_1 and R_2 are computed using the defining equations for ω_n and ζ.

Active filter calculations for R_1 and R_2

$$\omega_n = \sqrt{\frac{G}{N\tau_1}} \rightarrow R_1 = \frac{G}{N\omega_n^2 C}$$

$$\zeta = \frac{\omega_n}{2}\tau_2 \rightarrow R_2 = \frac{2\zeta}{\omega_n C}$$

Passive filter calculations for R_1 and R_2

$$\omega_n = \sqrt{\frac{G}{\tau_1 + \tau_2}} \rightarrow R_1 = \frac{G}{\omega_n^2 C} - R_2$$

$$\zeta = \frac{\omega_n}{2}\left(\tau_2 + \frac{1}{G}\right) \rightarrow R_2 = \frac{2\zeta}{\omega_n C} - \frac{1}{GC}$$

NOTE: In order to insure R_1, $R_2 > 0$ in the passive case,

$$0 < \frac{2\zeta\omega_n G - \omega_n^2}{G^2} < 1$$

Finally, for both active and passive loops, the one-sided loop-noise bandwidth B in Hertz is computed

$$B = \frac{\omega_n}{2}\left(\zeta + \frac{1}{4\zeta}\right)$$

Reference: *Phaselock Techniques*, Floyd M. Gardner, John Wiley & Sons, 1966.

User Instructions—Phase Locked Loop

Select the Phase Locked Loop program by entering **RUN "PLL"**.

Step	Display	Procedure/Comment	Goto
1.	PHASE LOCKED LOOP	Program name.	2
2.	Use Printer?	a. Accept printer usage by entering **Y**.	3
		b. Reject printer usage by entering **N**.	4
3.	Device Name:	Enter the output device name.	4
4.	Active Filter?	a. Select active filters by entering **Y**.	6
		b. Display next option by entering **N**.	5
5.	Passive Filter?	a. Select passive filters by entering **Y**.	6
		b. Display next option by entering **N**.	26
6.	Compute R1, R2, B?	a. Compute R1, R2, B by entering **Y**.	7
		b. Display next option by entering **N**.	16
7.	Enter Gain:	Enter loop gain in $seconds^{-1}$.[1,3]	8
8.	Enter C:	Enter C in farads.[3]	9
9.	Enter N:	Enter the integer divisor.[2,5]	10
10.	Enter W:	Enter the natural angular frequency in rad/sec.[3]	11
11.	Enter DF:	Enter the damping factor.[3]	12
12.	Edit?	a. Edit data by entering **Y**.	7
		b. Accept data by entering **N**.	13
13.	R1=	Displays R1. Proceed by pressing **[ENTER]**.	14

(continued)

(continued)

Step	Display	Procedure/Comment	Goto
14.	R2=	Displays R2. Proceed by pressing **[ENTER]**.	15
15.	B=	Displays B. Proceed by pressing **[ENTER]**.	26
16.	Compute W, DF, B?	a. Compute W, DF, B by entering **Y**.	17
		b. Continue program by entering **N**.	26
17.	Enter Gain:	Enter loop gain in seconds – 1.[1,3]	18
18.	Enter C:	Enter C in farads.[3]	19
19.	Enter N:	Enter the integer divisor.[2,5]	20
20.	Enter R1:	Enter R1 in ohms.[3]	21
21.	Enter R2:	Enter R2 in ohms.[3]	22
22.	Edit?	a. Edit data by entering **Y**.	17
		b. Accept data by entering **N**.	23
23.	W=	Displays the natural angular frequency in rad/sec. Proceed by pressing **[ENTER]**.	24
24.	DF=	Displays the damping factor. Proceed by pressing **[ENTER]**.	25
25.	B=	Displays the loop-noise bandwidth in Hertz. Proceed by pressing **[ENTER]**.	26
26.	Exit Program?	a. Exit program by entering **Y**.	STOP
		b. Continue program by entering **N**.	4

Notes

1. The dimension for the loop gain is 1/second since G = Kp Kv where Kp = phase detector gain in volts/radian and Kv = VCO gain in radians/second volt.
2. Input must be an integer ≥ 1. Enter 1 for N when working with basic PLL design (Fin = Fout).
3. Inputs must be greater than zero.
4. Loop-noise bandwidth is one-sided.
5. Only entered for active filters.

