HEWLETT hp PACKARD

HP-65

E.E. PAC 1

SEPTEMBER, 1974

HEWLETT hp PACKARD

Sales and service from 172 offices in 65 countries.
19310 Pruneridge Avenue, Cupertino, California 95014

00065-90214 Rev. 9/74

LES BELL

Addendum

HP-65 EE PAC

This addendum contains information correcting three programs in the HP-65 EE Pac 1.

Chebyshev Filter (EE1–14A). In the equation for b_i on page 47, γ should be squared.

Inductance of a Single-Layer Close-Wound Coil (EE1–17A). The variable R on page 52 should be defined as "radius of coil to center of wire in inches."

Skin Effect and Coil Q (EE1–18A). The expression for Q on page 54 yields answers too large by a factor of 1000. Change the constant in the equation from 25.59 to .0256. Change the answer on page 55 from $Q = 1.08 \times 10^5$ to $Q = 1.08 \times 10^2$. Change the program listing on page 128 as follows:

Step	Change from		Change to	
67	02	2	83	•
68	05	5	00	0
69	83	•	02	2
70	05	5	05	5
71	09	9	06	6

(continued on back of card)

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CONTENTS

INTRODUCTION

Programs for the HP-65 Electrical Engineering Pac I were selected to cover a broad range of electrical engineering applications. There are programs for impedance matching, filter design, transmission line calculations, parameter conversion, power supply design, transistor biasing, control system analysis, waveform analysis, and wire tables.

Electrical Engineering Pac I includes 40 pre-recorded magnetic cards, a card case, 20 pocket instruction cards, and an instruction booklet with program descriptions, formulas, example problems, user instructions and program listings.

Through the Users' Library and electrical engineering pac development, Hewlett-Packard hopes to provide useful programs for the many fields within electrical engineering. We hope you find Electrical Engineering Pac I a useful tool, and we welcome your comments and suggestions.

FORMAT OF USER INSTRUCTIONS

The completed User Instruction Form is your guide to operating the programs in this Pac.

The form is composed of five labeled columns. Reading from left to right, the first column, labeled STEP, gives the instruction step number.

The INSTRUCTIONS column gives instructions and comments concerning the operations to be performed.

The INPUT-DATA/UNITS column specifies the input data, and the units of data if applicable. Data input keys consist of the numeric keys [0] to [9], [•] (decimal point), [EEX] (enter exponent), and [CHS] (change sign).

The KEYS column specifies the keys to be pressed. All key designations are identical to those appearing on the HP-65. Ignore any blank spaces in the KEYS columns.

The OUTPUT-DATA/UNITS column specifies intermediate and final outputs and their units where applicable.

The following is an example of the User Instruction Form for Program EE1–09A, PI Network Impedance Matching.

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	Enter program				
2	Initialize		RTN	R/S	0.0000×10^0
3	Inputs				
	Input impedance	Z_1, Ω	E	A	
	Output impedance	Z_2, Ω	A		
	Frequency	f, Hz	E	B	
	Quality factor	Q	B		
4	Outputs				
	Input capacitor		E	C	C_1, F
	Output capacitor		C		C_2, F
	Inductor		D		L, H
5	Recall inputs (optional)				
	Input impedance		RCL	1	Z_1, Ω
	Output impedance		RCL	2	Z_2, Ω
	Frequency		RCL	3	f, Hz
	Quality factor		RCL	4	Q
6	For new case, return to step 3.				

Step 1: The first step in all programs is to enter the prerecorded magnetic card into the HP-65 (see *Entering a Program,* page 7).

Step 2: The initialization step clears certain registers, if necessary, and sets an appropriate display format. After initialization, the user may select another display format if desired. Most programs contain an initialization routine which is executed by pressing RTN, R/S. When there was no room for such a routine, the user instructions indicate an alternate method of initialization (if necessary).

Step 3: In this step, the known values are input. In this case there were so many knowns and unknowns that it was necessary to program key E as a shift key to double the functions of the remaining four keys. The data may be input in arbitrary order. (In some cases the user instruction form designates a particular order for data input or output).

Step 4: In this step of the example the order in which the output data is computed and displayed is unimportant. However, it is a good practice to output data in the same order as shown on the User Instruction Form.

Step 5: In this step the input data previously stored may be recalled for inspection. Circled numbers on the magnetic card indicate the registers in which data is stored.

Step 6: This step gives instructions for starting a new case. In this example, return to Step 3.

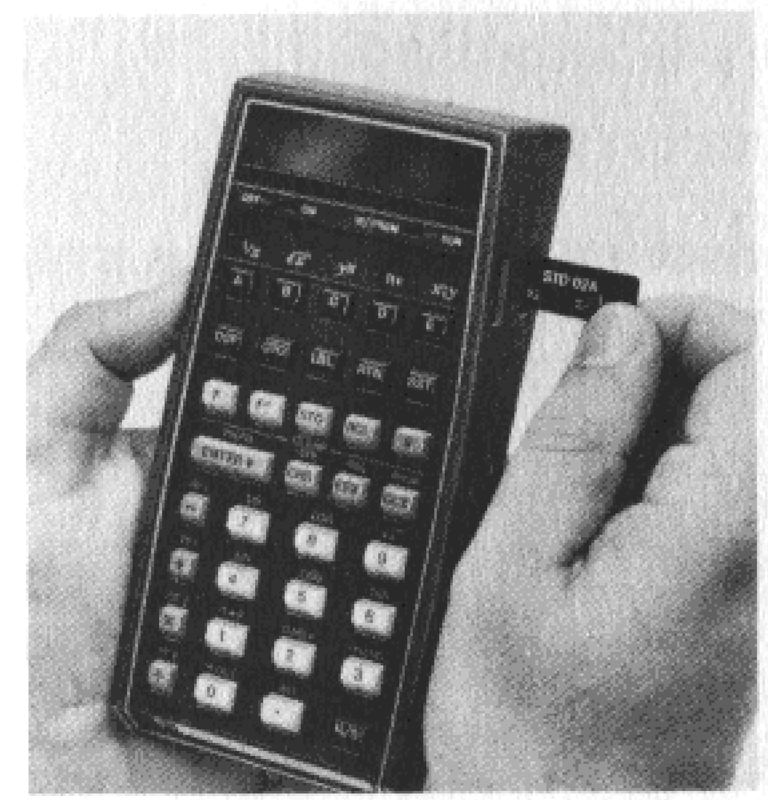
ENTERING A PROGRAM

From the card case supplied with this application pac, select a program card.

Set W/PRGM-RUN switch to RUN.

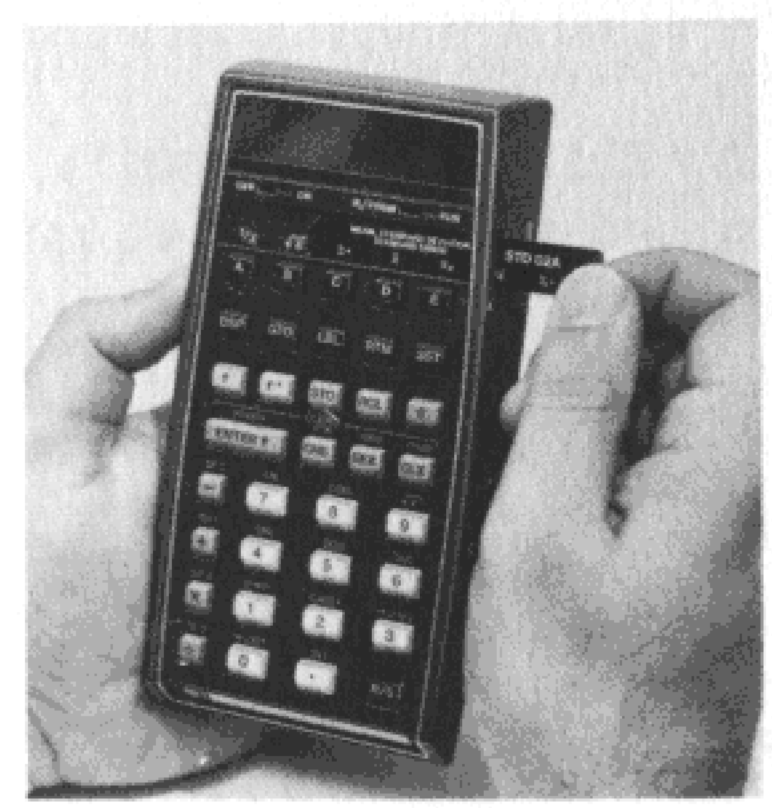
Turn the calculator ON. You should see 0.00

Gently insert the card (printed side up) in the right, lower slot as shown. When the card is part way in, the motor engages it and passes it out the left side of the calculator. Sometimes the motor engages but does not pull the card in. If this happens, push the card a little farther into the machine. Do not impede or force the card; let it move freely. (The display will flash if the card reads improperly. In this case, press [CLX] and reinsert the card.)



When the motor stops, remove the card from the left side of the calculator and insert it in the upper "window slot" on the right side of the calculator.

The program is now stored in the calculator. It remains stored until another program is entered or the calculator is turned off.



REACTANCE CHART

	REACTANCE CHART			EE 1-01A		
f①	C②	L③	CALC X_C X_L	↑		

This program provides a means of determining the missing value in the relation

$$f = \frac{1}{2\pi\sqrt{LC}}$$

where

f = resonant frequency in hertz

L = inductance in henrys

C = capacitance in farads

when any two values are known. It can also be used to find the reactance of an element at a given frequency:

$$X_C = \frac{1}{2\pi fC}$$

$$X_L = 2\pi fL$$

where X_C = capacitive reactance in Ω

X_L = inductive reactance in Ω

Examples:

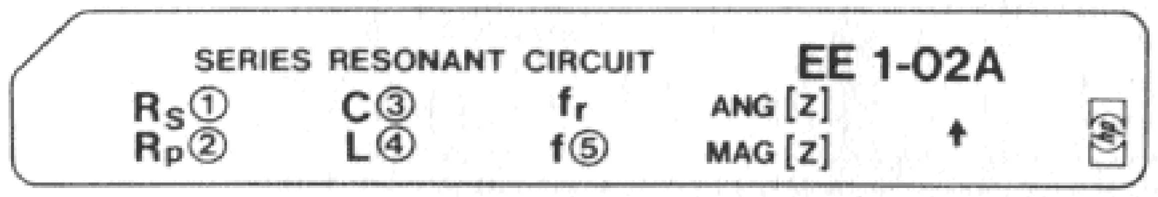
1. C = 100 pF
   f = 100 MHz
   Calculate L = 25.33 nH (2.5330×10^{-8})
   X_C = –15.915 Ω (-1.5915×10^{1})

2. L = 2.5 H
   f = 60 Hz
   Calculate C = 2.8145 μF (2.8145×10^{-6})
   X_L = 942.48 Ω (9.4248×10^{2})

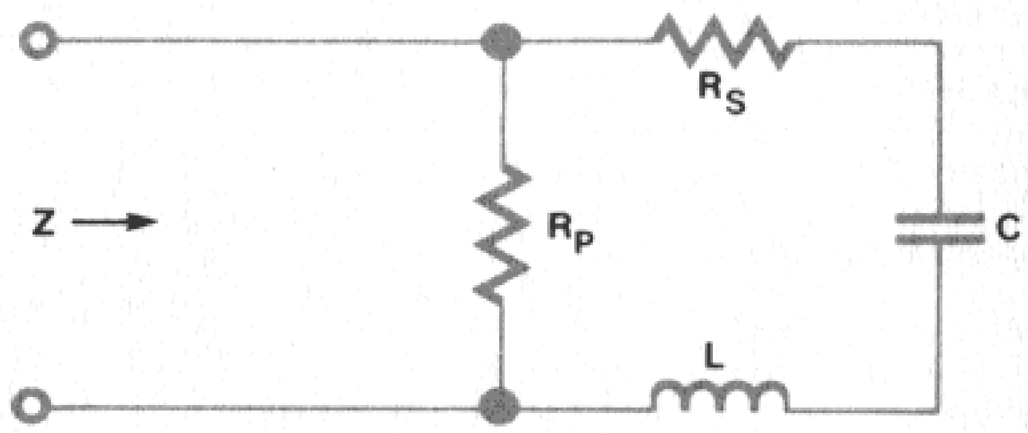
3. C = 0.01 μF
   L = 160 μH
   Calculate f = 125.82 kHz (1.2582×10^{5})

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	Enter program				
2	Initialize		RTN	R/S	
3	Input knowns (any 2)				
	Frequency	f, Hz	A		$(2\pi f)^{-2}$
	Capacitance	C, F	B		
	Inductance	L, H	C		
4	Compute unknown				
	Frequency		E	A	f, Hz
	Capacitance		E	B	C, F
	Inductance		E	C	L, H
	Capacitive reactance*		E	D	X_C, Ω
	Inductive reactance*		D		X_L, Ω
5	Recall inputs				
	Frequency		RCL	1	f, Hz
	Capacitance		RCL	2	C, F
	Inductance		RCL	3	L, H
6	Change appropriate inputs or				
	go to 2 for new case.				
*	The desired frequency must be				
	input in step 3.				

SERIES RESONANT CIRCUIT



This program computes the input impedance Z and the resonant frequency f_r of the series resonant circuit shown. At any desired frequency the magnitude and phase of Z are calculated and displayed.



The input impedance is given by

$$Z = \frac{R_p\left(s^2 + \frac{R_s}{L}s + \frac{1}{LC}\right)}{s^2 + \frac{R_s + R_p}{L}s + \frac{1}{LC}} = R_p\,\frac{(1-\omega^2 LC) + j\,R_s C\omega}{(1-\omega^2 LC) + j\,(R_s + R_p)\,C\omega}$$

where

- $s = j2\pi f = j\omega$
- f = frequency in hertz
- ω = frequency in radians per second
- C = capacitance in farads
- L = inductance in henrys
- R = resistance in ohms

The magnitude and angle of Z are

$$\mathrm{MAG}[Z] = \frac{R_p\,[(1-\omega^2 LC)^2 + R_s^2 C^2 \omega^2]^{1/2}}{[(1-\omega^2 LC)^2 + (R_s + R_p)^2 C^2 \omega^2]^{1/2}}$$

$$\mathrm{ANG}[Z] = \tan^{-1}\frac{R_s C\omega}{1-\omega^2 LC} - \tan^{-1}\frac{(R_s + R_p)\,C\omega}{1-\omega^2 LC}$$

The resonant frequency is

$$f_r = \frac{1}{2\pi\sqrt{LC}}$$

Notes:

1. When MAG[Z] or ANG[Z] has been computed, the other may be displayed by pressing [g] [x⇄y].
2. Be sure that DEG mode is selected.

Examples:

1. $R_p = 10{,}000\ \Omega$
   $R_s = 1\ \Omega$
   $C = 100\ pF$
   $L = 1\ \mu H$
   Calculate
   $f_r = 1.59 \times 10^7$ Hz (15 915 494.31)

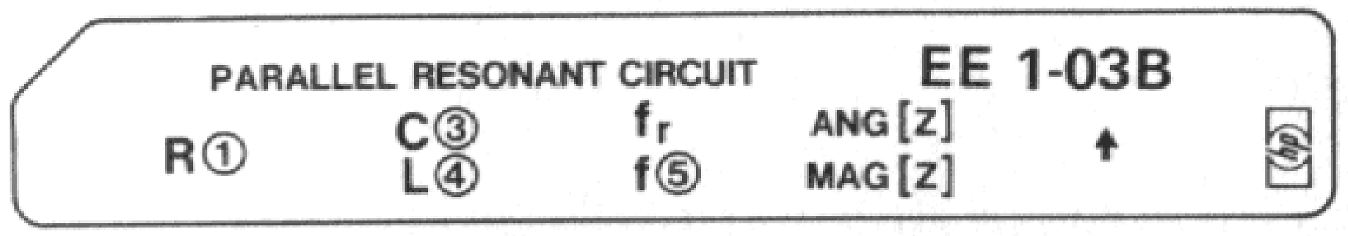
f, Hz	MAG[Z], Ω	ANG[Z], degrees
1 MHz	1565.56	–80.96
15 MHz	11.90	–85.11
16 MHz	1.46	46.64
100 MHz	611.20	86.40

2. $R_p = 10^{80}$
   $R_s = 0$
   $C = .159155$
   $L = .159155$
   Calculate
   $f_r = 1.0$ Hz (1.00×10^0)

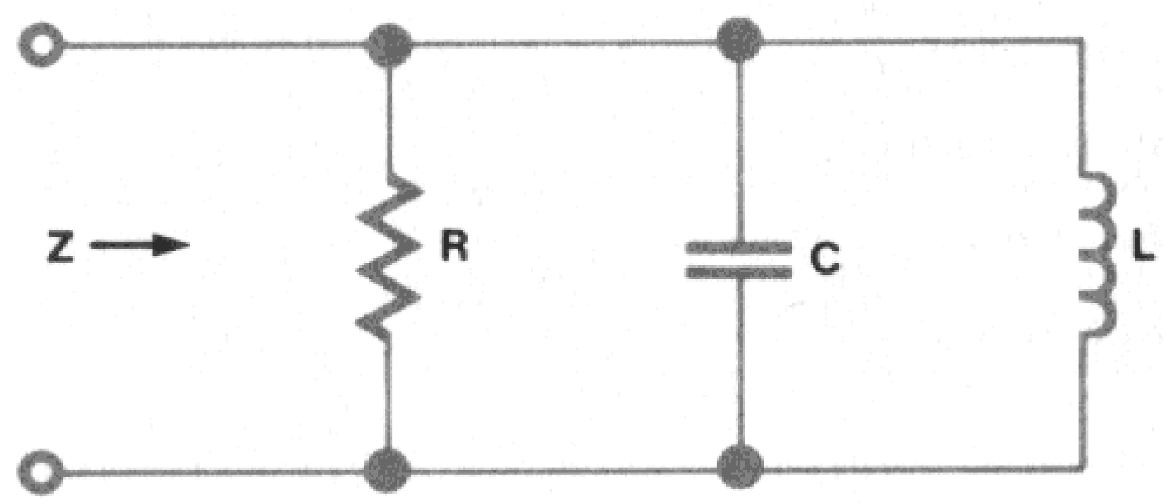
f, Hz	MAG[Z], Ω	ANG[Z], degrees
0.5	1.50×10^0	2.70×10^2
1	7.16×10^{-7}	9.00×10^1
1.5	8.33×10^{-1}	9.00×10^1

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	Enter program				
2	Initialize		RTN	R/S	
3	Input values				
	Series resistor	R_s, Ω	E	A	
	Parallel resistor	R_p, Ω	A		
	Capacitor	C, F	E	B	
	Inductor	L, H	B		
	Frequency	f, Hz	C		
4	Select desired outputs				
	Resonant frequency		E	C	f_r, Hz
	Magnitude of impedance		D		MAG[Z], Ω
	Angle of impedance		E	D	ANG[Z], deg.
5	Recall inputs (optional)				
			RCL	1	R_s, Ω
			RCL	2	R_p, Ω
			RCL	3	C, F
			RCL	4	L, H
			RCL	5	f, Hz
6	For new case, return to step 3				
	to enter any new values.				

PARALLEL RESONANT CIRCUIT



This program computes the input impedance Z and the undamped natural frequency f_r of the parallel resonant circuit shown. At any desired frequency, the magnitude and phase of Z are calculated and displayed. A special routine allows automatic incrementation of frequency as a plotting aid.