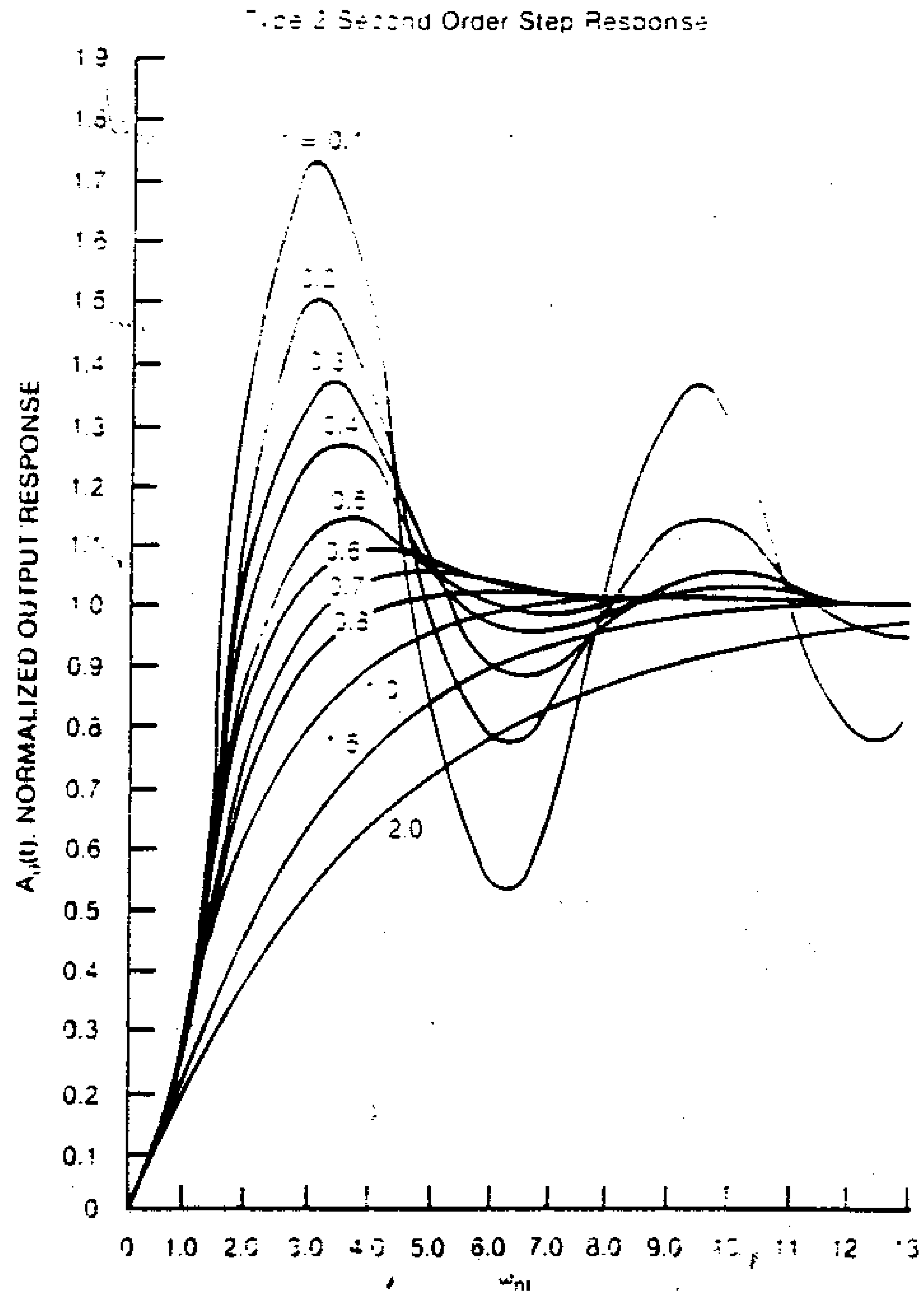
Data sheet specifications for the phase detector give a value of 0.111 volts/radian for the gain constant. The measured value for the gain of the VCO is 9.5×10^6 radians/second volt. The output frequency is 10 megahertz with a channel spacing of 250 Hertz. Thus, N = 10 megahertz/250 Hertz = 40000 and loop gain = (0.111) (9.5×10^6) = 1054500. The value for C is chosen to be 10 microfarads.

Select the Phase Locked Loop program by entering **RUN "PLL"**.

Step	Display	Procedure/Comment
1.	PHASE LOCKED LOOP	Program name.
2.	Use Printer?	Enter **N.**
3.	Active Filter?	Enter **Y.**
4.	Compute R1, R2, B?	Enter **Y.**
5.	Enter Gain: 0	Enter **105500.**
6.	Enter C: 0	Enter **.00001.**
7.	Enter N: 0	Enter **40000.**
8.	Enter W: 0	Enter **90.**
9.	Enter DF: 0	Enter **.5.**
10.	Edit?	Enter **Y.**
11.	Enter Gain: 105500	Enter **1054500.**
12.	Enter C: .00001	Accept current value by pressing **[ENTER].**
13.	Enter N: 40000	Accept current value by pressing **[ENTER].**
14.	Enter W: 90	Enter **9.**
15.	Enter DF: .5	Accept current value by pressing **[ENTER].**
16.	Edit?	Enter **N.**
17.	R1= 32546.2963	Displays R1. Proceed by pressing **[ENTER].**
18.	R2= 11111.11111	Displays R2. Proceed by pressing **[ENTER].**
19.	B= 4.5	Displays the loop-noise bandwidth in Hertz. Proceed by pressing **[ENTER].**
20.	Exit Program?	Enter **Y.**