The input impedance is given by

$$Z = \frac{1}{C}\,\frac{s}{s^2 + s\,\frac{1}{RC} + \frac{1}{LC}} = \frac{jRL\omega}{R(1 - \omega^2 LC) + j\omega L}$$

where

$s = j2\pi f = j\omega$
f = frequency in hertz
ω = frequency in radians per second
C = capacitance in farads
L = inductance in henrys
R = resistance in ohms

The resonant frequency is

$$f_r = \frac{1}{2\pi\sqrt{LC}}$$

The magnitude and angle of Z are

$$\mathrm{MAG}[Z] = \frac{RL\omega}{[R^2(1 - \omega^2 LC)^2 + \omega^2 L^2]^{1/2}}$$

$$\mathrm{ANG}[Z] = 90^\circ - \tan^{-1}\frac{\omega L}{R(1 - \omega^2 LC)}$$

Notes:

1. When MAG[Z] or ANG[Z] has been computed, the other may be displayed by pressing [g] [x⇄y].

2. Frequency incrementation may be made multiplicative by changing the programs as follows:

   PRESS [GTO] [1]
   SWITCH TO W/PRGM
   PRESS [SST] [SST] [SST] [g] [DEL] [×]
   SWITCH TO RUN

Examples:

1. R = 100 Ω
   C = 100 pF
   L = 10 μH

   Calculate
   f_r = 5.033 MHz (5 032 921.21)

   Set up iteration
   $f_0 = 0$, $\Delta f = 1 \times 10^6$

f, MHz	MAG[Z], Ω	ANG[Z], degrees
1	54.74	56.81
2	83.07	33.83
3	94.62	18.88
4	98.94	8.34
5	100.00	0.24
6	99.38	−6.38
7	97.82	−11.99
8	95.68	−16.89
9	93.21	−21.24

2. R = 5000 Ω
   C = 1 μF
   L = 3 mH

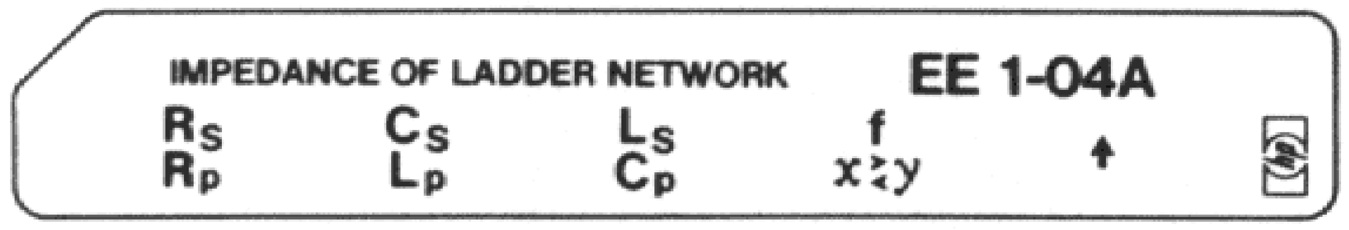
   Calculate
   f_r = 2905.76 Hz

   Set up iteration
   $f_0 = 100$, $\Delta f = 2$ (program altered to multiply by Δf)

f, Hz	MAG[Z], Ω	ANG[Z], degrees
200	3.79	89.96
400	7.69	89.91
800	16.32	89.81
1600	43.28	89.50
3200	283.03	−86.76
6400	31.32	−89.64
12800	13.11	−89.85

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	Enter program				
2	Initialize		RTN	R/S	
3	Input values				
		R, Ω	A		
		C, F	E	B	
		L, H	B		
4	Compute natural				
	frequency (optional)		E	C	f_r, Hz
5	Input frequency				
		f, Hz	C		
6	Select desired output				
			D		MAG[Z], Ω
			E	D	ANG[Z], deg.
7	For new case, return to step 3				
	or step 5				
8	Recall inputs (optional)				
			RCL	1	R, Ω
			RCL	3	C, F
			RCL	4	L, H
			RCL	5	f, Hz
9	(Optional iteration)				
	Input starting f	f_0, Hz	STO	5	
	Input increment	Δf, see note 2	STO	2	
9a	Branch to LBL 1		GTO	1	
9b	Display f		R/S		f, Hz
9c	Display MAG[Z]		R/S		MAG[Z], Ω
9d	Display ANG[Z]		R/S		ANG[Z], deg.
	Repeat 9b, 9c, and 9d as desired				

IMPEDANCE OF LADDER NETWORK



This program computes the input impedance of an arbitrary ladder network. Elements are added one at a time starting from the right. The first element must be in parallel.

Suppose we have a network whose input admittance is Y_{in}. Adding a shunt R, L, or C, the input admittance becomes

$$Y_{new} = \begin{cases} Y_{in} + \left(\frac{1}{R} + j0\right) \\ Y_{in} + \left(0 - j\,\frac{1}{\omega\, L_p}\right) \\ Y_{in} + (0 + j\,\omega\, C_p) \end{cases}$$

Adding a series R, L, or C, we have

$$Y_{new} = \begin{cases} \left(\frac{1}{Y_{in}} + (R_s + j0)\right)^{-1} \\ \left(\frac{1}{Y_{in}} + (0 + j\,\omega\, L_s)\right)^{-1} \\ \left(\frac{1}{Y_{in}} + \left(0 - j\,\frac{1}{\omega\, C_s}\right)\right)^{-1} \end{cases}$$

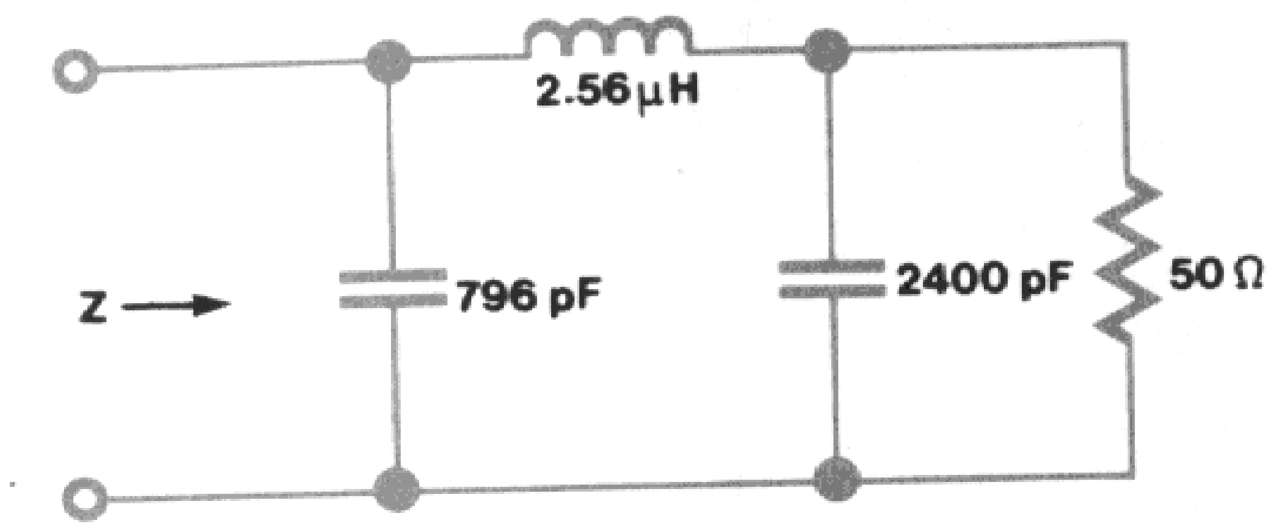
The program converts this admittance to an impedance for display.

Note:

An erroneous entry may be corrected by entering the negative of the incorrect value.

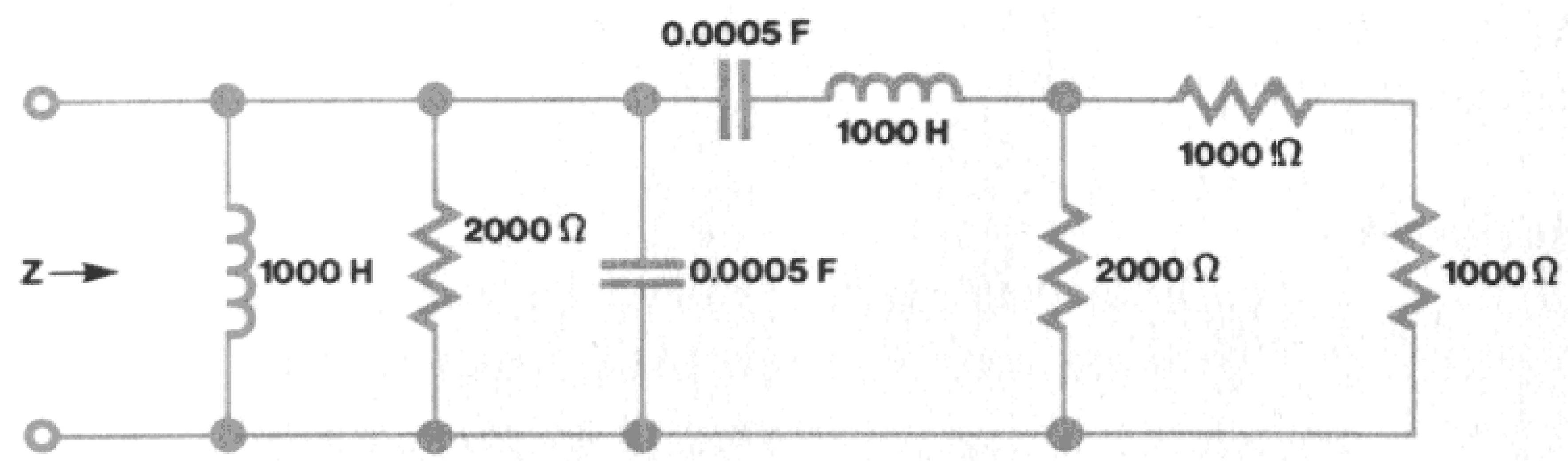
Examples:

1. f = 4 MHz



INPUT	Z_{IN}
$R_p = 50$	$50.00 \measuredangle 0.00^\circ$
$C_p = 2400$ E−12	$15.74 \measuredangle -71.66^\circ$
$L_s = 2.56$ E−6	$49.65 \measuredangle 84.28^\circ$
$C_p = 796$ E−12	$497.69 \measuredangle 0.98^\circ \cong 500 \measuredangle 0$

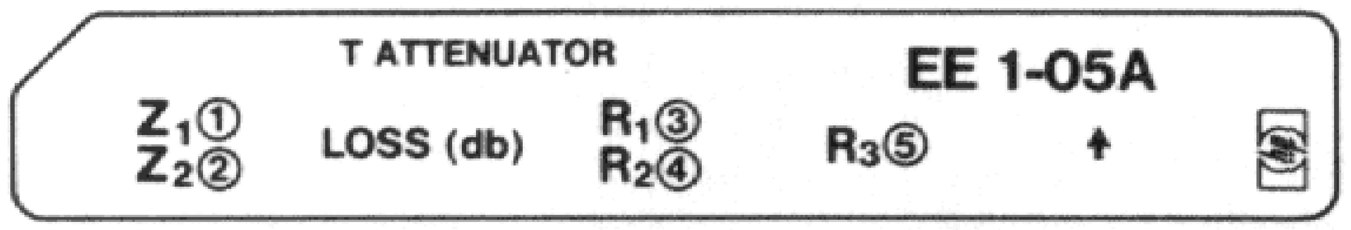
2. $f = (2\pi)^{-1}$ Hz



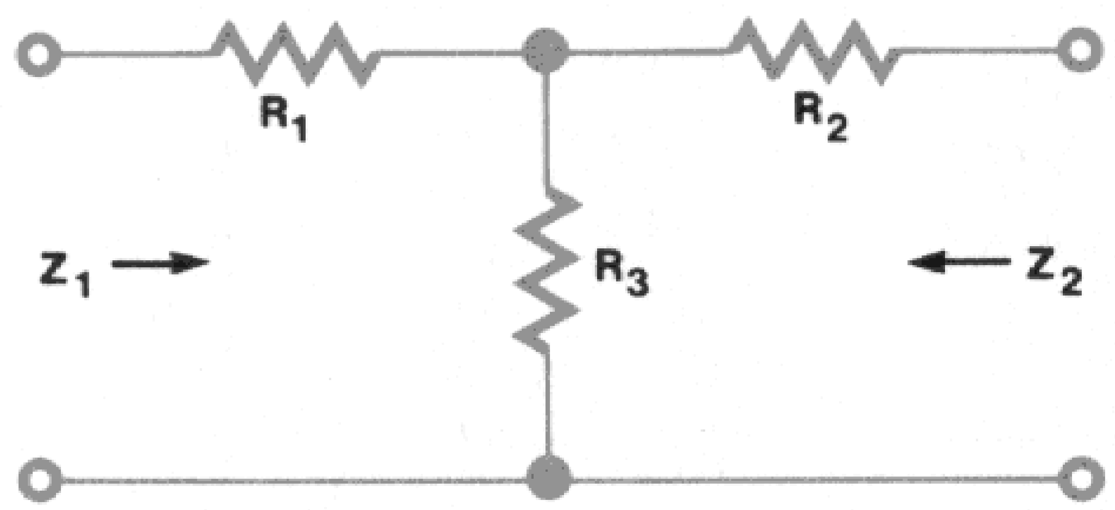
INPUT	Z_{IN}
$R_p = 1000$	$1000 \measuredangle 0^\circ$
$R_s = 1000$	$2000 \measuredangle 0^\circ$
$R_p = 2000$	$1000 \measuredangle 0^\circ$
$L_s = 1000$	$1414 \measuredangle 45^\circ$
$C_s = .0005$	$1414 \measuredangle -45^\circ$
$C_p = .0005$	$894 \measuredangle -63^\circ$
$R_p = 2000$	$707 \measuredangle -45^\circ$
$L_p = 100$	$110 \measuredangle 84^\circ$ (input made was an error—see note)
$L_p = -100$	$707 \measuredangle -45^\circ$
$L_p = 1000$	$1000 \measuredangle 0^\circ$

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
1	Enter program			
2	Initialize		RTN R/S	
3	Input frequency	f, Hz	E D	$2\pi f$
4	Input a parallel element			
	Parallel resistor	R_p, Ω	A	MAG [Z_{in}]
	Parallel inductor	L_p, H	B	MAG [Z_{in}]
	Parallel capacitor	C_p, F	C	MAG [Z_{in}]
5	Input another element			
	Series resistor	R_s, Ω	E A	MAG [Z_{in}]
	or Series capacitor	C_s, F	E B	MAG [Z_{in}]
	or Series inductor	L_s, H	E C	MAG [Z_{in}]
	or Parallel resistor	R_p, Ω	A	MAG [Z_{in}]
	or Parallel inductor	L_p, H	B	MAG [Z_{in}]
	or Parallel capacitor	C_p, F	C	MAG [Z_{in}]
6	Optional output			
	Angle of Z_{in}		D	ANG [Z_{in}]
7	Return to step 5 to input next			
	element			
8	Return to step 2 for a new case			

T ATTENUATOR



The T attenuator can be used to match between two impedances, Z_1 and Z_2. This program computes the minimum loss of the attenuator and values for the resistors R_1, R_2, and R_3 which will yield an attenuator having any desired loss.



The minimum loss in decibels is given by

$$\text{Min Loss} = 10 \log\left(\sqrt{\frac{Z_1}{Z_2}} + \sqrt{\frac{Z_1}{Z_2} - 1}\right)^2$$

where

$$Z_1 \geqslant Z_2$$

If N is the desired loss of the attenuator expressed as a ratio (loss in dB = 10 log N), then

$$R_3 = \frac{2\sqrt{N Z_1 Z_2}}{N - 1}$$

$$R_1 = Z_1\left(\frac{N+1}{N-1}\right) - R_3$$

$$R_2 = Z_2\left(\frac{N+1}{N-1}\right) - R_3$$

Note: If the desired loss is less than the minimum loss, R_2 will be negative.

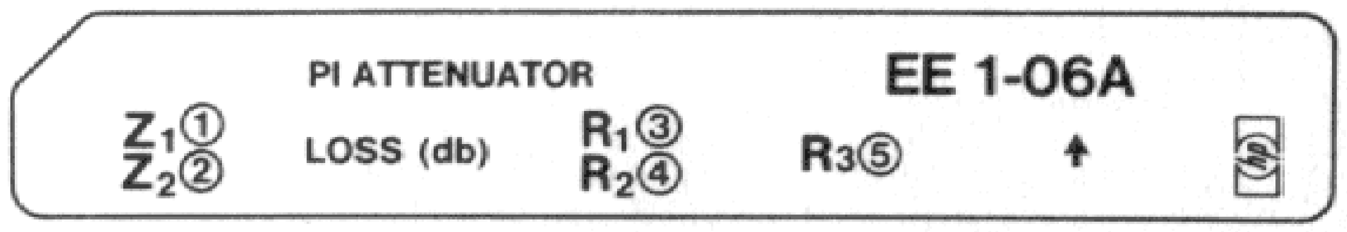
Examples:

1. $Z_1 = 75\ \Omega$
   $Z_2 = 50\ \Omega$
   Loss = 6 dB
   Compute
   Min Loss = 5.72 dB (5.7195×10^0)
   $R_1 = 43.34\ \Omega$ (4.334×10^1)
   $R_2 = 1.57\ \Omega$ (1.5715×10^0)
   $R_3 = 81.97\ \Omega$ (8.1973×10^1)

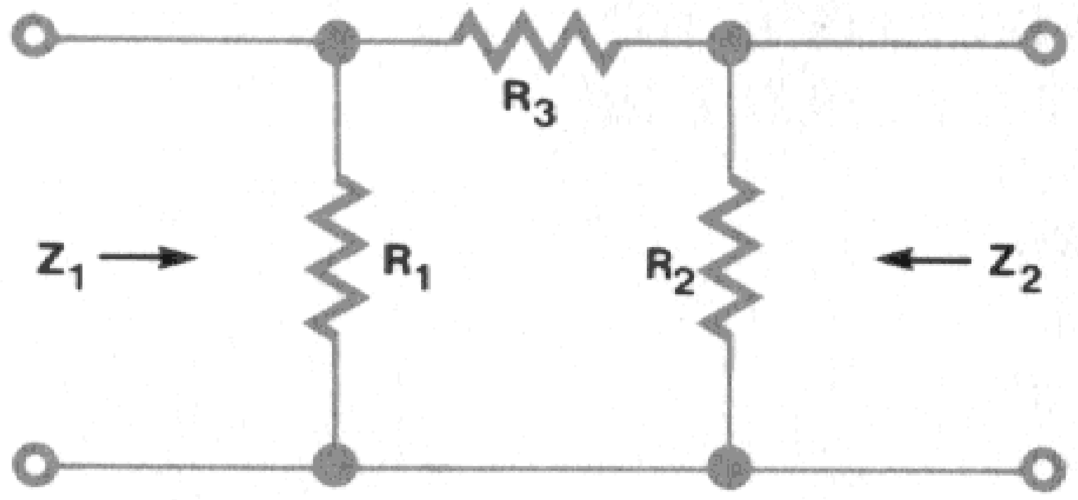
2. $Z_1 = 50\ \Omega$
   $Z_2 = 50\ \Omega$
   Loss = 10 dB
   Compute
   Min Loss = 0 dB
   $R_1 = 25.97\ \Omega$ (2.5975×10^1)
   $R_2 = 25.97\ \Omega$ (2.5975×10^1)
   $R_3 = 35.14\ \Omega$ (3.5136×10^1)

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	Enter program				
2	Initialize		RTN	R/S	
3	Inputs				
	Source impedance	Z_1, Ω	E	A	
	Termination impedance	Z_2, Ω	A		
	Desired Loss	Loss, dB	B		Min Loss, dB
	(If Min Loss > Desired Loss				
	enter a new Desired Loss)				
4	Outputs				
	R_1		E	C	R_1, Ω
	R_2		C		R_2, Ω
	R_3		D		R_3, Ω
5	Recall inputs (optional)				
			RCL	1	Z_1, Ω
			RCL	2	Z_2, Ω
6	For new case change inputs				
	in step 3.				

PI ATTENUATOR



The PI attenuator can be used to match between two impedances, Z_1 and Z_2. This program computes the minimum loss of the attenuator and values for the resistors R_1, R_2, and R_3 which will yield an attenuator having any desired loss.



The minimum loss in decibels is given by

$$\text{Min Loss} = 10 \log \left(\sqrt{\frac{Z_1}{Z_2}} + \sqrt{\frac{Z_1}{Z_2} - 1} \right)^2$$

where $Z_1 \geqslant Z_2$

If N is the desired loss of the attenuator expressed as a ratio (loss in dB = 10 log N), then

$$R_3 = \frac{1}{2}(N - 1) \left(\frac{Z_1 Z_2}{N} \right)^{1/2}$$

$$\frac{1}{R_1} = \frac{1}{Z_1} \left(\frac{N+1}{N-1} \right) - \frac{1}{R_3}$$

$$\frac{1}{R_2} = \frac{1}{Z_2} \left(\frac{N+1}{N-1} \right) - \frac{1}{R_3}$$

Examples:

1. $Z_1 = 75\ \Omega$
   $Z_2 = 50\ \Omega$
   loss = 6 dB

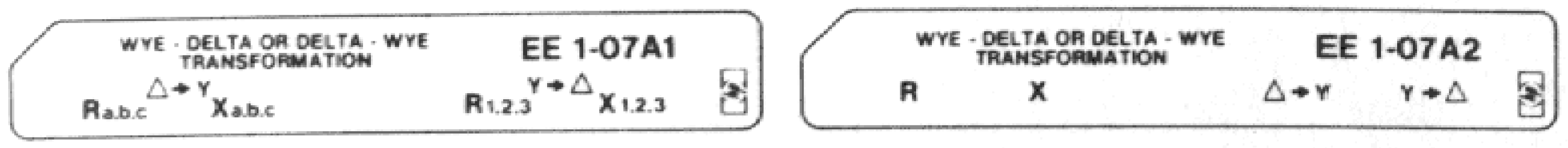
   Compute
   Min Loss = 5.72 dB (5.7195×10^0)
   $R_1 = 2386.20\ \Omega$ (2.3862×10^3)
   $R_2 = 86.52\ \Omega$ (8.6517×10^1)
   $R_3 = 45.75\ \Omega$ (4.5747×10^1)

2. $Z_1 = 50\ \Omega$
   $Z_2 = 50\ \Omega$
   loss = 10 dB

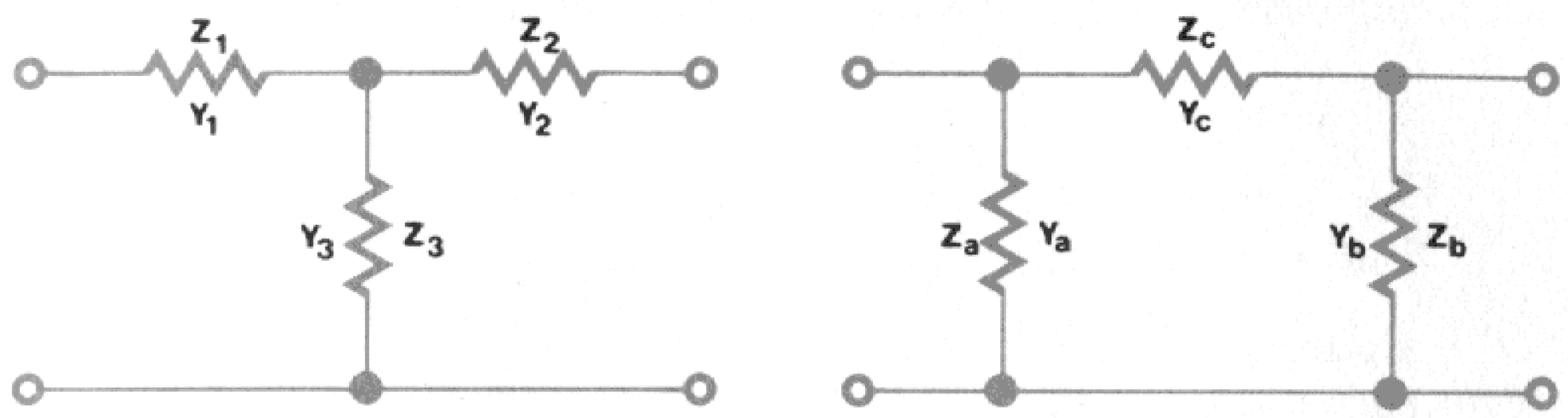
   Compute
   Min Loss = 0 dB
   $R_1 = 96.25\ \Omega$ (9.6248×10^1)
   $R_2 = 96.25\ \Omega$ (9.6248×10^1)
   $R_3 = 71.15\ \Omega$ (7.1151×10^1)

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	Enter program				
2	Initialize		RTN	R/S	
3	Inputs				
	Source impedance	Z_1, Ω	E	A	
	Termination impedance	Z_2, Ω	A		
	Desired loss	Loss, dB	B		Min Loss, dB
	(If Min Loss > Desired Loss,				
	enter a new Desired Loss)				
4	Outputs				
	R_1		E	C	R_1, Ω
	R_2		C		R_2, Ω
	R_3		D		R_3, Ω
5	Recall inputs (optional)				
			RCL	1	Z_1, Ω
			RCL	2	Z_2, Ω
6	Change inputs in step 3 for				
	new case.				

WYE-DELTA OR DELTA-WYE TRANSFORMATION



This program converts either of the networks shown into the other. Values are input as impedances and are converted to admittances for the T→π transformation.



$$Z_1 = \frac{Z_a Z_c}{Z_a + Z_b + Z_c} \qquad Z_c = \left(\frac{Y_1 Y_2}{Y_1 + Y_2 + Y_3} \right)^{-1}$$

$$Z_2 = \frac{Z_b Z_c}{Z_a + Z_b + Z_c} \qquad Z_a = \left(\frac{Y_1 Y_3}{Y_1 + Y_2 + Y_3} \right)^{-1}$$

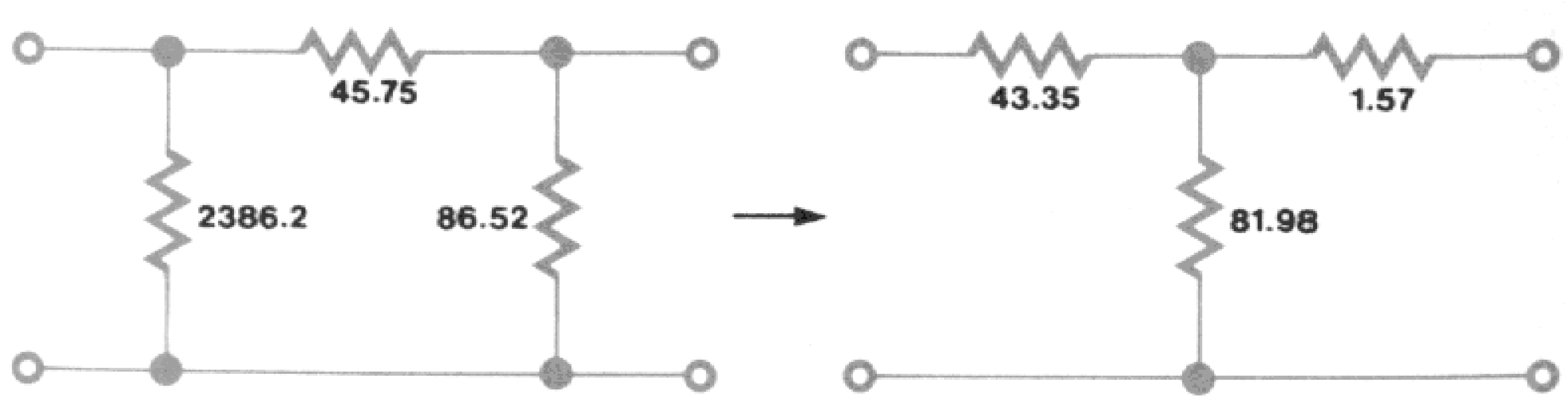
$$Z_3 = \frac{Z_a Z_b}{Z_a + Z_b + Z_c} \qquad Z_b = \left(\frac{Y_2 Y_3}{Y_1 + Y_2 + Y_3} \right)^{-1}$$

Note:

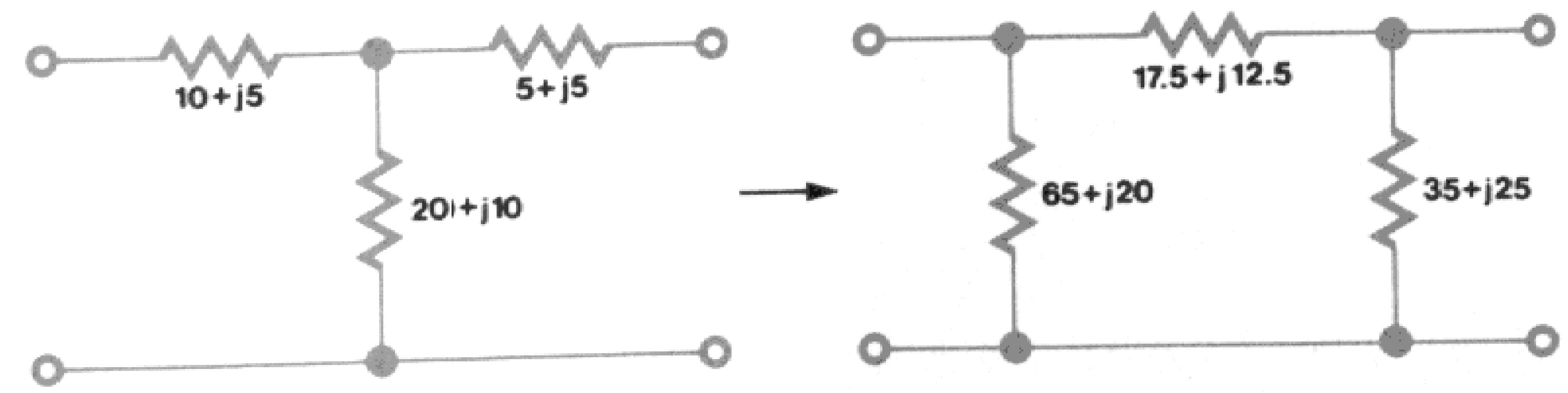
1. It is very important to observe the component designations.
2. Be sure to input zero (do not simply press CLX) for X (or R) when Z is purely resistive (or reactive).

Examples:

1.



2.

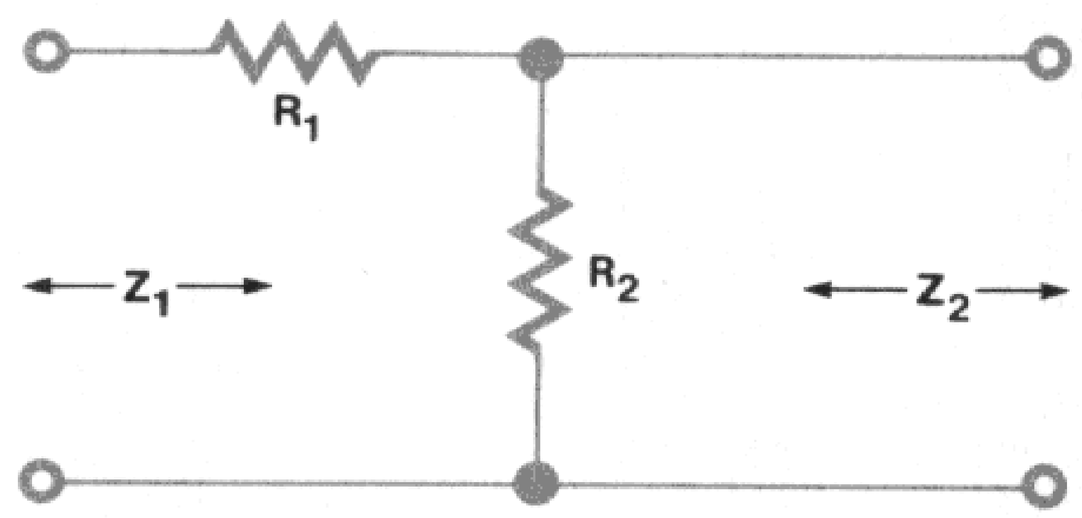


STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
1	Enter program 1			
2	Initialize		RTN R/S	1
3	Input impedances			
	R_a		A	1
	X_a		B	2
	Δ→Y R_b		A	2
	π→T X_b		B	3
	R_c		A	3
	X_c		B	
	or			
	R_1		D	1
	X_1		E	2
	R_2		D	2
	Y→Δ X_2		E	3
	T→π R_3		D	3
	X_3		E	
4	Enter program 2			
5	Select conversion			
	Δ→Y or π→T		D	
	Y→Δ or T→π		E	
6	Output impedances			π→T T→π
			A	R_1 or R_a
			B	X_1 or X_a
			A	R_2 or R_b
			B	X_2 or X_b
			A	R_3 or R_c
			B	X_3 or X_c
7	For new case return to step 1			

MINIMUM-LOSS PAD MATCHING

MINIMUM - LOSS PAD MATCHING				EE 1–08B
$Z_1$①	$Z_2$②	R_1	R_2	LOSS

This program computes resistances R_1 and R_2 which will match resistive impedances Z_1 and Z_2 ($Z_1 > Z_2$). The resulting attenuation is also computed.



$$R_1 = Z_1 \sqrt{1 - \frac{Z_2}{Z_1}}$$

$$R_2 = \frac{Z_2}{\sqrt{1 - \frac{Z_2}{Z_1}}}$$

$$\text{loss} = 20 \log \left(\sqrt{\frac{Z_1}{Z_2}} + \sqrt{\frac{Z_1}{Z_2} - 1} \right)$$

Example:

$Z_1 = 1200$

$Z_2 = 500$

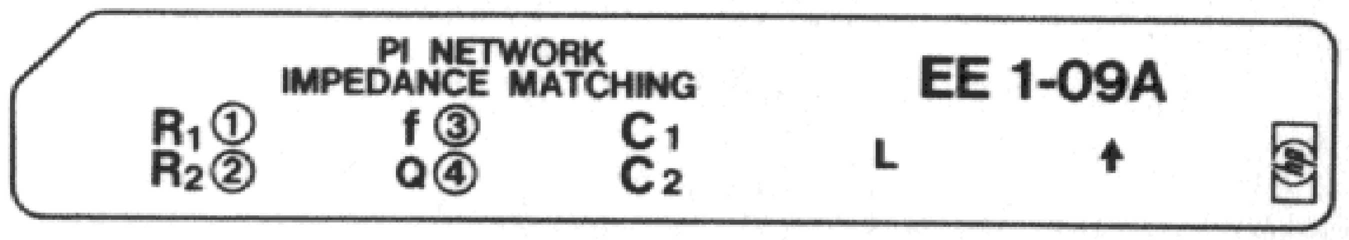
Calculate $R_1 = 916.52\ \Omega$

$R_2 = 654.65\ \Omega$

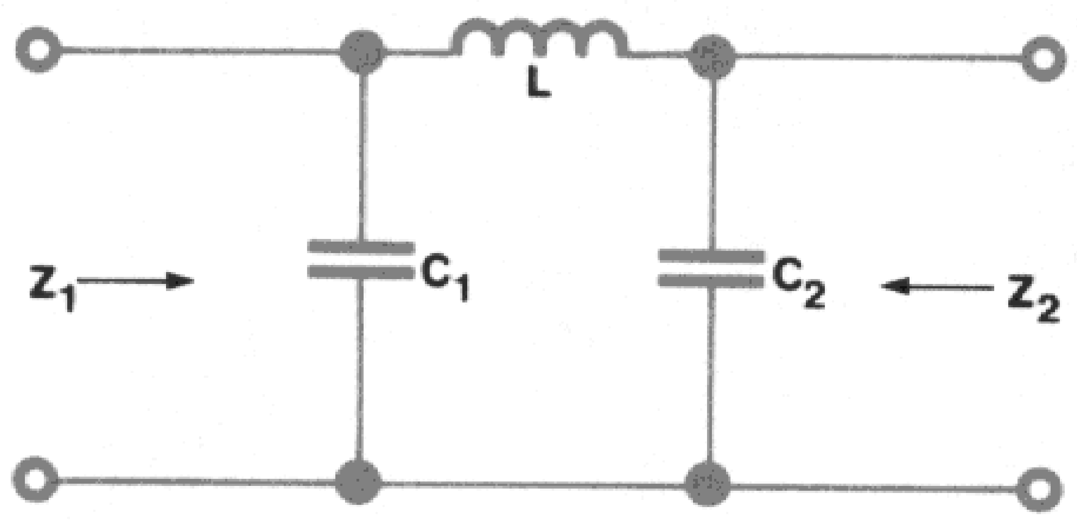
loss = 8.73 dB

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
1	Enter program			
2	Inputs			
	Input impedance	Z_1, ohms	A	
	Output impedance	Z_2, ohms	B	
3	Outputs			
	Series resistor		C	R_1, ohms
	Shunt resistor		D	R_2, ohms
	Attenuation		E	Loss, dB
4	Recall inputs			
			RCL 1	Z_1, ohms
			RCL 2	Z_2, ohms
5	For new case change inputs in			
	step 2.			