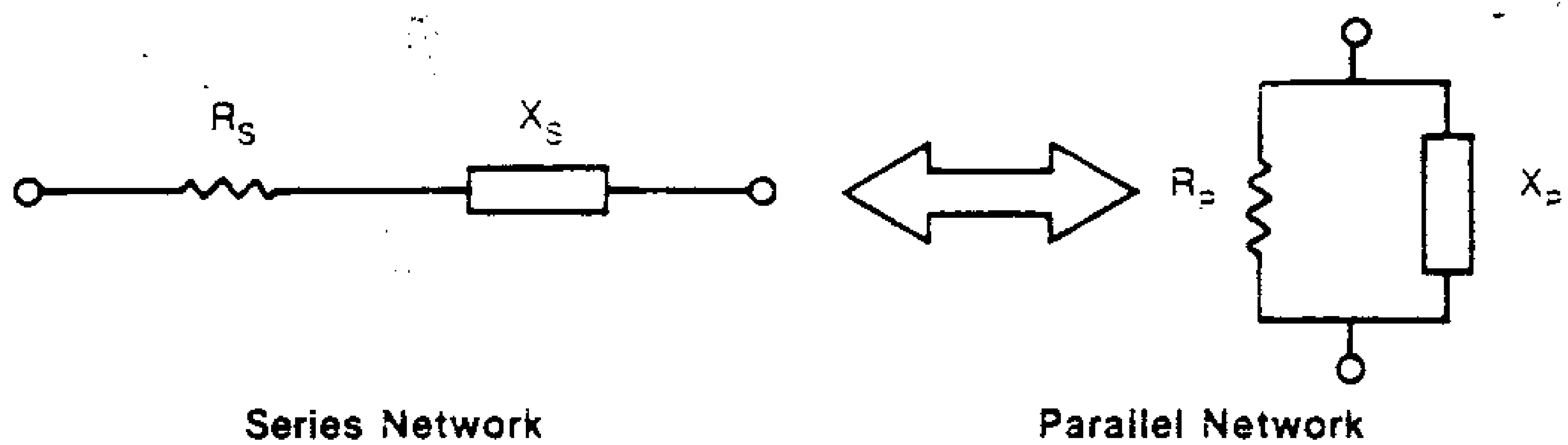
Example

Determine the active filter component values for a phase-locked loop with the following specifications. The loop must achieve a lock so that $A_0(t)$ is within 10% of its final value after 500 milliseconds with a damping factor(g*) of 0.5. From the curves below, where the normalized output response, $A_0(t)$, is plotted as a function of the normalized time (wnt*), g* = 0.5 is within 10% at w0t* = 4.5. Thus, wn* = 4.5/.5 = 9 radians/second.



Series/Parallel Impedance Conversions—"SP"

This program converts a two-element series impedance network to an equivalent two-element parallel impedance network, or vice-versa. The conversion is illustrated in the following diagram.



Any two-element impedance network can be represented equivalently as a series network or a parallel network.

The transformation equations are

Given R_S and X_S

$$R_P = R_S + \frac{X_S^2}{R_S}$$

$$X_P = \frac{R_P R_S}{X_S}$$

Given R_P and X_P

$$R_S = \left(\frac{1}{R_P} + \frac{R_P}{X_P^2}\right)^{-1}$$

$$X_S = \frac{R_S R_P}{X_P}$$

User Instructions—Series/Parallel Conversion

Select the Series/Parallel Conversion program by entering **RUN "SP"**.

Step	Display	Procedure/Comment	Goto
1.	SERIES/PARALLEL CONVERSION	Program name.	2
2.	Use Printer?	a. Accept printer usage by entering **Y**. b. Reject printer usage by entering **N**.	3 4
3.	Enter Device Name:	Enter the output device name.	4
4.	Convert S --> P?	a. Convert from series to parallel by entering **Y**. b. Display next option by entering **N**.	5 9
5.	Enter Rs:	Enter series resistance in ohms.	6
6.	Enter Xs:	Enter series reactance in ohms.	7
7.	Rp=	Displays parallel resistance in ohms. Proceed by pressing **[ENTER]**.	8
8.	Xp=	Displays parallel reactance in ohms. Proceed by pressing **[ENTER]**.	14
9.	Convert P --> S?	a. Convert from parallel to series by entering **Y**. b. Continue program by entering **N**.	10 14
10.	Enter Rp:	Enter parallel resistance in ohms.	11
11.	Enter Xp:	Enter parallel reactance in ohms.	12
12.	Rs=	Displays series resistance in ohms. Proceed by pressing **[ENTER]**.	13
13.	Xs=	Displays series reactance in ohms. Proceed by pressing **[ENTER]**.	14
14.	Exit Program?	a. Exit program by entering **Y**. b. Continue program by entering **N**.	STOP 4

Example 1

A 1375 ohm resistance is in series with a 331.67 ohm reactance. Determine the equivalent parallel network.

Select the Series/Parallel Conversion program by entering **RUN "SP"**.

Step	Display	Procedure/Comment
1.	SERIES/PARALLEL CONVERSION	Program name.
2.	Use Printer?	Enter **N**.
3.	Convert S --> P?	Enter **Y**.
4.	Enter Rs: 0	Enter **1375**.
5.	Enter Xs: 0	Enter **331.67**.
6.	Rp= 1455.003628	Displays parallel resistance in ohms. Proceed by pressing **[ENTER]**.
7.	Xp= 6031.989595	Displays parallel reactance in ohms. Proceed by pressing **[ENTER]**.
8.	Exit Program?	Enter **Y**.

Example 2

A 75 ohms resistance is in parallel with a 50.929582 ohm reactance. Determine the equivalent series network.

Select the Series/Parallel Conversion program by entering **RUN "SP"**.

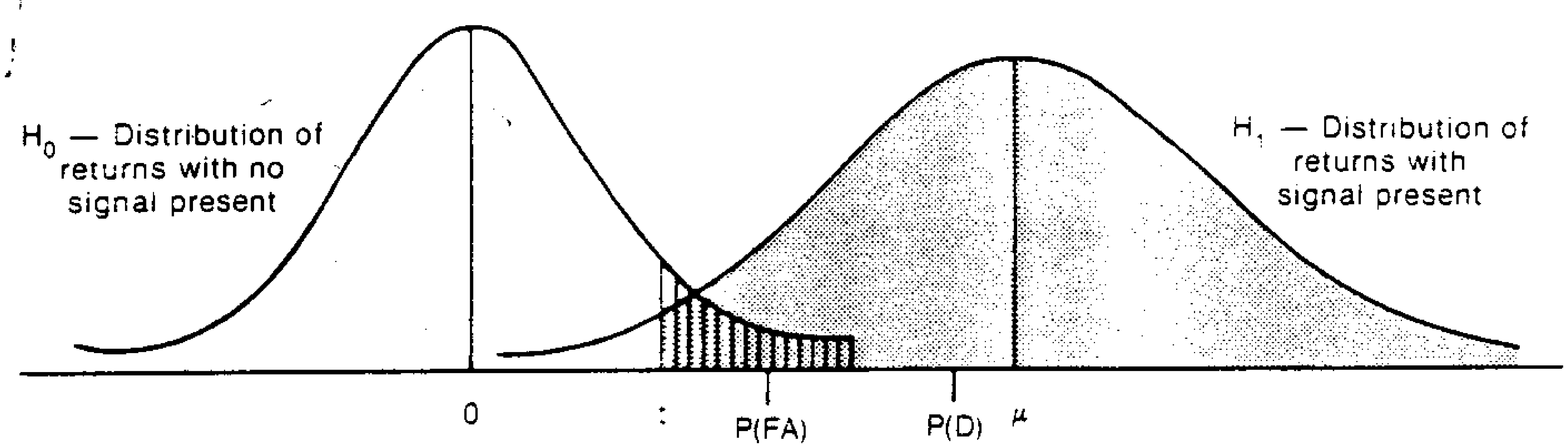
Step	Display	Procedure/Comment
1.	SERIES/PARALLEL CONVERSION	Program name.
2.	Use Printer?	Enter **N.**
3.	Convert S -->P?	Enter **N.**
4.	Convert P -->S?	Enter **Y.**
5.	Enter Rp: 0	Enter **75.**
6.	Enter Xp: 0	Enter **50.929582.**
7.	Rs= 23.66965321	Displays series resistance in ohms. Proceed by pressing **[ENTER]**.
8.	Xs= 34.85644141	Displays series reactance in ohms. Proceed by pressing **[ENTER]**.
9.	Exit Program?	Enter **Y.**

Signal Detection—"SIGNAL"

There are circumstances in which you must decide if an information bearing signal is present in the midst of noise. This program uses the relationship between the areas under two overlapping normal curves to determine the probability of falsely declaring a signal present when none exists (probability of a false alarm), as well as the probability of properly declaring a signal present (probability of detection).

This program is stated in terms of radar detection. However, this procedure applies to all problems of this type. The radar return to a given range cell is subject to both internally and externally generated noise. Under most conditions this return is approximately normally distributed about a mean we may take to be 0 with a standard deviation σ_0. This normal curve is referred to as H_0.

The presence of a point target in this range cell alters the mean and standard deviation of the normal distribution H_0. This new mean is referred to as m and the new standard deviation as σ_1. This new normal distribution is referred to as H_1.



Let t represent a threshold value which you may vary. When the signal strength is greater than t, a signal is declared present. When the signal strength is less than t, no signal is declared present. The area under H_0 to the right of t represents the probability of a false alarm P(FA), and the area under H_1 to the left of t represents the probability of detection, P(D).

The signal-to-noise ratio (in dB) may be defined as

$$SNR = 20 \log_{10} (\mu/\sigma_0)$$

Once $\sigma_1/\ \sigma_0$ has been entered, this program calculates

1. SNR given P(FA) and the P(D).
2. P(FA) given P(LD) and SNR.
3. P(D) given P(FA) and SNR.

Method Used—Signal Detection

SIGNAL DETECTION FORMULAS

Let U represent the normalized values for X for the normal curve in question.

1. $$P(D) = \frac{1}{\sqrt{2\pi}} \int_{U_{P(D)}}^{\infty} e^{-t^2/2}\, dt$$

2. $$P(FA) = \frac{1}{\sqrt{2\pi}} \int_{U_{P(FA)}}^{\infty} e^{-t^2/2}\, dt$$

3. $$U_{P(FA)} = \frac{X_{P(FA)}}{\sigma_0} = \frac{X_{P(D)}}{\sigma_0}$$

4. $$U_{P(D)} = \frac{\dfrac{X_{P(D)}}{\sigma_0} - \dfrac{\mu}{\sigma_0}}{\dfrac{\sigma_1}{\sigma_0}}$$

5. $U_{P(FA)} = \frac{X_{P(FA)}}{\sigma_0} = U_{P(D)} \frac{\sigma_1}{\sigma_0} + \frac{\mu}{\sigma_0}$

6. $SNR = 20 \log_{10}\left(\frac{\mu}{\sigma_0}\right)$

7. $\frac{\mu}{\sigma_0} = 10^{SNR/20}$

Find SNR given P(FA) and P(D)

1. Calculate $U_{P(D)}$ from Formula 1.
2. Calculate $U_{P(D)} \frac{\sigma_1}{\sigma_0}$.
3. Calculate $U_{P(FA)}$ from Formula 2.
4. Calculate $\frac{\mu}{\sigma_0}$ from Formula 4 using relationship in Formula 3.
5. Calculate SNR from Formula 6.

Find P(FA) given P(D) and SNR

1. Calculate $U_{P(D)}$ from Formula 1.
2. Calculate $U_{P(D)} \frac{\sigma_1}{\sigma_0}$.
3. Calculate $\frac{\mu}{\sigma_0}$ from Formula 7.
4. Calculate $U_{P(FA)}$ from Formula 5.
5. Calculate P(FA) from Formula 2.