PI NETWORK IMPEDANCE MATCHING



A lossless network is often used to match between two resistive impedances Z_1 and Z_2, as shown



Given the values of Z_1 and Z_2 ($Z_1 > Z_2$) the frequency f, and the desired circuit Q, the values of C_1, C_2, and L can be found from the following formulas:

$$X_{C1} = \frac{Z_1}{Q} \qquad C_1 = \frac{1}{2\pi f X_{C1}}$$

$$X_{C2} = \frac{Z_2}{\left[\frac{Z_2}{Z_1}(Q^2+1) - 1\right]^{1/2}} \qquad C_2 = \frac{1}{2\pi f X_{C2}}$$

$$X_L = \frac{Q Z_1}{Q^2+1}\left[1 + \frac{Z_2}{Q X_{C2}}\right] \qquad L = \frac{X_L}{2\pi f}$$

Note: Z_1, Z_2, and Q must be chosen so that

$$\frac{Z_2}{Z_1}(Q^2+1) > 1$$

Examples:

1. $Z_1 = 500\ \Omega$
   $Z_2 = 50\ \Omega$
   $Q = 10$
   $f = 4$ MHz

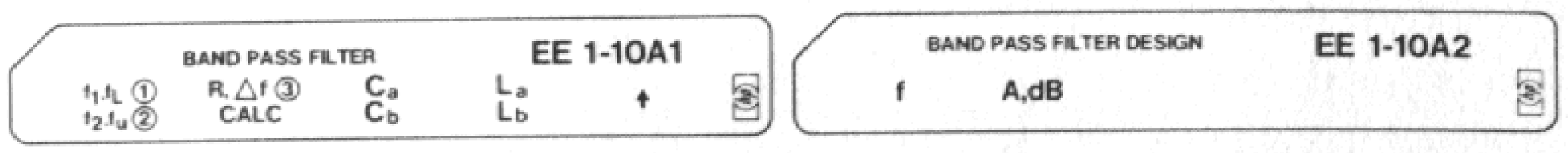
   Compute
   $C_1 \cong 796$ pF (7.9577×10^{-10})
   $C_2 \cong 2400$ pF (2.4006×10^{-9})
   $L \cong 2.56\ \mu$H (2.5639×10^{-6})

2. $Z_1 = 75\ \Omega$
   $Z_2 = 50\ \Omega$
   $Q = 4$
   $f = 100$ MHz

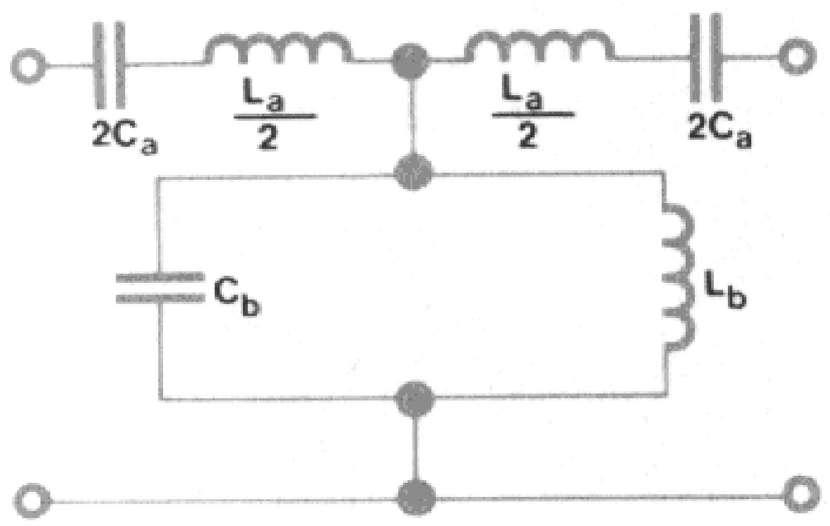
   Compute
   $C_1 \cong 84.9$ pF (8.4883×10^{-11})
   $C_2 \cong 102.3$ pF (1.0232×10^{-10})
   $L \cong 50.7$ nH (5.0657×10^{-8})

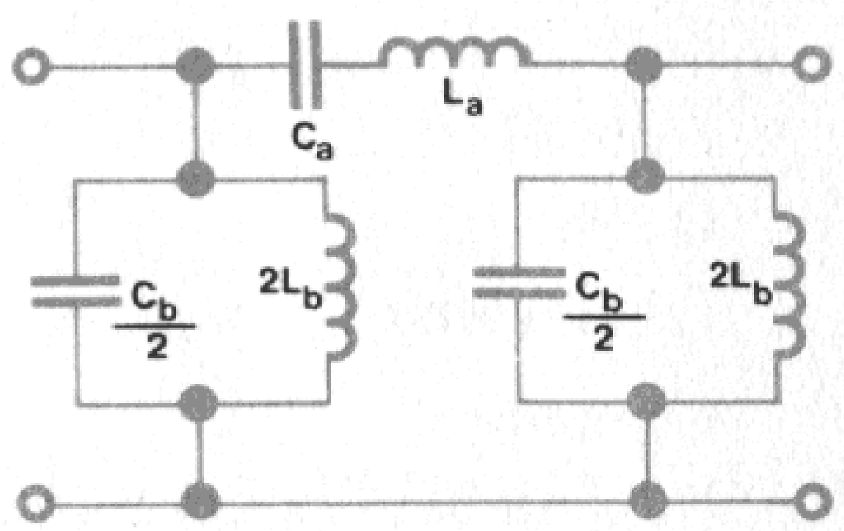
STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	Enter program				
2	Initialize		RTN	R/S	0.0000×10^0
3	Inputs				
	Input impedance	Z_1, Ω	E	A	
	Output impedance	Z_2, Ω	A		
	Frequency	f, Hz	E	B	
	Quality factor	Q	B		
4	Outputs				
	Input capacitor		E	C	C_1, F
	Output capacitor		C		C_2, F
	Inductor		D		L, H
5	Recall inputs (optional)				
	Input impedance		RCL	1	Z_1, Ω
	Output impedance		RCL	2	Z_2, Ω
	Frequency		RCL	3	f, Hz
	Quality factor		RCL	4	Q
6	For new case, return to step 3.				

BAND PASS FILTER DESIGN



This program computes the ideal component values for the filters shown below given the image impedance level and the desired band pass. The program also computes the frequency response of the ideal or a proposed filter.





$$C_a = \frac{f_2 - f_1}{4\pi f_1 f_2 R} \qquad C_b = \frac{1}{\pi (f_2 - f_1) R}$$

$$L_a = \frac{R}{\pi (f_2 - f_1)} \qquad L_b = \frac{R (f_2 - f_1)}{4 \pi f_1 f_2}$$

$$\frac{X_a}{4X_b} = \frac{(\omega^2 C_a L_a - 1)(1 - \omega^2 C_b L_b)}{4\omega^2 C_a L_b}$$

where

- f = frequency in hertz
- $\omega = 2\pi f$ = radian frequency
- f_1 = low cutoff frequency in hertz
- f_2 = high cutoff frequency in hertz
- f_L = low plotting frequency
- f_U = high plotting frequency
- Δf = plotting increment
- R = input and output impedance in ohms
- C = capacitance in farads
- L = inductance in henrys

Let A = attenuation in dB, then

for

$$0 < \frac{X_a}{4X_b}, \qquad A = 40 \log e \left(\sinh^{-1} \sqrt{\frac{X_a}{4X_b}}\right)$$

for

$$-1 < \frac{X_a}{4X_b} < 0, \qquad A = 0$$

for

$$\frac{X_a}{4X_b} < -1, \qquad A = 40 \log e \left(\cosh^{-1} \sqrt{-\frac{X_a}{4X_b}}\right)$$

Note:

Frequency may be plotted logarithmically by changing program 2 as follows:

PRESS GTO 2

SWITCH TO W/PRGM

PRESS SST 9 DEL ×

Record modified program on other track of card 2.

SWITCH TO RUN

Examples:

1. $f_1 = 300$
   $f_2 = 3000$
   $R = 50$

   Compute
   $C_a = 4.775\ \mu F\ (4.775 \times 10^{-6})$
   $C_b = 2.358\ \mu F\ (2.358 \times 10^{-6})$
   $L_a = 5.895$ mH (5.895×10^{-3})
   $L_b = 11.94$ mH (1.194×10^{-2})

   Enter
   $f_L = 100$
   $f_U = 3600$
   $\Delta f = 500$

f	A, dB
100	32.35
600	0.00
1100	0.00
1600	0.00
2100	0.00
2600	0.00
3100	4.93
3600	11.82

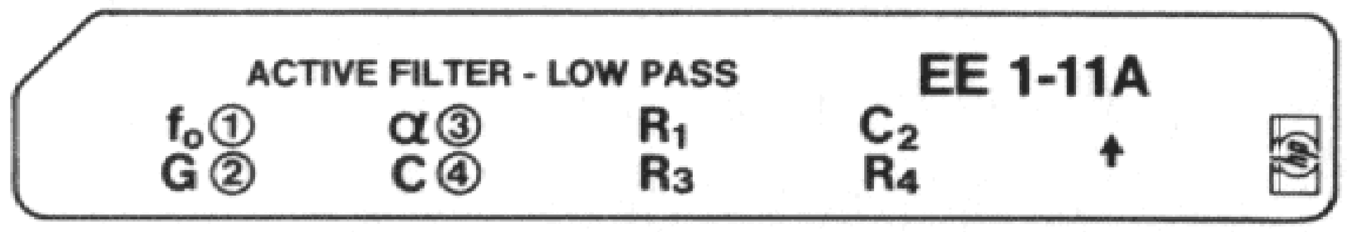
2. Same problem except enter approximate values and plot logarithmically with $\Delta f = \sqrt{10}$

   $C_a = 5\ \mu F$
   $C_b = 2.5\ \mu F$
   $L_a = 6$ mH
   $L_b = 12$ mH

f	A, dB
10.00	72.50
31.62	52.45
100.00	31.87
316.23	0.00
1 000.00	0.00
3 162.28	8.22
10 000.00	35.00
31 622.78	55.40
100 000.00	75.44

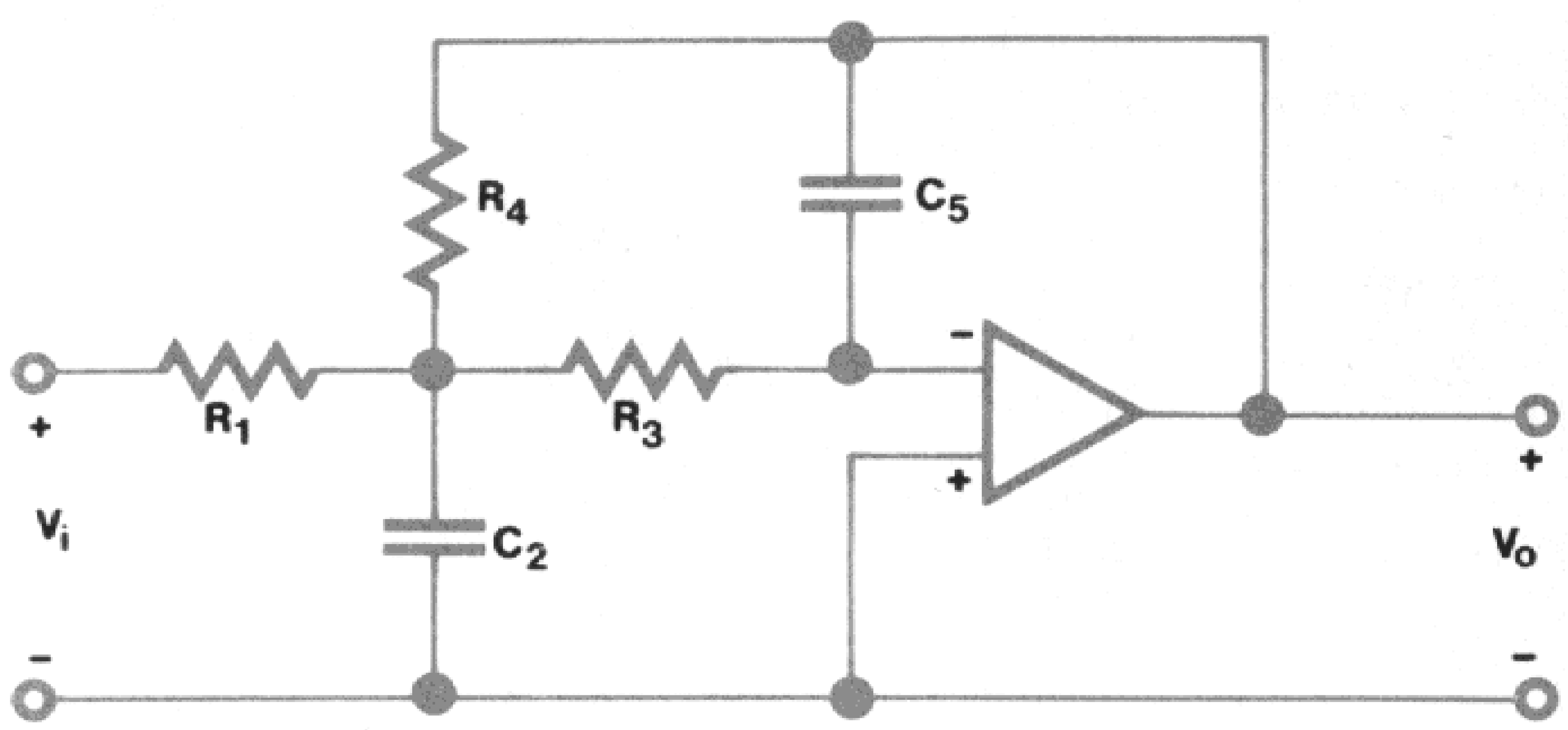
STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
1	Enter program 1			
2	Initialize		RTN R/S	
3	Inputs			
	Low cutoff freq.	f_1, Hz	E A	
	High cutoff freq.	f_2, Hz	A	
	Image impedance	R, Ω	E B	
	Calculate		B	0.00
4	Outputs (any order)			
			E C	C_a, F
			C	C_b, F
			E D	L_a, H
			D	L_b, H
5	For new case go to step 3			
6	Set up for plot			
	Freq. lower	f_L, Hz	E A	
	Freq. upper	f_U, Hz	A	
	Freq. increment	Δf, Hz	E B	
7	Input real component values			
	(optional)			
	Approximate C_a	C_a, F	STO 4	
	Approximate C_b	C_b, F	STO 5	
	Approximate L_a	L_a, H	STO 6	
	Approximate L_b	L_b, H	STO 7	
8	Enter program 2			
9	Outputs			
	Frequency		A	f, Hz
	Attenuation		B	A, dB
10	Repeat step 9 until flashing			
	zero indicates all output has			
	been displayed			
11	Return to step 1 or proceed to			
	step 12			
12	Input desired frequency	f, Hz	STO 1	
13	Output			
	Attenuation		B	A, dB
14	For new case return to step 1			

ACTIVE FILTER - LOW PASS



The transfer function of the active filter shown is

$$\frac{V_o}{V_i}(s) = -\frac{1}{R_1 R_3 C_2 C_5} \frac{1}{s^2 + \frac{s}{C_2}\left(\frac{1}{R_1} + \frac{1}{R_3} + \frac{1}{R_4}\right) + \frac{1}{R_3 R_4 C_2 C_5}}$$



Given

$G = \frac{V_o}{V_i}$, the desired low frequency gain

f_c, the cutoff frequency in hertz

α, the reciprocal quality factor or "alpha peaking factor"

C, a value for C_5 in farads

the program computes values for R_1, C_2, R_3 and R_4 according to the following formulas.

$$R_4 = \frac{\alpha}{4\pi f_c C}$$

$$R_1 = \frac{R_4}{G}$$

$$R_3 = \frac{R_4}{G+1}$$

$$C_2 = \frac{G+1}{R_4 \alpha \pi f_c}$$

Note:

If α is not specified, $\alpha = \sqrt{2}$ is used, giving component values for a Butterworth filter.

Examples:

1. f_c = 100 Hz
   G = 10
   $\alpha = \sqrt{2}$ (default value)
   C = 0.1 μF

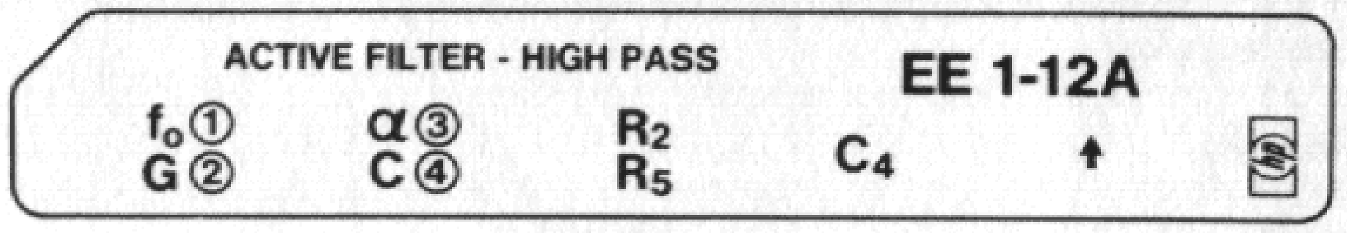
   Compute
   R_1 = 1125.40 Ω
   R_3 = 1023.09 Ω
   C_2 = 2.20 μF (2.200 000 x 10^{-6})
   R_4 = 11.254 kΩ (11 253.95)

2. f_c = 10 Hz
   G = 10
   α = 1
   C = 10 μF

   Compute
   R_1 = 79.58 Ω
   R_3 = 72.34 Ω
   C_2 = 440 μF (4.400 000 x 10^{-4})
   R_4 = 795.77 Ω

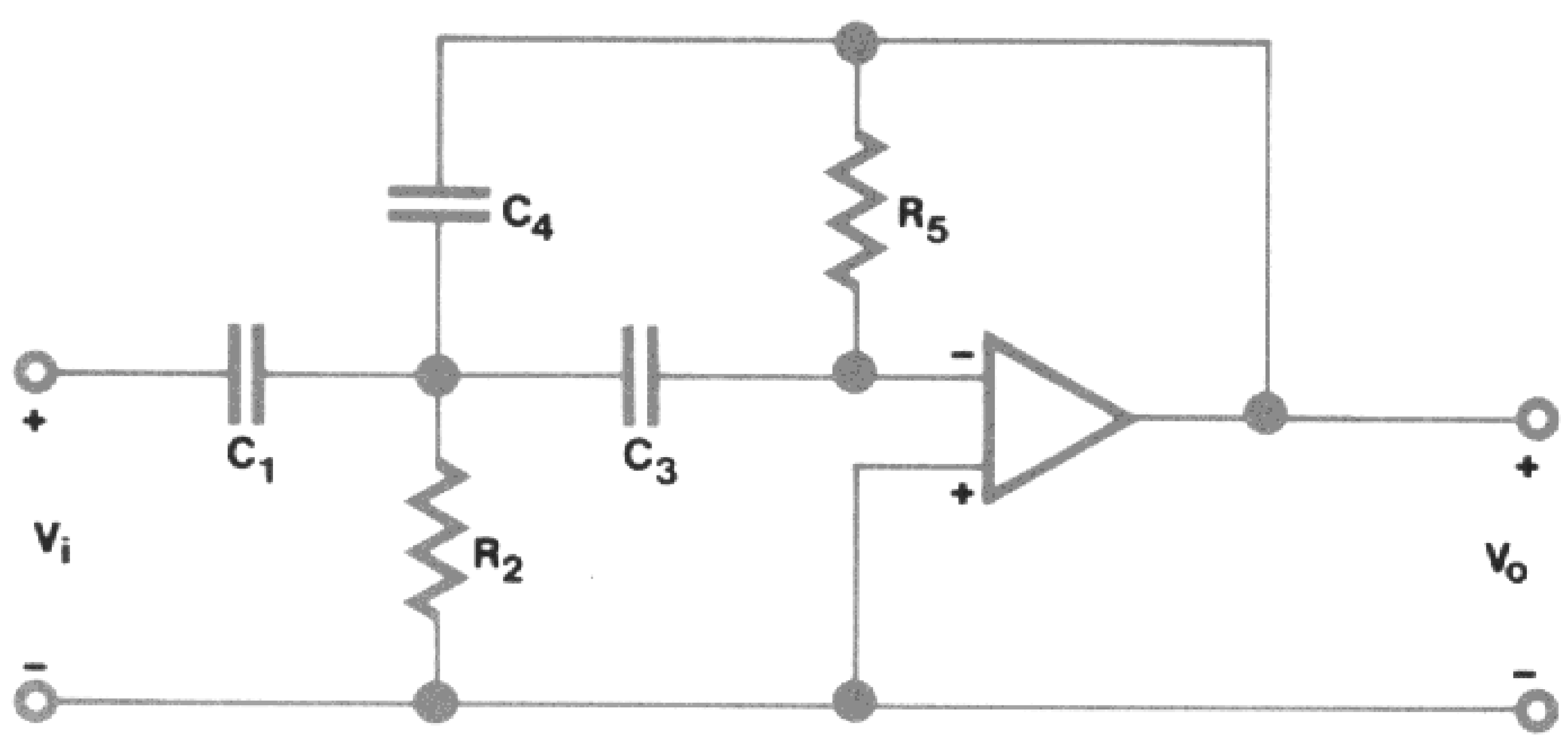
STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	Enter program				
2	Initialize		RTN	R/S	
3	Inputs	(any order)			
	Cutoff frequency	f_c, Hz	E	A	
	Overall gain	G	A		
	2 x damping factor	α*	E	B	
	Capacitor C_s	C, F	B		
4	Outputs (any order)				
			E	C	R_1, Ω
			C		R_3, Ω
			E	D	C_2, F
			D		R_4, Ω
5	Recall inputs (optional)				
	Cutoff frequency		RCL	1	f_c, Hz
	Overall gain		RCL	2	G
	2 x damping factor		RCL	3	α
	Capacitor C_s		RCL	4	C_s, F
*	$\alpha = \sqrt{2}$ if not entered				

ACTIVE FILTER - HIGH PASS



The transfer function of the active high-pass filter shown is

$$\frac{V_o}{V_i}(s) = -\frac{C_1}{C_4}\,\frac{s^2}{s^2 + \dfrac{s}{R_5}\left(\dfrac{C_1}{C_3C_4} + \dfrac{1}{C_4} + \dfrac{1}{C_3}\right) + \dfrac{1}{R_2R_5C_3C_4}}$$



Given

$G = \left|\dfrac{V_o}{V_i}\right|$, the desired high frequency gain

f_c, the desired corner frequency

α, the desired "alpha peaking factor" ($\alpha = 2\zeta$, where ζ is the damping factor)

$C_1 = C_3 = C$, farads

this program solves the following equations for the values of R_2, R_5, and C_4.

$$R_2 = \frac{\alpha}{2\pi f_c\,C\left(2 + \dfrac{1}{G}\right)}$$

$$R_5 = \frac{2\,G + 1}{\alpha\,2\pi f_c\,C}$$

$$C_4 = \frac{C}{G}$$

Note:

If α is not specified, $\alpha = \sqrt{2}$ is used, giving component values for a Butterworth filter.