Find P(D) given P(FA) and SNR

1. Calculate $U_{P(FA)}$ from Formula 2.
2. Calculate $\frac{\mu}{\sigma_0}$ from Formula 7.
3. Calculate $\frac{X_{P(D)}}{\sigma_0} - \frac{\mu}{\sigma_0}$ using relationship in Formula 3.
4. Calculate $U_{P(D)}$ from Formula 4.
5. Calculate P(D) from Formula 1.

METHOD USED FOR INTEGRAL EVALUATION

$$P(U) = \frac{1}{\sqrt{2\pi}} \int_{\infty}^{U} e^{-t^2/2}\, dt$$

$$P(U) \approx 1 - Z(U)\,(a_1 t + a_2 t^2 + a_3 t^3) + \epsilon(U)$$

$$Q(U) = \frac{1}{\sqrt{2\pi}} \int_{U}^{\infty} e^{-t^2/2}\, dt = 1 - P(U)$$

$$Q(U) \approx Z(U)\,(a_1 t + a_2 t^2 + a_3 t^3) + \epsilon(U)$$

where:

$$Z(U) = \frac{1}{\sqrt{2\pi}}\, e^{-U^2/2}$$

$$t = (1 + pU)^{-1}$$

$p = .33267$

$a_1 = .4361836$

$a_2 = -.1201676$

$a_3 = .9372980$

$|\epsilon(U)| < 1 \times 10^{-5}$

METHOD USED FOR FINDING U_P WHEN THE PROBABILITY (P) IS GIVEN

$$P = Q(U_P) = \frac{1}{\sqrt{2\pi}} \int_{U_P}^{\infty} e^{-t^2/2}\, dt$$

$$U_P \approx t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3} + \epsilon(P)$$

where:

$t = \left(\ln \frac{1}{P^2}\right)^{1/2}$ $\qquad d_1 = 1.432788$

$c_0 = 2.515517$ $\qquad d_2 = .189269$

$c_1 = .802853$ $\qquad d_3 = .001308$

$c_2 = .010328$ $\qquad |\epsilon(P)| < 4.5 \times 10^{-4}$

Reference: *Handbook of Mathematical Functions*, Abramowitz and Stegun, National Bureau of Standards, 1964.

User Instructions—Signal Detection

Select the Signal Detection program by entering **RUN "SIGNAL"**.

Step	Display	Procedure/Comment	Goto
1.	SIGNAL DETECTION	Program name.	2
2.	Use Printer?	a. Accept printer usage by entering **Y.**	3
		b. Reject printer usage by entering **N.**	4
3.	Enter Device Name:	Enter the output device name.	4
4.	Compute for P(FA)?	a. Compute for P(FA) by entering **Y.**	5
		b. Display next option by entering **N.**	9
5.	Enter S1/S0:	Enter the ratio of standard deviations.[1]	6
6.	Enter P(D):	Enter the probability of detecting a signal.[2]	7
7.	Enter SNR:	Enter the signal-to-noise ratio (dB).	8
8.	P(FA)=	Displays the probabilty of false alarm. Proceed by pressing **[ENTER]**.	19
9.	Compute for P(D)?	a. Compute for P(D) by entering **Y.**	10
		b. Display next option by entering **N.**	14
10.	Enter S1/S0:	Enter the ratio of standard deviations.[1]	11
11.	Enter P(FA):	Enter the probability of declaring a signal present when none exists.[2]	12
12.	Enter SNR:	Enter the signal-to-noise ratio (dB).	13
13.	P(D)=	Displays the probability of detection. Proceed by pressing **[ENTER]**.	19
14.	Compute for SNR?	a. Compute for SNR by entering **Y.**	15
		b. Continue program by entering **N.**	19
15.	Enter S1/S0:	Enter the ratio of standard deviations.[1]	16

(continued)

(continued)

Step	Display	Procedure/Comment	Goto
16.	Enter P(FA):	Enter the probability of declaring a signal present when none exists.[2]	17
17.	Enter P(D):	Enter the probability of detecting a signal.[2]	18
18.	SNR=	Displays the signal-to-noise ratio. Proceed by pressing **[ENTER]**.	19
19.	Exit Program?	a. Exit program by entering **Y**. b. Continue program by entering **N**.	STOP 4

Notes

1. S1/S0 must be > 0.
2. Probabilities must be > 0 and < 1.

Example 1

For $S_1 = SQR(2)\ S_0$, what is the false alarm probability when the threshold is set for a detection probability of 0.9 and the signal-to-ratio is 10 dB.

Select the Signal Detection program by entering **RUN "SIGNAL"**.

Step	Display	Procedure/Comment
1.	SIGNAL DETECTION	Program name.
2.	Use Printer?	Enter **N**.
3.	Compute for P(FA)?	Enter **Y**.
4.	Enter S1/S0: 0	Enter **SQR(2)**.
5.	Enter P(D): 0	Enter **.9**.
6.	Enter SNR: 0	Enter **10**.
7.	P(FA)= .0885568121	Displays the probability of false alarm. Proceed by pressing **[ENTER]**.
8.	Exit Program?	Enter **Y**.

Example 2

For $S_1 = 2\ S_0$ and a signal-to-noise ratio of 20 dB, what is the probability of detection if the probability of a false alarm is set at 1E – 9.

Select the Signal Detection program by entering **RUN "SIGNAL"**.