Examples:

1. $f_o = 0.1$ Hz
   $G = 1$
   $\alpha = \sqrt{2}$ (default value)
   $C = 10\ \mu F$

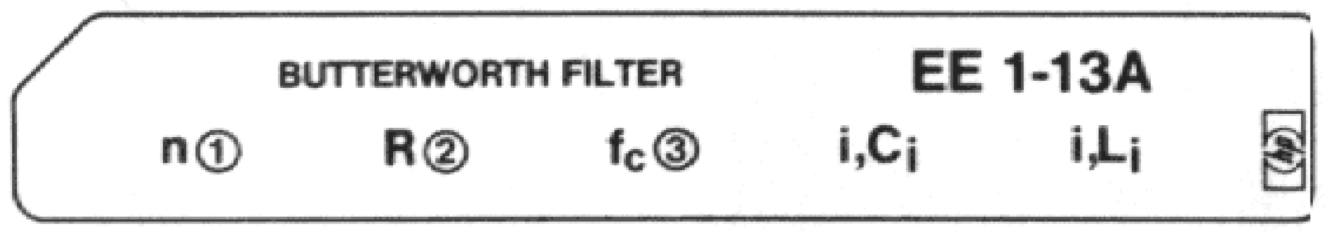
   Compute
   $R_2 = 75026.36\ \Omega$
   $R_5 = 337618.62\ \Omega$
   $C_4 = 10\ \mu F\ (1.000\ 000 \times 10^{-5})$

2. $f_o = 10$ Hz
   $G = 10$
   $\alpha = 1$
   $C = 1\ \mu F$

   Compute
   $R_2 = 7578.81\ \Omega$
   $R_5 = 334\ 225.38\ \Omega$
   $C_4 = 0.1\ \mu F\ (1.000\ 000 \times 10^{-7})$

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	Enter program				
2	Initialize		RTN	R/S	
3	Inputs (any order)				
	Corner frequency	f_c, Hz	E	A	
	Overall gain	G	A		
	2 x damping factor	α*	E	B	
	Capacitors C_1 and C_3	C, F	B		
4	Outputs				
	Resistor R_2		E	C	R_2, Ω
	Resistor R_5		C		R_5, Ω
	Capacitor C_4		D		C_4, F
5	Recall inputs (optional)				
	Corner frequency		RCL	1	f_c, Hz
	Overall gain		RCL	2	G
	2 x damping factor		RCL	3	α
	Capacitors C_1 and C_3		RCL	4	C, F
6	Return to step 2 for new case				
*	$\alpha = \sqrt{2}$ if not entered				

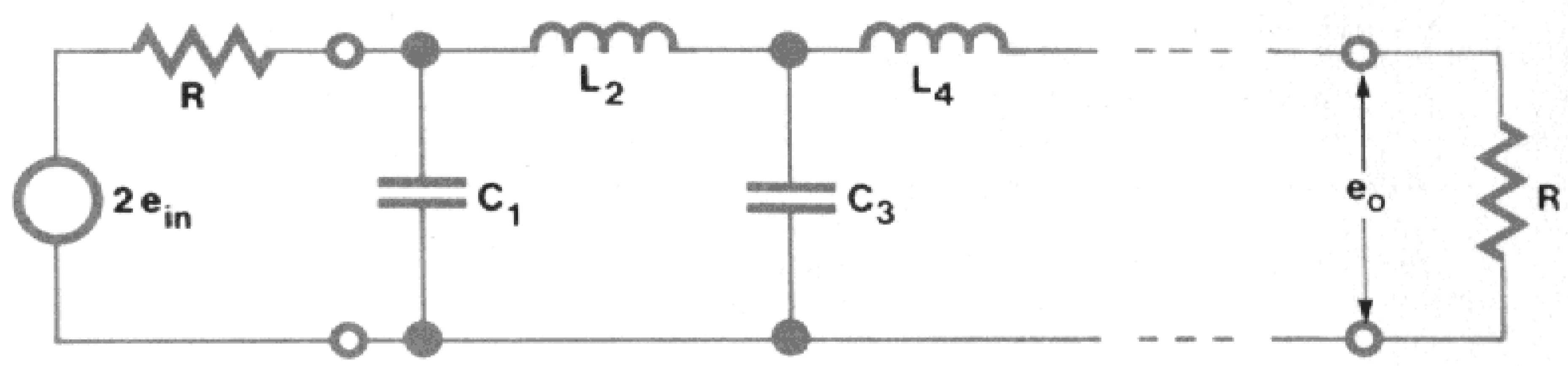
BUTTERWORTH FILTER

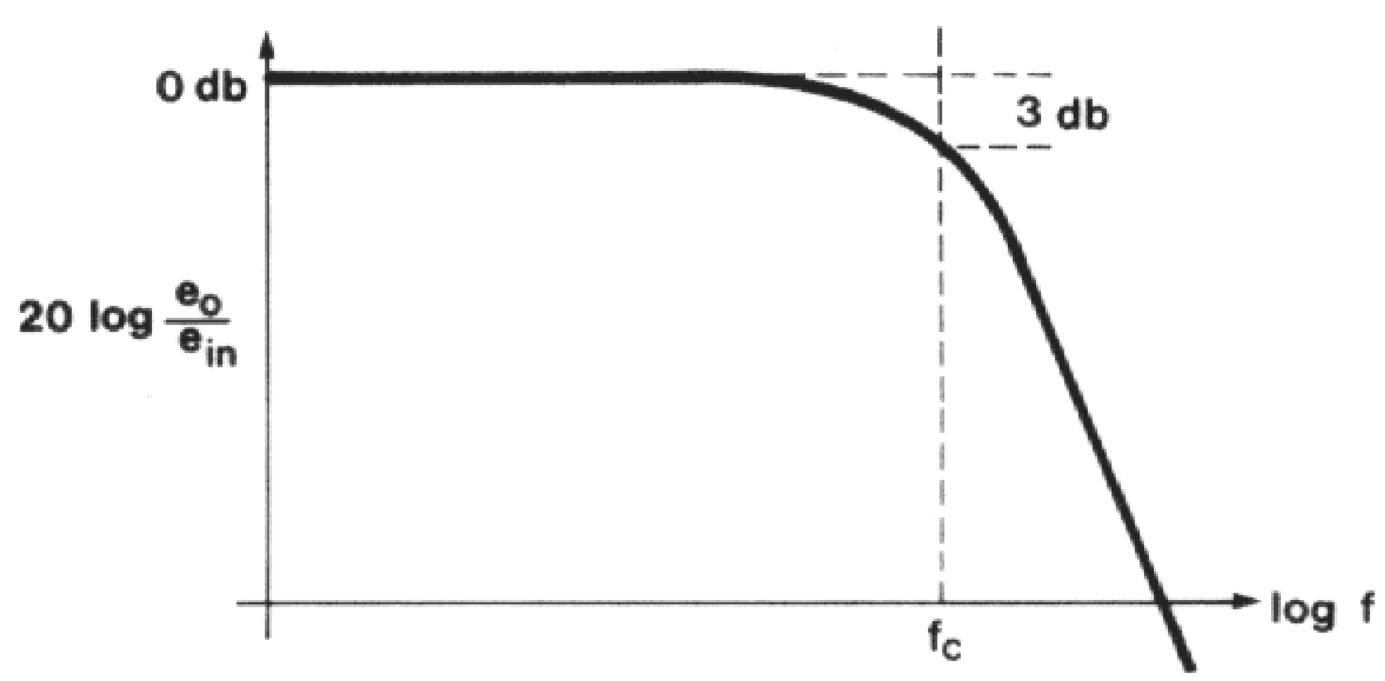


This program computes component values for Butterworth low-pass filters between equal terminations given filter order, termination resistance in ohms, and corner frequency in hertz.

$$C_i = \frac{1}{\pi f_c R} \sin \frac{(2i-1)\pi}{2n}, \quad i = 1, 3, 5, \ldots$$

$$L_i = \frac{R}{\pi f_c} \sin \frac{(2i-1)\pi}{2n}, \quad i = 2, 4, 6, \ldots$$





Example:

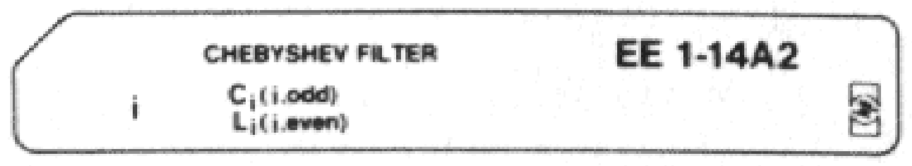
$n = 6$
$R = 50\ \Omega$
$f_c = 10$ MHz

Compute
$C_1 = 164.8$ pF (1.6477×10^{-10})
$L_2 = 1.13\ \mu$H (1.1254×10^{-6})
$C_3 = 614.9$ pF (6.1493×10^{-10})
$L_4 = 1.54\ \mu$H (1.5373×10^{-6})
$C_5 = 450.2$ pF (4.5016×10^{-10})
$L_6 = .412\ \mu$H (4.1192×10^{-7})

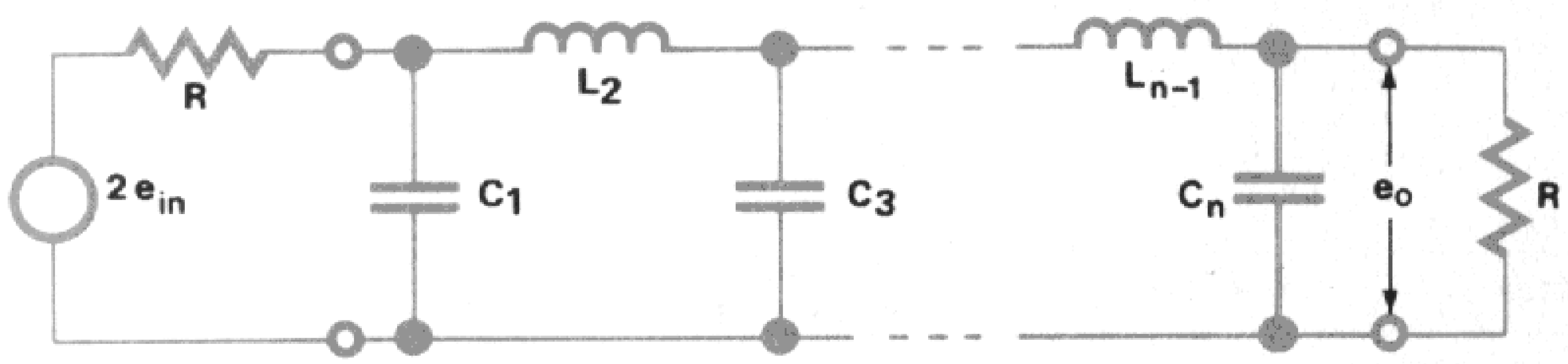
EE1–13A

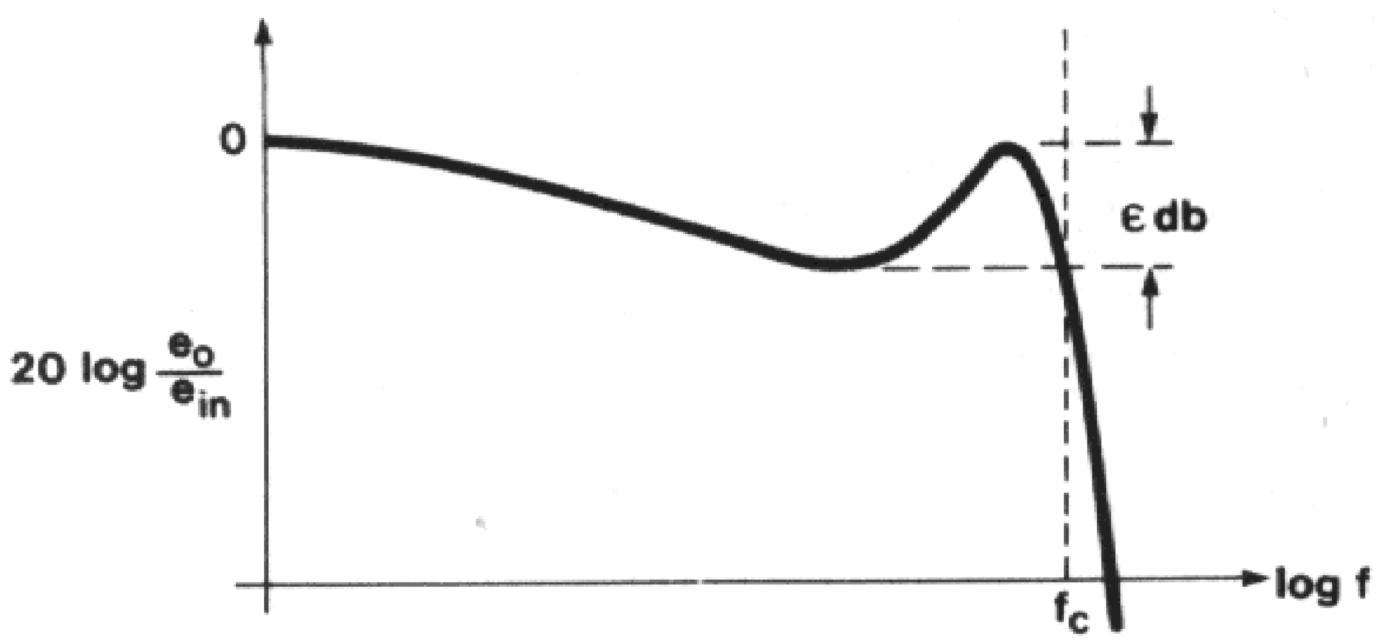
STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
1	Enter program			
2	Input filter parameters			
	Filter order	n	A	
	Termination resistance	R, Ω	B	
	Corner frequency	f_c, Hz	C	
3	Output element values			
	Position of C value		D	i(odd)
	Capacitance		R/S	C_i, F
	Position of L value		E	i(even)
	Inductance		R/S	L_i, H
4	Repeat step 3 until flashing			
	zero indicates all data has been			
	displayed.			
5	Return to step 2 for new case			

CHEBYSHEV FILTER



This program computes component values for Chebyshev low-pass filters between equal terminations given filter order, termination resistance in ohms, corner frequency in hertz, and allowable ripple in decibels.





The capacitors and inductors are given by

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

$$L_i = \frac{R\,G_i}{2\pi f_c}, \qquad i = 2, 4, 6, \ldots, (n-1)$$

where

$$G_1 = \frac{2a_1}{\gamma}$$

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

$$\gamma = \sinh\left[\frac{\ln\left(\coth\dfrac{\epsilon}{40\log e}\right)}{2n}\right]$$

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

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

Example:

$n = 7$

$R = 50\ \Omega$

$f_c = 3.2$ MHz

$\epsilon = 0.1$ dB

Compute

$C_1 = 1175$ pF (1.175×10^{-9})

$C_3 = 2086$ pF (2.086×10^{-9})

$C_5 = 2086$ pF (2.086×10^{-9})

$C_7 = 1175$ pF (1.175×10^{-9})

$L_2 = 3.538\ \mu$H (3.538×10^{-6})

$L_4 = 3.913\ \mu$H (3.913×10^{-6})

$L_6 = 3.538\ \mu$H (3.538×10^{-6})

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
1	Enter program 1			
2	Inputs (any order)			
	Filter order	n	A	
	Termination resistance	R, Ω	B	
	Corner frequency	f_c, Hz	C	
	Passband ripple	ε, dB	D	
3	Begin calculations		E	
4	Enter program 2			
5	Outputs			
	Counter		A	i(odd) or i(even)
	Component value		B	C_i, F or L_i, H
6	Repeat step 5 until flashing zero			
	indicates all data has been			
	displayed			
7	Go to step 1 for new case			

CAPACITANCE OF PARALLEL PLATES

CAPACITANCE OF PARALLEL PLATES				EE 1-15A
ϵ_r ①	d ②	L ③	W ④	C

The capacitance of parallel plates and thin strips is given approximately by

$$C = 0.0885419 \frac{\epsilon_r LW}{d} [1 + P]$$

where

$$P = \begin{cases} 0; & 100\,W > L \\ \dfrac{d}{\pi W}\left(1 + \ln \dfrac{2\pi W}{d}\right); & L \geqslant 100\,W \end{cases}$$

ϵ_r = relative permittivity of medium between plates

d = distance between plates in cm or inches

L = length of plates in cm or inches

W = width of plates in cm or inches

C = capacitance in picofarads

The formula given is accurate only when L >> d and W >> d, however the error is only –4% for $\frac{W}{d} = 2$ (Terman, *Radio Engineers Handbook*, 1943, Sec. 2, Par. 31).

Examples:

1. $\epsilon_r = 1$
   d = .01 cm
   L = 10 cm
   W = 1 cm
   C = 88.5 pF (8.854×10^1)

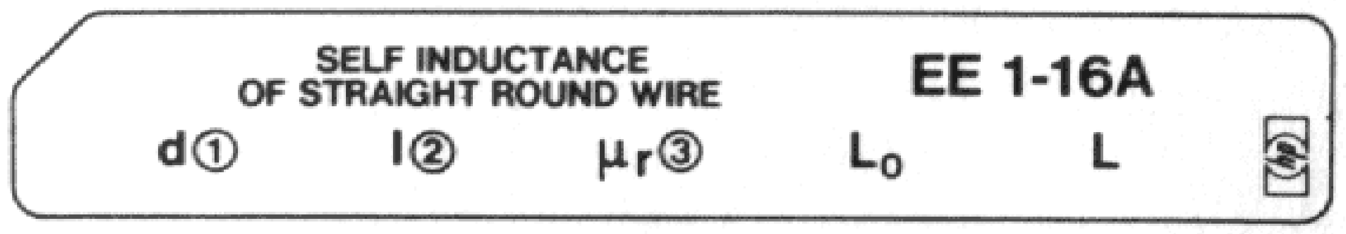
2. $\epsilon_r = 1$
   d = .01 cm
   L = 99 cm
   W = 1 cm
   C = 877 pF (8.766×10^2)

3. $\epsilon_r = 1$
   d = .01 cm
   L = 101 cm
   W = 1 cm
   C = 915 pF (9.155×10^2)

4. $\epsilon_r = 1$
   d = .01 cm
   L = 60 inches (enter as –60)
   W = .5 inch (enter as –.5)
   C = 1747 pF (1.747×10^3)

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	Enter program				
2	Initialize		RTN	R/S	–2.540
3	Inputs				
	Relative permittivity	ϵ_r	A		
	Plate spacing	d, cm or in.*	B		d, cm
	Length	L, cm or in.*	C		L, cm
	Width	W, cm or in.*	D		W, cm
4	Outputs				
	Capacitance		E		C, pF
	Capacitance with P = 0		RCL	5	C, pF
5	Recall inputs (optional)				
	Relative permittivity		RCL	1	ϵ_r
	Plate spacing		RCL	2	d, cm
	Length		RCL	3	L, cm
	Width		RCL	4	W, cm
6	Change data in step 3 for				
	new case				
*	Input inches negatively.				