Step	Display	Procedure/Comment
1.	SIGNAL DETECTION	Program name.
2.	Use Printer?	Enter **N.**
3.	Compute for P(FA)?	Enter **N.**
4.	Compute for P(D)?	Enter **Y.**
5.	Enter S1/S0: 0	Enter **2.**
6.	Enter P(FA): 0	Enter **1E – 9.**
7.	Enter SNR: 0	Enter **20.**
8.	P(D)= .9773102447	Displays the probability of detection. Proceed by pressing **[ENTER]**.
9.	Exit Program?	Enter **Y.**

S<—>Y, Z, H, G Parameter Conversions—"SY"

Small-signal, two-port "black boxes" are often characterized in terms of complex scattering (S) parameters with a characteristic input and output transmission line impedance Z_0. The translation of these parameters to admittance (Y) parameters, impedance (Z) parameters, hybrid (H) and (G) parameters is necessary to create equivalent circuit models. This program converts S parameters to Y, Z, H, G or vice-versa.

$$M_{11} = bf[\frac{2}{D}(1 + ag\ A_{22}) - 1] \qquad M_{22} = bh[\frac{2}{D}(1 + ae\ A_{11}) - 1]$$

$$M_{12} = \frac{cdgh\ 2\ A_{12}}{D} \qquad D = (1 + ae\ A_{11})\ (1 + ag\ A_{22}) - (eg\ A_{12}\ A_{21})$$

$$M_{21} = \frac{cdef\ 2\ A_{21}}{D}$$

This set of equations is valid for Y, Z, H, and G parameters if they are normalized to Z_0.

	a	b	c	d	e	f	g	h
S-Z	−1	1	1	1	1	1	1	1
Z-S	1	−1	1	1	1	1	1	1
S-Y	1	1	−1	1	1	1	1	1
Y-S	1	1	1	−1	1	1	1	1
S-H	1	1	1	1	−1	1	1	1
H-S	1	1	1	1	1	−1	1	1
S-G	1	1	1	1	1	1	−1	1
G-S	1	1	1	1	1	1	1	−1

Parameter Normalizer

$Z_{11} = z_{11}\ Z_0$,	$Z_{12} = z_{12}\ Z_0$,	$Z_{21} = z_{21}\ Z_0$,	$Z_{22} = z_{22}\ Z_0$,
$z_{11} = Z_{11}/Z_0$,	$z_{12} = Z_{12}/Z_0$,	$z_{21} = Z_{21}/Z_0$,	$z_{22} = Z_{22}/Z_0$,
$Y_{11} = y_{11}/Z_0$,	$Y_{12} = y_{12}/Z_0$,	$Y_{21} = y_{21}/Z_0$,	$Y_{22} = y_{22}/Z_0$,
$y_{11} = Y_{11}\ Z_0$,	$y_{12} = Y_{12}\ Z_0$,	$y_{21} = Y_{21}\ Z_0$,	$y_{22} = Y_{22}\ Z_0$,
$H_{11} = h_{11}\ Z_0$,	$H_{12} = h_{12}\ Z_0$,	$H_{21} = h_{21}\ Z_0$,	$H_{22} = h_{22}\ Z_0$,
$h_{11} = H_{11}/Z_0$,	$h_{12} = H_{12}$,	$h_{21} = H_{21}$,	$h_{22} = H_{22}$,
$G_{11} = g_{11}/Z_0$,	$G_{12} = g_{12}$,	$G_{21} = g_{21}$,	$G_{22} = g_{22}$,
$g_{11} = G_{11}\ Z_0$,	$g_{12} = G_{12}$,	$g_{21} = G_{21}$,	$g_{22} = G_{22}/Z_0$,

When converting from S to Y, Z, H or G parameters, the normalization operations are performed after the matrix elements are calculated to give the actual parameters. When converting from Y, Z, H or G parameters to S, the normalization operations are performed before the matrix elements are calculated to give the actual S parameters. (Default for $Z_0 = 50$ ohms. Z_0 is a real quantity.)

User Instructions—S<—>Y, Z, H, G Parameter Conversions

Select the S<—>Y, Z, H, G Conversion program by entering **RUN "SY"**.

Step	Display	Procedure/Comment	Goto
1.	S <--> Y, Z, H, G	Program name.	2
2.	Use Printer?	a. Accept printer usage by entering **Y**.	3
		b. Reject printer usage by entering **N**.	4
3.	Enter Device Name:	Enter the output device name.	4
4.	Convert From S?	a. Convert from S by entering **Y**.[2]	5
		b. Display next option by entering **N**.	6
5.	Enter To; 1-Y 2-Z 3-H 4-G:	Select which option to convert to by entering the option number.	8
6.	Convert To S?	a. Convert to S by entering **Y**.[1]	7
		b. Continue program by entering **N**.	48
7.	Enter From; 1-Y, 2-Z, 3-H, 4-G:	Select which option to convert from by entering the option number.	8
8.	(r,e) Form?	a. Input data in magnitude, angle form by entering **Y**.	9
		b. Display next option by entering **N**.	19
9.	Enter Zo:	Enter the real characteristic impedance.	10
10.	Enter w(1,1) r:	Enter the magnitude of parameter.	11
11.	Enter w(1,1) e:	Enter the angle of parameter in degrees.	12
12.	Enter w(1,2) r:	Enter the magnitude of parameter.	13
13.	Enter w(1,2) e:	Enter the angle of parameter in degrees.	14
14.	Enter w(2,1) r:	Enter the magnitude of parameter.	15
15.	Enter w(2,1) e:	Enter the angle of parameter in degrees.	16
16.	Enter w(2,2) r:	Enter the magnitude of parameter.	17