SELF INDUCTANCE OF A STRAIGHT ROUND WIRE



This program computes the inductance of a straight round wire of length l, diameter d, and relative permeability μ_r.

The low-frequency inductance is (from Terman, *Radio Engineers' Handbook,* 1943, Sec. 2, Par. 8).

$$L_0 = 0.002l\left(\ln\frac{4l}{d} - 1 + \frac{\mu_r}{4}\right)$$

where

L_0 = inductance in μH
l = length in centimeters or inches
d = diameter in centimeters or inches
μ_r = relative permeability

The high-frequency inductance is

$$L = 0.002l\left(\ln\frac{4l}{d} - 1\right)$$

Note:

If μ_r is not specified, $\mu_r = 1$ is used.

Examples:

1. $d = 0.10$ cm (#18 AWG)
$l = 25$ cm
$\mu_r = 1$ (copper)
Compute
$L_o = 0.31\ \mu$H
$L = 0.30\ \mu$H

2. $d = 0.02535$ in. (#22 AWG)
$l = 5$ in.
$\mu_r = 1$
Compute
$L_o = 0.15\ \mu$H
$L = 0.14\ \mu$H

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	Enter program				
2	Initialize		RTN	R/S	0.00
3	Inputs				
	Wire diameter	d, cm or in.*	A		d, cm
	Wife length	l, cm or in.*	B		l, cm
	Relative permeability	μ_r**	C		
4	Outputs				
	Low frequency inductance		D		L_o, μH
	High frequency inductance		E		L, μH
5	Recall inputs (optional)				
	Wire diameter		RCL	1	d, cm
	Wire length		RCL	2	l, cm
	Relative permeability		RCL	3	μ_r
6	Return to step 3 for new case.				
*	Input inches negatively				
**	If not specified, $\mu_r = 1$				

INDUCTANCE OF A SINGLE-LAYER CLOSE-WOUND COIL

INDUCTANCE OF SINGLE - LAYER CLOSE - WOUND COIL			EE 1-17A	
R①	D②	N③	L④	CALC

The inductance of a single-layer coil is given approximately by Wheeler's formula:

$$L = \frac{N^2 R^2}{9R + 10\,ND}$$

where

L = inductance in μH

N = number of turns

R = ~~inside~~ radius of coil to centre of wire in inches

D = turn spacing in inches

This program will compute any one of these values given the other three.

Note:

This formula is accurate to about 1% when $\frac{2R}{ND} > 3$ (*Radiotron Designer's Handbook*, 1954, p. 432).

Examples:

1. L = 3.5 μH
   R = 0.25 inch
   D = 0.034 inch (#20 enamel wire)
   Calculate N = 24.24 turns

2. R = 1 inch
   D = 0.086 inch
   N = 30 turns
   Calculate L = 25.86 μH

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	Enter program				
2	Input knowns (any 3)				
	Coil radius	R, inches	A		
	Turn spacing	D, inches	B		
	Number of turns	N	C		
	Inductance	L, μH	D		
3	Calculate unknown (any 1)				
	Coil radius		E	A	R, inches
	Turn spacing		E	B	D, inches
	Number of turns		E	C	N
	Inductance		E	D	L, μH
4	Recall inputs				
	Coil radius		RCL	1	R, inches
	Turn spacing		RCL	2	D, inches
	Number of turns		RCL	3	N
	Inductance		RCL	4	L, μH
5	For new case, return to step 3.				

SKIN EFFECT AND COIL Q

SKIN EFFECT AND COIL Q			EE 1-18A		
d①	I③	δ	R_s	↑	
D②	f④	Q	R		

This program computes the skin depth, surface resistance (resistance per square), and resistance per meter of a cylindrical conductor.

$$\delta = \frac{1}{\sqrt{\pi\sigma\mu}} \frac{1}{\sqrt{f}} \cong \frac{6.608}{\sqrt{f}} \text{ cm}$$

$$R_s = \frac{1}{\delta\sigma} \cong 2.61 \times 10^{-7} \sqrt{f} \text{ ohm}$$

$$R = \frac{100\, R_s}{\pi d} \text{ ohms/meter}$$

where

$\mu = 4\pi \times 10^{-7}$ henrys/meter

$\frac{1}{\sigma} = 1.724 \times 10^{-8}$ ohm-meter (copper)

f = frequency, Hz

d = diameter of conductor, cm

This program also computes the Q of an unshielded solenoid using an approximation to Figure 3 on page 6–4 of *Reference Data for Radio Engineers,* fifth edition:

$$\text{for } d > 5.8 \text{ and } 0.4 < \frac{d}{\tau} < 0.8$$

$$Q \cong \overset{.0256}{\cancel{25.59}} \left(1.18 + \sin\left(.38 + 1.2 \log \frac{l}{D}\right)\right) D\sqrt{f}$$

where

D = mean diameter of coil, cm

d = conductor diameter or twice radial thickness (tubing)

τ = turn spacing

l = length of coil, cm

f = frequency, Hz

Notes:

1. Skin depth δ and surface resistance R_s may be computed at a given frequency without inputting coil dimensions.
2. The machine will be left in RAD mode.

Examples:

1. f = 100 MHz
   d = 0.1 cm
   Compute δ = 0.00066 cm
   $R_s = 2.61 \times 10^{-3}$ ohms
   R = 0.83 ohms/meter

2. f = 100 MHz
   d = 0.05 cm
   D = 0.2 cm
   l = 1 cm
   Compute $Q = 1.08 \times 10^5$

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	Enter program				
2	Initialize		RTN	R/S	
3	Input coil data				
	Wire diameter	d, cm	E	A	
	Coil diameter	D, cm	A		
	Coil length	l, cm	E	B	
	Frequency	f, Hz	B		
4	Compute desired outputs				
	Skin depth		E	C	δ, cm
	Q of unshielded coil		C		Q
	Resistance per square		E	D	R_s, Ω
	Resistance per meter		D		R, Ω/m
5	Return to step 3 for new data				

TRANSFORMER DESIGN

TRANSFORMER DESIGN			EE 1-19A	
Np①	f②	Ac③	Bm④	Ep⑤

This program evaluates transformer design equations found in *Reference Data for Radio Engineers,* fifth edition, Chapter 12.

A rough estimate of the net core area required for a temperature rise of about 50°C is given by

$$(A_c)_{est.} = \frac{\sqrt{W_{out}/f}}{0.72}$$

where

$(A_c)_{est.}$ = estimated core area in square inches

W_{out} = transformer output in watts

f = frequency in hertz

The number of primary turns required is

$$N_p = \frac{3.49 \times 10^6 \; E_p}{f \, A_c \, B_m} \text{ turns}$$

where

N_p = number of primary turns

B_m = flux density in gauss

E_p = input voltage in volts

This program solves for $(A_c)_{est}$ given W_{out} and f and it solves for the missing parameter in the turns equation given any four.

Example:

f = 60 Hz

W_{out} = 20 watts

Compute

$(A_c)_{est}$ = .80 in.^{2}

Enter

E_p = 120 volts

A_c = 1 in.^{2}

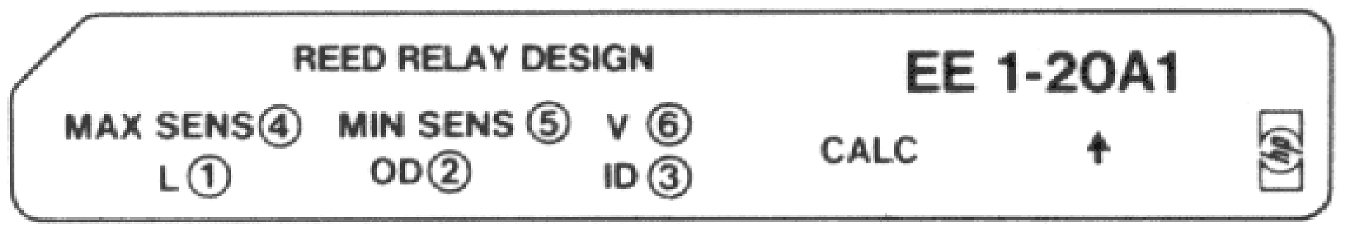
B_m = 13,000 gauss

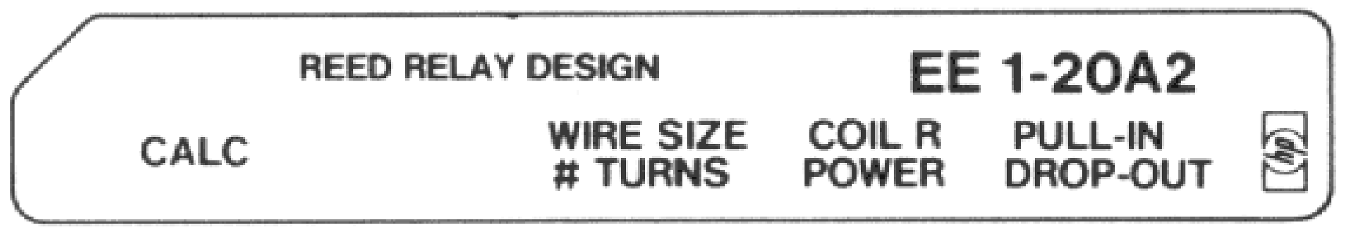
Compute

N_p = 537 turns (536.92)

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	Enter program				
2	If minimum core requirement				
	is known, skip to step 6				
3	Input frequency	f, Hz	B		f, Hz
4	Initialize		R/S		3 490 000
5	Input transformer output and				
	compute min core	W_{out}, W	R/S		$(A_c)_{est}$
6	Inputs knowns (any 4)				
	Number of primary turns	N_p	A		
	Frequency	f, Hz	B		
	Core area	A_c, (in.)^2	C		
	Flux density	B_m, Gs	D		
	Primary voltage	E_p, V	E		
7	Re-initialize		R/S		3 490 000
8	Compute unknown				
	Number of primary turns		A		N_p
	Frequency		B		f, Hz
	Core area		C		A_c, (in.)^2
	Flux density		D		B_m, Gs
	Primary voltage		E		E_p, V
9	Recall inputs (optional)				
	Number of primary turns		RCL	1	N_p
	Frequency		RCL	2	f, Hz
	Core area		RCL	3	A_c, (in.)^2
	Flux density		RCL	4	B_m, Gs
	Primary voltage		RCL	5	E_p, V
	Power output		RCL	6	W_{out}, W
10	For new case return to step 2				

REED RELAY DESIGN





This program designs a reed relay given the following data:

Sensitivity

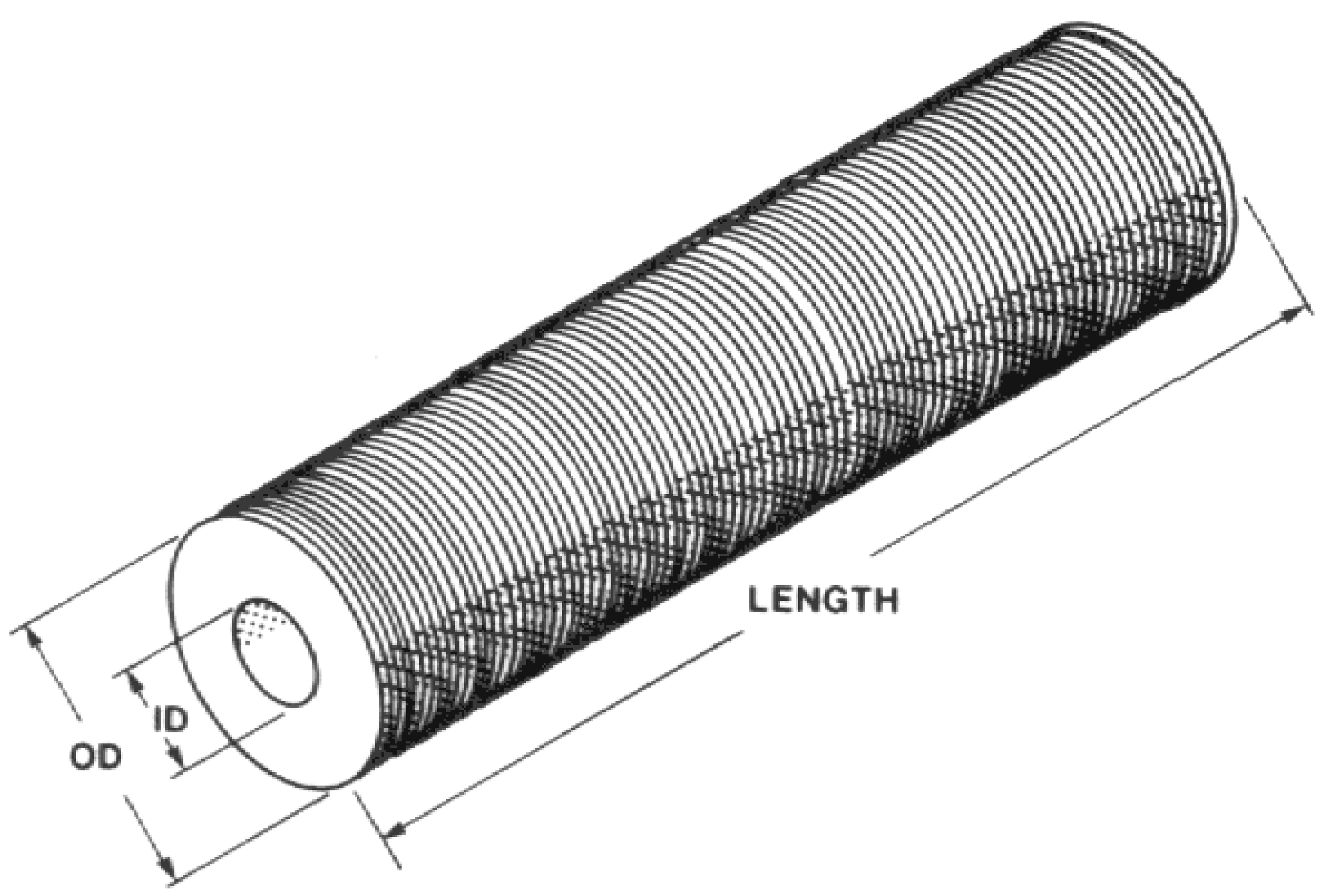
S_{max} = maximum ampere-turns needed for pull-in

S_{min} = minimum ampere-turns needed for drop-out

V = operating voltage

Geometry of coil

L = coil length, cm or in.
ID = inside diameter, cm or in.
OD = outside diameter, cm or in.



The program computes

Wire size (single insulation)
Number of turns
Coil resistance, Ω
Coil power, mW
Pull-in voltage (MAX @ 25°C), volts
Drop-out voltage (MIN @ 25°C), volts

using the equations below which assume a 50% overdrive.

Winding Area $$A = \frac{L(OD - ID)}{2}$$

Winding Volume $$V_w = .7854\,((OD)^2 - (ID)^2)L$$

Wire Size $$WS = INT\left[4 \ln\left(\frac{2.6 \times 10^5\ V}{2.3562(OD + ID)S_{max}}\right) + .5\right]$$

Number of turns $$T = 8.57\ A\ e^{.229ws}$$

Resistance of wire $$R = \frac{.0992\ e^{.2312ws}}{12000}\ \text{ohms/inch}$$

Coil resistance $$R_c = \frac{OD + ID}{2}\ \pi RT$$

Coil power $$P = \frac{V^2}{R_c}\ 1000$$

Pull-in voltage $$V_{pi} = \frac{1.1 S_{max}}{T}\ R_c$$

Drop-out voltage $$V_{do} = \frac{.3\ S_{min}}{T}\ R_c$$

Example:

Length = .8 in.
OD = .3 in.
ID = .2 in.
S_{max} = 50 ampere-turns
S_{min} = 30 ampere-turns
Voltage = 10 volts

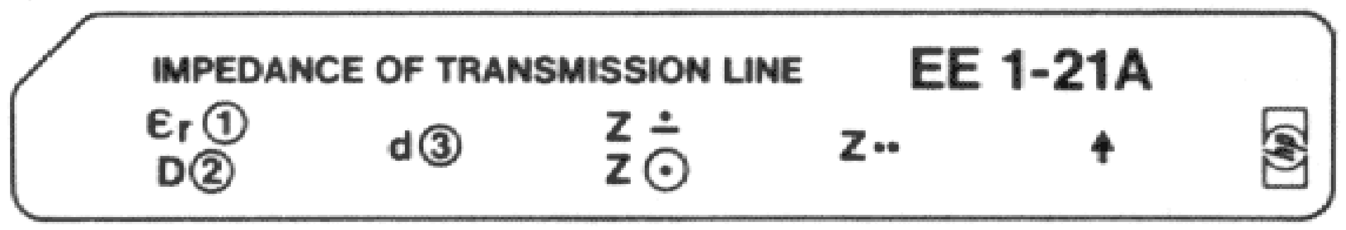
Compute
Wire size = 43
Number of turns = 6479
Coil resistance = 874 Ω
Coil power = 114 mW
Pull-in voltage = 7.42 volts
Drop-out voltage = 1.21 volts

Input WS = 40

Compute
Wire size = 40
Number of turns = 3260
Coil resistance = 220 Ω
Coil power = 455 mW
Pull-in voltage = 3.71 volts
Drop-out voltage = 0.61 volts

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	Enter program 1				
2	Initialize		RTN	R/S	
3	Input parameters				
	Length	L, cm or in.*	A		
	Outside diameter	OD, cm or in.*	B		
	Inside diameter	ID, cm or in.*	C		
	Maximum sensitivity	S_{max}, amp-turn	E	A	
	Minimum sensitivity	S_{min}, amp-turn	E	B	
	Voltage	V, volts	E	C	
4	Begin calculations		D		0.00
5	Enter program 2				
6	Continue calculations		A		0.00
7	Output data				
	Wire size		C		wire size
	Number of turns		R/S		No. of turns
	Coil resistance		D		Coil R, Ω
	Coil power		R/S		Power, mW
	Pull-in voltage		E		V_{pi}, volts
	Drop-out voltage		R/S		V_{do}, volts
8	Input new wire size	WS	STO	1	
9	Return to step 7.				
10	Return to step 1 for new case				
*	Input inches negatively				

IMPEDANCE OF TRANSMISSION LINE



This program computes high frequency characteristic impedance for three types of transmission lines.