(continued)

(continued)

Step	Display	Procedure/Comment	Goto
17.	Enter w(2,2) e:	Enter the angle of parameter in degrees.	18
18.	Edit?	a. Edit data by entering **Y.** b. Accept data by entering **N.**	9 30
19.	a+bj Form?	a. Input data in rectangular form by entering **Y.** b. Display next option by entering **N.**	20 8
20.	Enter Zo:	Enter the real characteristic impedance.	21
21.	Enter w(1,1) a:	Enter the real part of parameter.	22
22.	Enter w(1,1) b:	Enter the imaginary part of parameter.	23
23.	Enter w(1,2) a:	Enter the real part of parameter.	24
24.	Enter w(1,2) b:	Enter the imaginary part of parameter.	25
25.	Enter w(2,1) a:	Enter the real part of parameter.	26
26.	Enter w(2,1) b:	Enter the imaginary part of parameter.	27
27.	Enter w(2,2) a:	Enter the real part of parameter.	28
28.	Enter w(2,2) b:	Enter the imaginary part of parameter.	29
29.	Edit?	a. Edit data by entering **Y.** b. Accept data by entering **N.**	20 30
30.	Print in (r,e) Form?	a. Print in (r,e) form by entering **Y.** b. Display next option by entering **N.**	31 39
31.	x(1,1) r=	Displays magnitude of parameter. Proceed by pressing **[ENTER]**.	32
32.	x(1,1) e=	Displays angle of parameter. Proceed by pressing **[ENTER]**.	33
33.	x(1,2) r=	Displays magnitude of parameter. Proceed by pressing **[ENTER]**.	34

(continued)

Step	Display	Procedure/Comment	Goto
34.	`x(1,2) e=`	Displays angle of parameter. Proceed by pressing [ENTER].	35
35.	`x(2,1) r=`	Displays magnitude of parameter. Proceed by pressing [ENTER].	36
36.	`x(2,1) e=`	Displays angle of parameter. Proceed by pressing [ENTER].	37
37.	`x(2,2) r=`	Displays magnitude of parameter. Proceed by pressing [ENTER].	38
38.	`x(2,2) e=`	Displays angle of parameter. Proceed by pressing [ENTER].	48
39.	`Print in a+bj Form?`	a. Print in a + bj form. b. Display next option.	40 30
40.	`x(1,1) a=`	Displays real part of parameter. Proceed by pressing [ENTER].	41
41.	`x(1,1) b=`	Displays imaginary part of parameter. Proceed by pressing [ENTER].	42
42.	`x(1,2) a=`	Displays real part of parameter. Proceed by pressing [ENTER].	43
43.	`x(1,2) b=`	Displays imaginary part of parameter. Proceed by pressing [ENTER].	44
44.	`x(2,1) a=`	Displays real part of parameter. Proceed by pressing [ENTER].	45
45.	`x(2,1) b=`	Displays imaginary part of parameter. Proceed by pressing [ENTER].	46
46.	`x(2,2) a=`	Displays real part of parameter. Proceed by pressing [ENTER].	47

(continued)

(continued)

Step	Display	Procedure/Comment	Goto
47.	x(2,2) b=	Displays imaginary part of parameter. Proceed by pressing **[ENTER]**.	48
48.	Exit Program?	a. Exit program by entering **Y**. b. Continue program by entering **N**.	STOP 4

Notes

1. If converting to S, w is either Y, Z, H, or G, whichever you have chosen; x is S.
2. If converting from S, w is S; x is either Y, Z, H, or G, whichever you have chosen.

Example

Convert the following S parmeters to Y parameters.

$S_{11} = .1\angle 50°$, $S_{12} = .2\angle 55°$, $S_{21} = .3\angle 60°$, and $S_{22} = .4\angle 65°$

$Z_0 = 50$ ohms

Select the S <--> Y, Z, H, G Converion program by entering **RUN "SY"**.

Step	Display	Procedure/Comment
1.	S <--> Y, Z, H, G	Program name.
2.	Use Printer?	Enter **N**.
3.	Convert from S?	Enter **Y**.
4.	Enter To; 1-Y 2-Z 3-H 4-G:	Enter **1**.
5.	(r,e) Form?	Enter **Y**.
6.	Enter Zo: 50	Accept current value by pressing **[ENTER]**.
7.	Enter S(1,1) r: 0	Enter **.1**.
8.	Enter S(1,1) e: 0	Enter **50**.

(continued)

(continued)

Step	Display	Procedure/Comment
9.	Enter S(1,2) r: 0	Enter **.2**.
10.	Enter S(1,2) e: 0	Enter **55**.
11.	Enter S(2,1) r: 0	Enter **.3**.
12.	Enter S(2,1) e: 0	Enter **60**.
13.	Enter S(2,2) r: 0	Enter **.4**.
14.	Enter S(2,2) e: 0	Enter **65**.
15.	Edit?	Enter **N**.
16.	Print in (r,e) Form?	Enter **Y**.
17.	Y(1,1) r= .0173534572 Y(1,1) e= -3.227794565 Y(1,2) r= .0061012628 Y(1,2) e= -143.7282528 Y(2,1) r= .0091518942 Y(2,1) e= -138.7282528 Y(2,2) r= .0141294793 Y(2,2) e= -35.53169433	Displays all requested values. Proceed after each output by pressing **[ENTER]**.
18.	Exit Program?	Enter **Y**.