1. The characteristic impedance of a coaxial line is

$$Z_0 = \frac{K}{\sqrt{\epsilon_r}} \log \frac{D}{d}$$

where

D = inner diameter of outer conductor
d = outer diameter of inner conductor
ϵ_r = relative permittivity of dielectric medium

$$K = \frac{\sqrt{\mu_0}}{2\pi\sqrt{\epsilon_0}\log e} \cong 138.06\ \Omega$$

where

μ_0 = permeability of free space
ϵ_0 = permittivity of free space

2. The characteristic impedance of a two-wire line is

$$Z_0 = \frac{2K}{\sqrt{\epsilon_r}} \log \left(\frac{D}{d} + \sqrt{\left(\frac{D}{d}\right)^2 - 1} \right)$$

where

D = center-to-center conductor spacing
d = conductor diameter
ϵ_r, K as above

3. The characteristic impedance of a single conductor near ground is

$$Z_0 = \frac{K}{\sqrt{\epsilon_r}} \log \frac{4D}{d}$$

where

D = spacing of center of conductor from ground
d = conductor diameter
ϵ_r, K as above

Examples:

1. D = .68 in. RG–218/U coaxial cable
d = .195 in.
ϵ_r = 2.3 (polyethylene)

Compute Z ⊙ = 49.38 Ω

2. D = 6. in.
d = .0808 in. (#12 AWG wire)
ϵ = 1 (air)

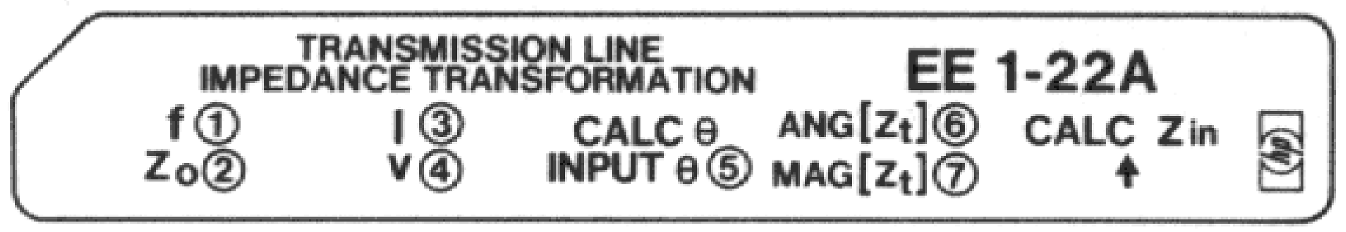
Compute Z • • = 599.66 Ω

3. D = 6 in.
d = .1285 in. (#8 AWG wire)
ϵ_r = 1

Compute Z ÷ = 313.58 Ω

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
1	Enter program			
2	Initialize		RTN R/S	138.06
3	Input data (any order)			
	Relative permittivity	ϵ_r	E A	
	Diameter or spacing	D } like units	A	
	Diameter	d } like units	B	
4	Compute outputs			
	Z_0 ÷		E C	Z_0, ohms
	Z_0 ⊙		C	Z_0, ohms
	Z_0 • •		D	Z_0, ohms
5	Recall inputs			
	Relative permittivity		RCL 1	ϵ_r
	Diameter or spacing		RCL 2	D } like units
	Diameter		RCL 3	d } like units
6	For new case, return to step 3.			

TRANSMISSION LINE IMPEDANCE TRANSFORMATION



The electrical length of a lossless transmission line of characteristic impedance Z_o ohms and length l centimeters

$$\theta = \frac{1.20083 \times 10^{-8}}{v} lf$$

where

θ = electrical length in degrees

l = physical length in centimeters

f = frequency in Hz

v = velocity factor of line $\left(v = \frac{1}{\sqrt{\epsilon_r}}\right)$

If such a line is terminated in Z_t, the input impedance of the line becomes

$$Z_{in} = Z_o \left[\frac{\frac{Z_t}{Z_o} + j \tan\theta}{1 + j \frac{Z_t}{Z_o} \tan\theta} \right]$$

This program computes θ from l, f, and v and computes Z_{in} from θ and Z_t.

Note:

If it is desired to transform through 90°, use θ = 89.99999 to avoid overflow during execution of LBL E.

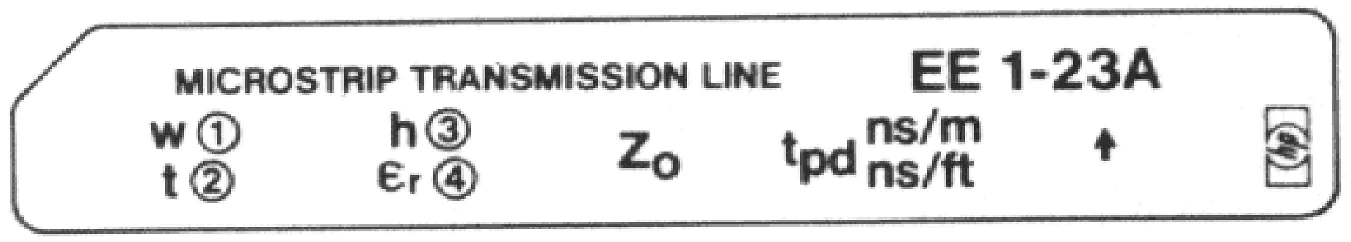
Examples:

1. f = 146 MHz
   Z_o = 50 Ω
   l = 20 centimeters
   v = .69 (Teflon)
   MAG [Z_t] = 75 Ω
   ANG [Z_t] = 30°
   Compute θ = 50.82°
   MAG [Z_{in}] = 74.12 Ω   ANG [Z_{in}] = –30.44°

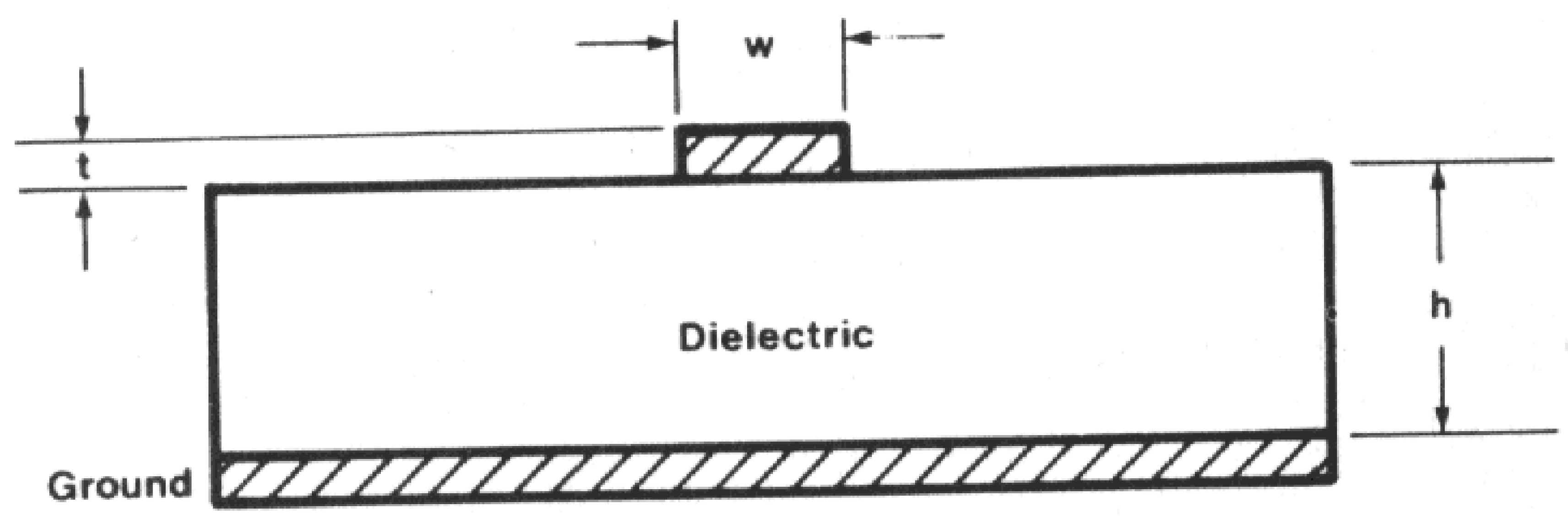
2. Same data as above except let θ = 89.99999°
   MAG [Z_{in}] = 33.33 Ω   ANG [Z_{in}] = –30.00°

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	Enter program				
2	Initialize		RTN	R/S	
3	Inputs				
	Frequency	f, Hz	E	A	
	Characteristic Impedance	Z_o, Ω	A		
	Length	l, cm	E	B	
	Velocity factor	v	B		
	MAG[Z termination]	MAG[Z_t], Ω	D		
	ANG[Z termination]	ANG[Z_t], deg.	E	D	
4	Compute electrical				
	length of line		E	C	θ, deg.
5	Input desired value for				
	θ (see note 1)	θ, deg.	C		
6	Compute transformed				
	impedance		E	E	MAG[Z_{in}], Ω
			g	x⇄y	ANG[Z_{in}], deg.
7	Recall inputs (optional)				
	Frequency		RCL	1	f, Hz
	Characteristic Impedance		RCL	2	Z_o, Ω
	Length		RCL	3	l, cm
	Velocity factor		RCL	4	v
	MAG[Z termination]		RCL	7	MAG[Z_t], Ω
	ANG[Z termination]		RCL	6	ANG[Z_t], deg.
	Electrical length of line		RCL	5	θ, deg.

MICROSTRIP TRANSMISSION LINE



This program computes the characteristic impedance and propagation delay of microstrip line using the formulas from p. 39 of Blood, William R., *MECL System Design Handbook,* Motorola, Inc., 1971.



The characteristic impedance of the line shown is

$$Z_o = \frac{87}{\sqrt{\epsilon_r + 1.41}} \ln\left(\frac{5.98\,h}{0.8w + t}\right)$$

and the propagation delay is

$$t_{pd} = 1.017\sqrt{0.475\,\epsilon_r + 0.67}\ \frac{\text{ns}}{\text{ft.}}$$

Note: The units of w, h, and t may be anything as long as they are alike.

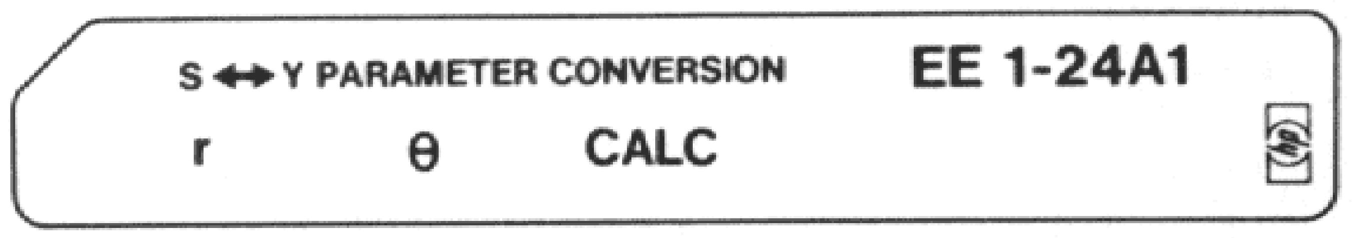
Examples:

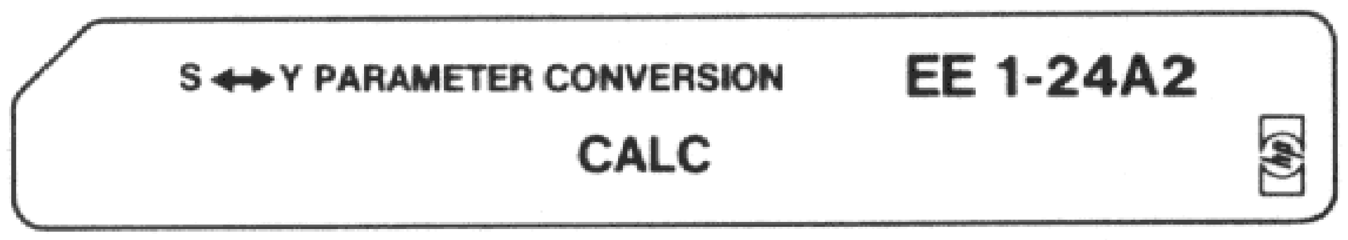
1. w = 50 mils
   t = 1.5 mils
   h = 30 mils
   $\epsilon_r = 4.7$
   Compute
   $Z_o = 51.52\ \Omega$
   $t_{pd} = 1.73\ \frac{\text{ns}}{\text{ft.}} = 5.68\ \frac{\text{ns}}{\text{m}}$

2. w = 90 mils
   t = 1.5 mils
   h = 60 mils
   $\epsilon_r = 4.7$
   Compute
   $Z_o = 55.80\ \Omega$
   $t_{pd} = 1.73\ \frac{\text{ns}}{\text{ft.}} = 5.68\ \frac{\text{ns}}{\text{m}}$

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	Enter program				
2	Initialize		RTN	R/S	
3	Inputs				
	Line width	w (like units)	E	A	
	Line thickness	t (like units)	A		
	Dielectric thickness	h (like units)	E	B	
	Relative permittivity	ϵ_r	B		
4	Outputs				
	Characteristic impedance		C		Z_o, Ω
	Propagation delay		E	D	t_{pd}, ns/m
	Propagation delay		D		t_{pd}, ns/ft.
5	Recall inputs (optional)				
	Line width		RCL	1	w (like units)
	Line thickness		RCL	2	t (like units)
	Dielectric thickness		RCL	3	h (like units)
	Relative permittivity		RCL	4	ϵ_r
6	Return to step 2 for new case.				

S⇄Y PARAMETER CONVERSION





This program converts s–parameters to y–parameters using the relationship

$$A = \frac{1}{(1 + s_{11})(1 + s_{22}) - s_{12}\,s_{21}}$$

$$\begin{bmatrix} y_{11} & y_{12} \\ y_{21} & y_{22} \end{bmatrix} = A \begin{bmatrix} (1 - s_{11})(1 + s_{22}) + s_{12}\,s_{21} & -2s_{12} \\ -2s_{21} & (1 + s_{11})(1 - s_{22}) + s_{12}\,s_{21} \end{bmatrix}$$

Note:

y–parameters may be converted to s–parameters by interchanging the y's and s's in the above relationship.

Examples:

1. $$S = \begin{bmatrix} .48 \measuredangle 133 & .115 \measuredangle 17 \\ 1.2 \measuredangle -15 & .67 \measuredangle -114 \end{bmatrix}$$

Compute

$$Y = \begin{bmatrix} 2.35 \measuredangle -34.2 & .391 \measuredangle -147 \\ 4.08 \measuredangle -179 & 1.97 \measuredangle 63.8 \end{bmatrix}$$

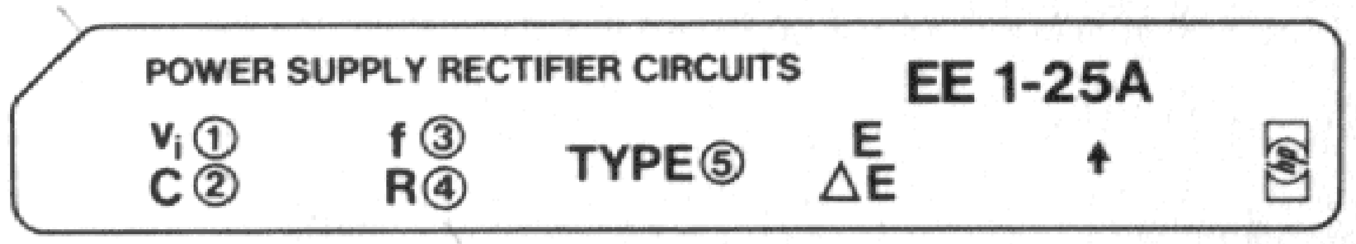
2. $$Y = \begin{bmatrix} 2.35 \measuredangle -34.2 & .391 \measuredangle -147 \\ 4.08 \measuredangle -179 & 1.97 \measuredangle 63.8 \end{bmatrix}$$

Compute

$$S = \begin{bmatrix} .480 \measuredangle 133 & .115 \measuredangle 17.2 \\ 1.21 \measuredangle -14.8 & .669 \measuredangle -114 \end{bmatrix}$$

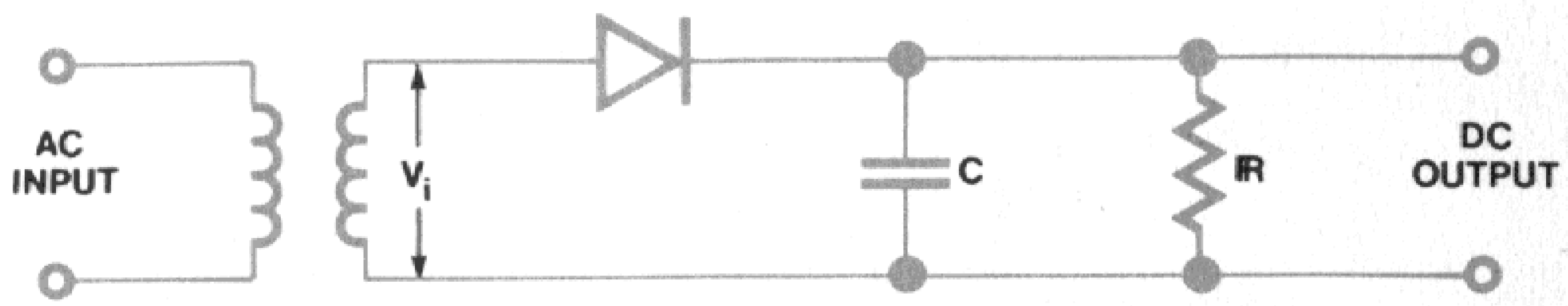
STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
1	Enter program 1			
2	Input s–parameters			
		MAG[s_{11}]	A	
		ANG[s_{11}]	B	
		MAG[s_{12}]	A	
		ANG[s_{12}]	B	
		MAG[s_{21}]	A	
		ANG[s_{21}]	B	
		MAG[s_{22}]	A	
		ANG[s_{22}]	B	
3	Output y–parameters			
			C	MAG[y_{12}]
			R/S	ANG[y_{12}]
			R/S	MAG[y_{21}]
			R/S	ANG[y_{21}]
4	Set up for program 2			
			R/S	
5	Enter program 2			
6	Output remaining			
	y–parameters		C	MAG[y_{11}]
			R/S	ANG[y_{11}]
			R/S	MAG[y_{22}]
			R/S	ANG[y_{22}]

POWER SUPPLY RECTIFIER CIRCUITS

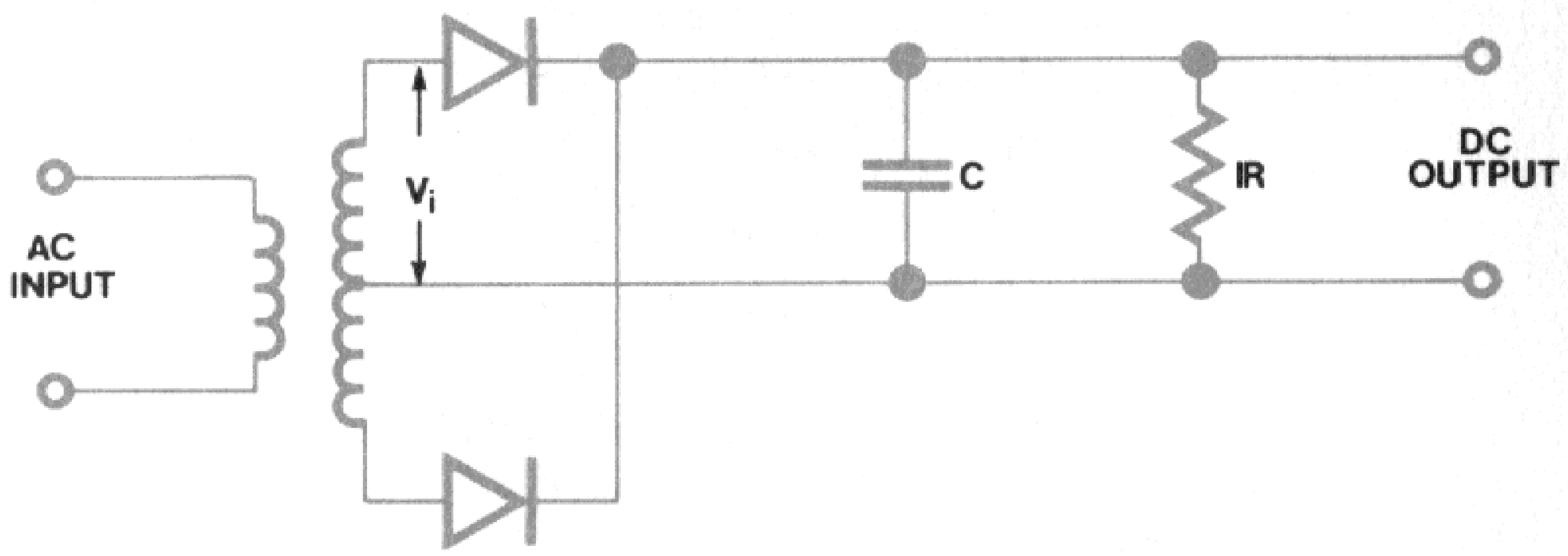


The following three circuits are commonly used to convert AC to DC.