Appendix—Subprograms

Many of the routines used in the programs of this library are developed as independent subprograms. These subprograms may be accessed for use in developing your own BASIC programs by calling the subprogram with its assigned arguments.

Refer to the Compact Computer *User's Guide* for details on the restrictions and requirements for use of subprograms.

The special format used for presentation of subprograms in this appendix provides all of the information necessary for you to select and run the subprograms which you need in your own BASIC program. There are three possible sections within the discussion of each subprogram: Description; Format; and Example. To insure proper execution of the subprograms, these sections should be read thoroughly before running the subprograms.

Description	briefly describes the routine which the subprogram performs.
Format	illustrates the format necessary for calling the subprogram and identifies the requirements, restrictions, and purpose of each element in the argument list.
Example	provides the procedure and comments for actual execution of the subprogram.

AU

Description

Input and edit a one dimensional array.

Format

CALL AU(TABPOS,PROMPT$,ARRAY( ),FIRST,LAST,NUMELEM,DEVICE)

TABPOS	Position to tab when printing the input value. Only used with a printer.
PROMPT$	Pass in the name or description of the array to be displayed preceding the subscript.
ARRAY( )	Pass in the array name used in program with no arguments.
FIRST	Pass in the first array element to be entered.
LAST	Pass in the last array element to be entered.
NUMELEM	Pass in the numer of elements actually entered.
DEVICE	Pass in the device number of output device. If DEVICE = 0, output is not printed.

You can enter a maximum of LAST − FIRST + 1 elements. The input routine can be ended by entering E when you are prompted for an element. You are then asked if you wish to edit the array. If you do not, the subprogram passes control back to the calling program. If you do, the subprogram allows editing of only the elements previously entered with the option of editing any or all of them.

Example

CALL AU(9,"NUMBER",A,(),1,5,N,PN)

1. Inputs into the array A( ) from elements 1 through 5 inclusive, or until you enter **E**, with the following prompt

```
Enter ''E'' to end input
Enter NUMBER(X):
```

   where X goes from 1 to 5.

2. After entry, you are prompted for editing by

```
Edit?
```

   An **N** response returns control to the calling routine.

   A **Y** response prompts

```
Edit all Data?
```

A **Y** response allows reentry of all previously entered elements. Execution then returns to step 2.

An **N** response continues at step 3.

3. The subprogram prompts

```
Enter element to be edited:
```

Enter the specific element number to be edited. It must also be one of the array elements previously entered. After editing the element, the subprogram prompts

```
Edit more elements?
```

A **Y** response continues execution at step 3.

An **N** response returns control to the calling program.

IR

Description

Input a number.

Format

CALL IR(TABPOS,PROMPT$,VARIABLE,DEVICE)

TABPOS	Position to tab when printing the input value. Only used with a printer.
PROMPT$	Pass in a prompt describing the variable being asked for.
VARIABLE	Returns the value entered.
DEVICE	Pass in the output device number.

Example

CALL IR(15,"Future Value",FV,PN)

1. The subprogram asks for input with the prompt

   ```
   Enter Future Value: X
   ```

   where X is the current value of FV.

2. After input, the value of PN is checked. If it is 0, control returns to the calling program. If PN 0, the prompt, along with the entered number, are printed on device #PN.

   ```
   Future Value=X
   ```

PR

Description

Convert polar to rectangular.

Format

CALL RP(R,E,X,Y)

R	Pass in the magnitude.
E	Pass in the angle.
X	Returns the X coordinate.
Y	Returns the Y coordinate.

Example

```
R=38
E=23.5
CALL RP(R,E,X,Y)
```

X is returned as 44.6794136 and Y is returned as 31.73351915.

RP

Description

Convert rectangular to polar.

Format

CALL RP(X,Y,R,E)

X	Pass in the X coordinate.
Y	Pass in the Y coordinate.
R	Returns the magnitude.
E	Returns the angle.

Example

```
X=45
Y=31.6
CALL RP(X,Y,R,E)
```

R is returned as 38.32771204 and E is returned as 23.57936577.

UP

Description

Ask to use printer.

Format

CALL UP(NAME$,DEVICE)

NAME$	Pass in the name of program to be displayed for 3 seconds.
DEVICE	Returns the device number of the opened output device. A device number of 0 indicates output will appear on the display, while a device number of 1 indicates the requested output device was opened as device #1.

Example

CALL UP("DATA FORECASTING",PN)

1. The name `DATA FORECASTING` appears in the display for three seconds.
2. The subprogram then prompts

   `Use Printer?`

   An **N** response exits the subprogram with PN = 0.

   A **Y** response causes the subprogram to prompt

   `Enter Device Name:`

   The entered device is opened under device number 1, setting PN = 1. The subprogram returns control to the calling program.

YN

Description

Ask a yes/no question.

Format

CALL YN(QUESTION$,ANSWER,DEVICE)

QUESTION$	Pass in the question to be asked with no question mark.
ANSWER	Returns ANSWER = 0 when "N" is chosen, or returns ANSWER = − 1 when Y chosen.
DEVICE	Pass in device number. If device number is zero, nothing is printed. If the device number is greater than zero, QUESTION$ is printed on the device.

Example

CALL YN("Edit",D,PN)

The question `Edit?` is displayed.

A **Y** response sets D = − 1 and prints the question, less the question mark, on device #PN.

An **N** response sets D = 0. Control is then passed back to the calling program.

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