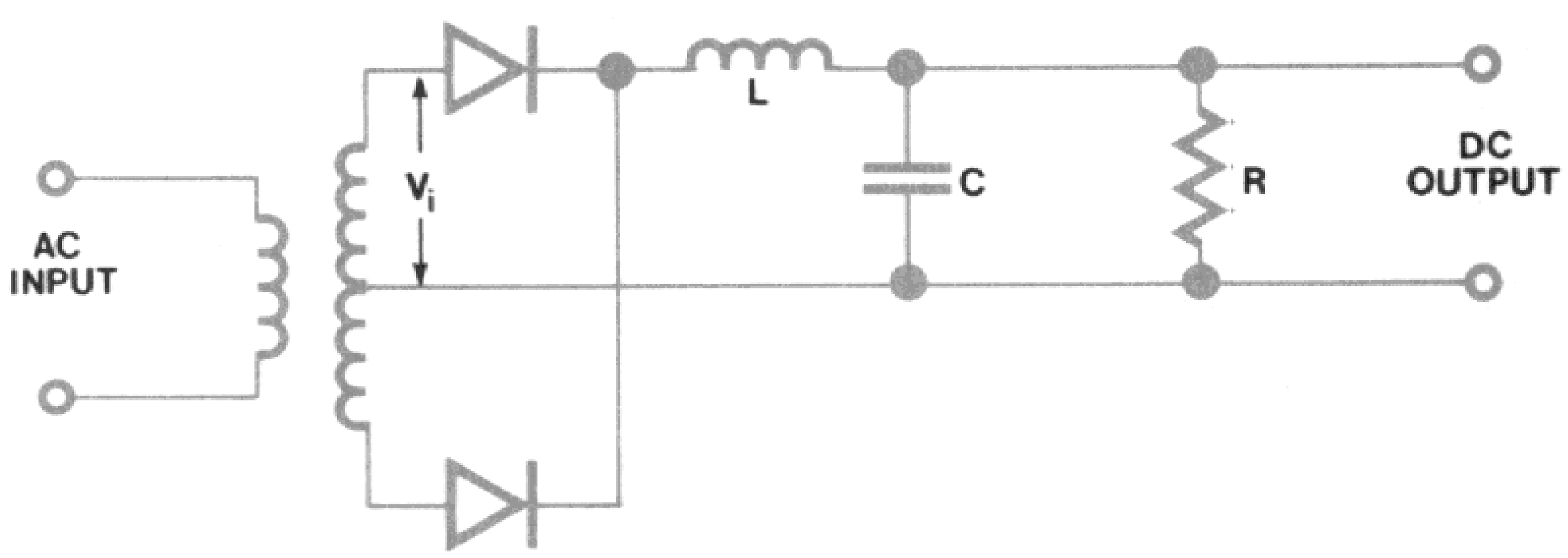
1. half-wave rectifier, capacitive input filter



2. full-wave rectifier, capacitive input filter



3. full-wave rectifier, inductive input filter



Given the following parameters:

V_i = RMS voltage at rectifier input in volts

f = frequency of a-c source in hertz

C = capacitance in farads

R = parallel combination of load resistance and bleeder resistance (if any) in ohms

L = inductance (type 3 only) in henrys

The average d-c output voltage, E, and the peak-to-peak ripple are given by these approximate formulas which are valid for $\Delta E \ll E$ and (type 3) $L \geqslant R/6\pi f$.

	1	2	3
ΔE	$\frac{\sqrt{2}\,V_i}{fRC}$	$\frac{\sqrt{2}\,V_i}{2\,fRC}$	$\frac{\sqrt{2}\,V_i}{6\pi^3 f^2 LC}$
E	$\sqrt{2}\,V_i - \frac{\Delta E}{2}$	$\sqrt{2}\,V_i - \frac{\Delta E}{2}$	$\frac{2\sqrt{2}\,V_i}{\pi}$

Examples:

1. Type 1

   V_i = 100 volts
   C = 100 μF
   f = 60 Hz
   R = 1000 Ω

   Compute ΔE = 23.57 volts peak-to-peak
   E = 129.64 volts

2. Type 2

   Same values as above

   Compute ΔE = 11.79 volts
   E = 135.53 volts

3. Type 3

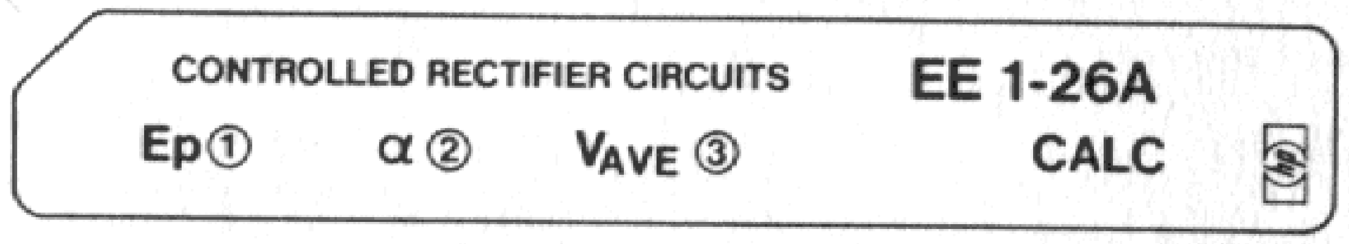
   Same values as above, plus L = 2H

   Check L_{MIN} = .884 < 2

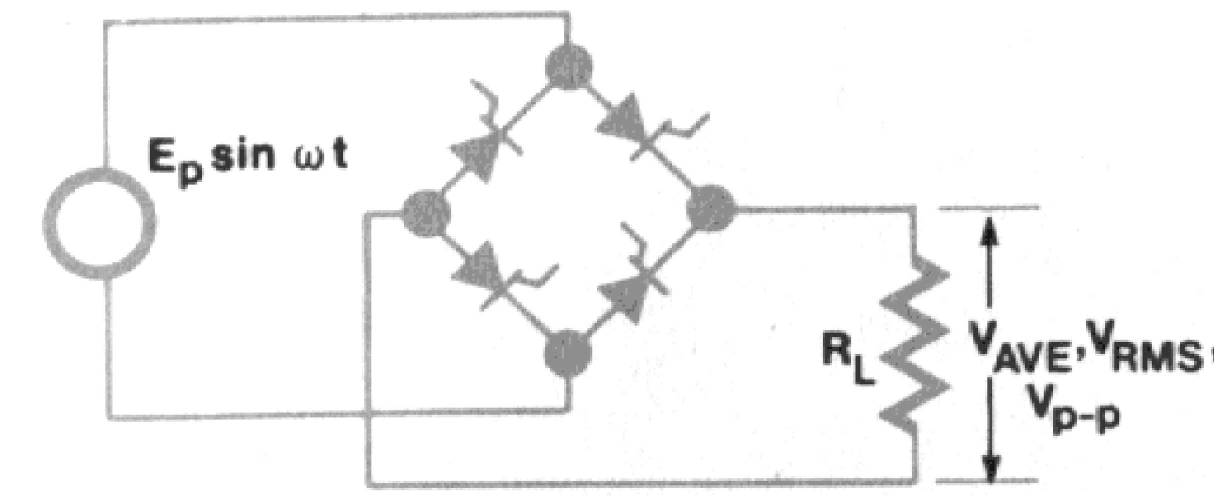
   Compute ΔE = 1.06 volts
   E = 90.03 volts

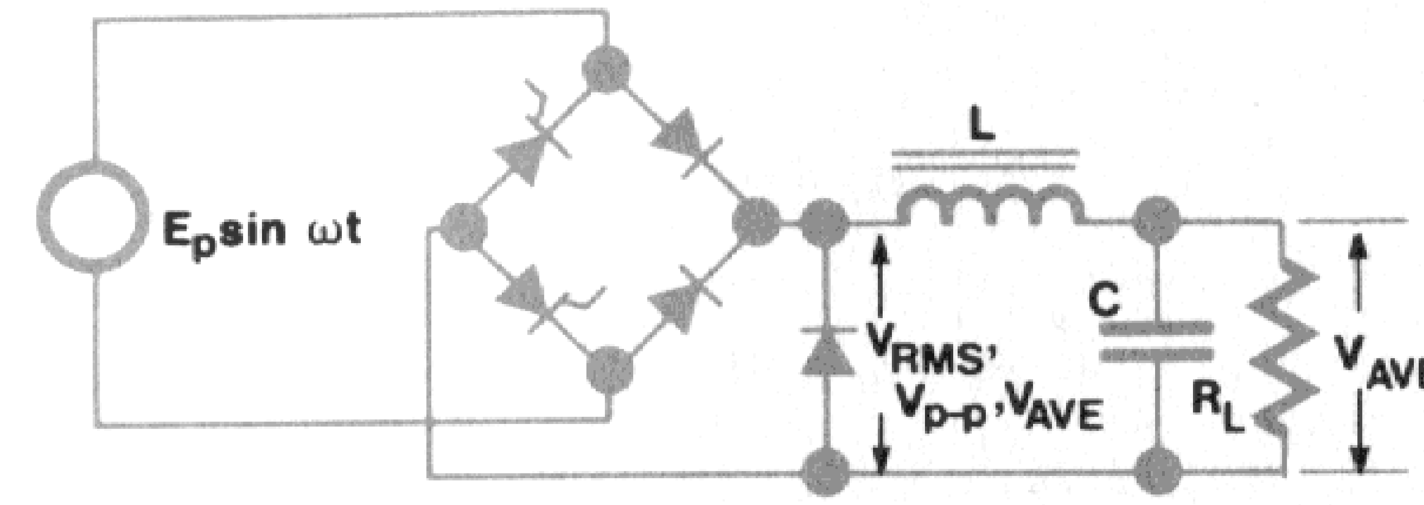
STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	Enter program				
2	Initialize		RTN	R/S	
3	Inputs (any order)				
	RMS input voltage	V_i, volts	E	A	
	Capacitance	C, F	A		
	Frequency	f, Hz	E	B	
	Resistance	R, Ω	B		
	Type (1=half wave,	Type	C		
	2=full wave, 3=full wave L–C)				
4	(Type 3 only)				
	Check L_{MIN}		RCL	7	L_{MIN}, H
	Input L $\geqslant L_{MIN}$	L, H	STO	7	
5	Outputs				
	Peak-to-peak ripple		D		ΔE, volts
	DC output voltage		E	D	E, volts
6	Recall inputs				
	RMS input voltage		RCL	1	V_i, volts
	Capacitance		RCL	2	C, F
	Frequency		RCL	3	f, Hz
	Resistance		RCL	4	R, Ω
	Type		RCL	5	Type
	Inductance		RCL	7	L or L_{MIN}
7	Return to step 3 for new case				

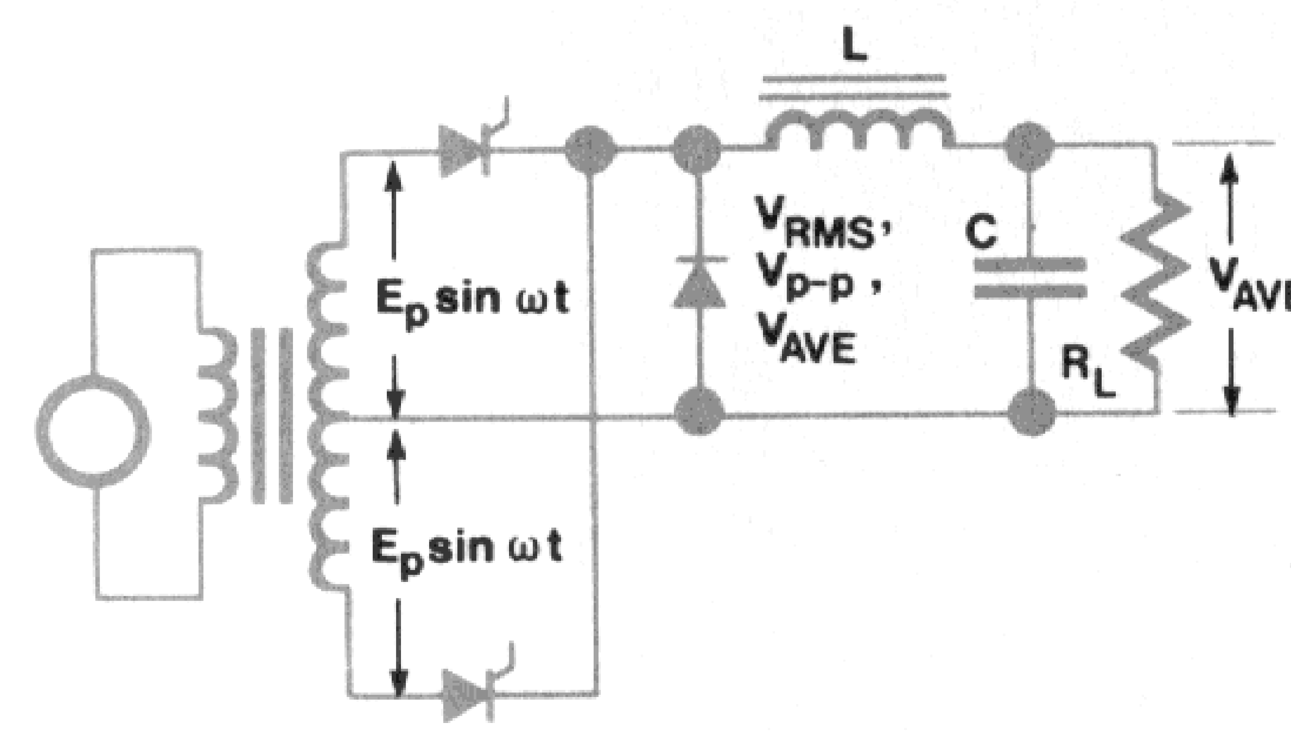
CONTROLLED RECTIFIER CIRCUITS

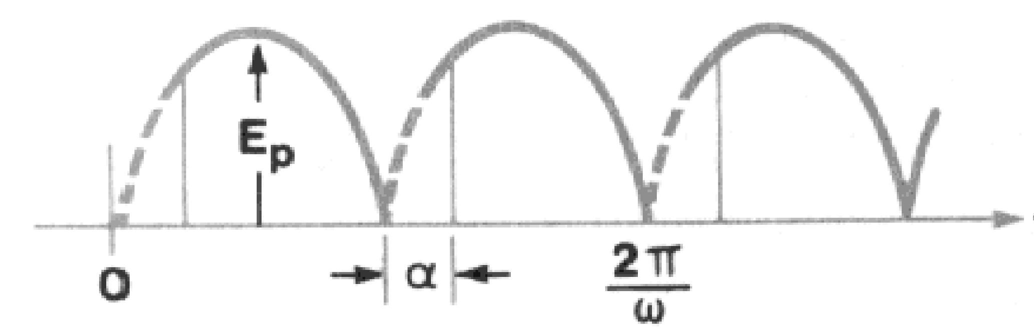


This program computes V_{AVE}, V_{RMS}, and $V_{p\text{-}p}$ as functions of E_p and α for the circuits shown. It also computes E_p (or α) given α and V_{AVE} (or E_p and V_{AVE}). The equations assume negligible voltage drops in the SCR's (or thyratrons) and in the other rectifiers. They also assume zero internal resistance in the chokes and zero equivalent series impedance in the power sources and transformers.







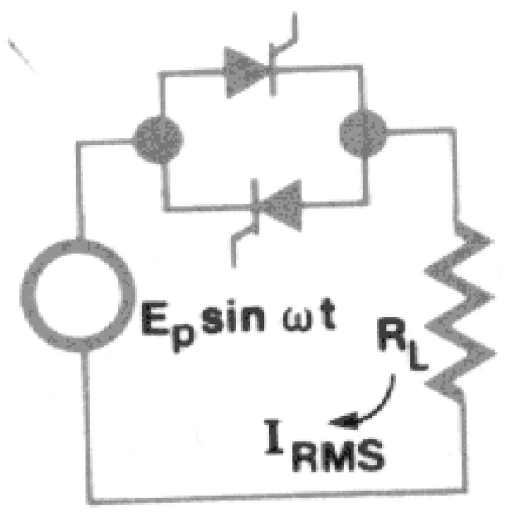


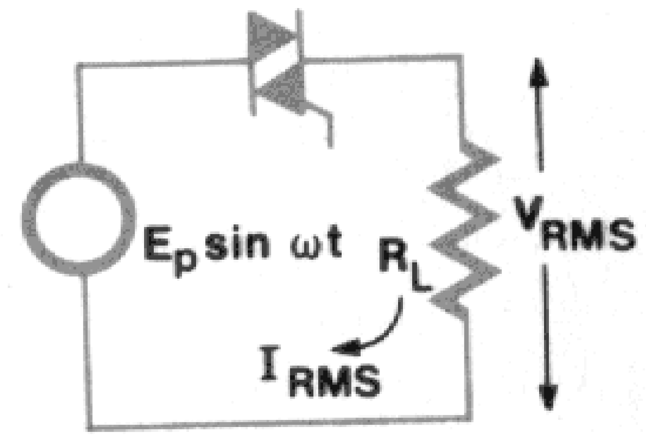
For these circuits the output is

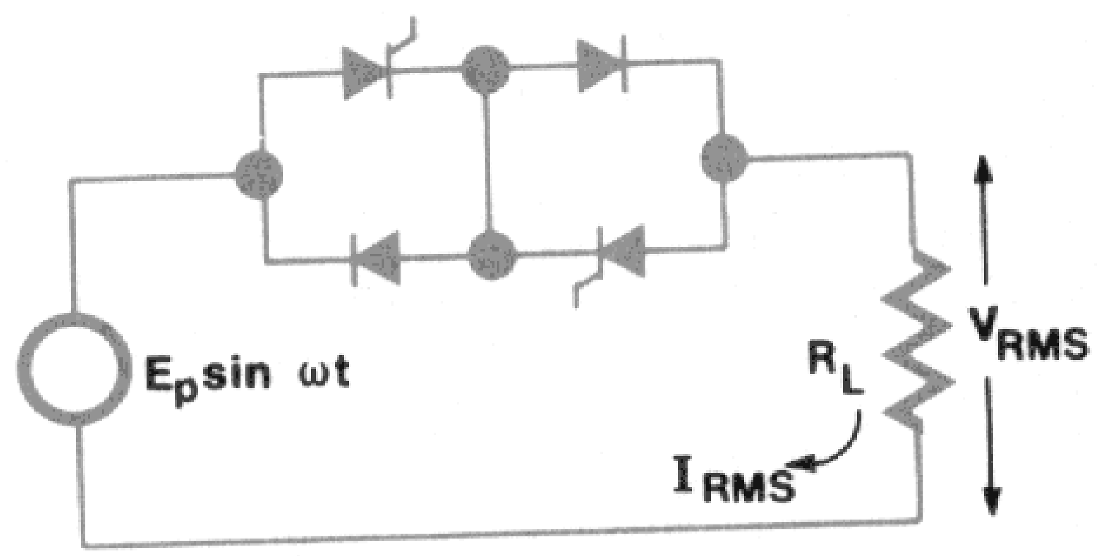
$$V_{AVE} = \frac{E_p}{\pi}(1 + \cos\alpha)$$

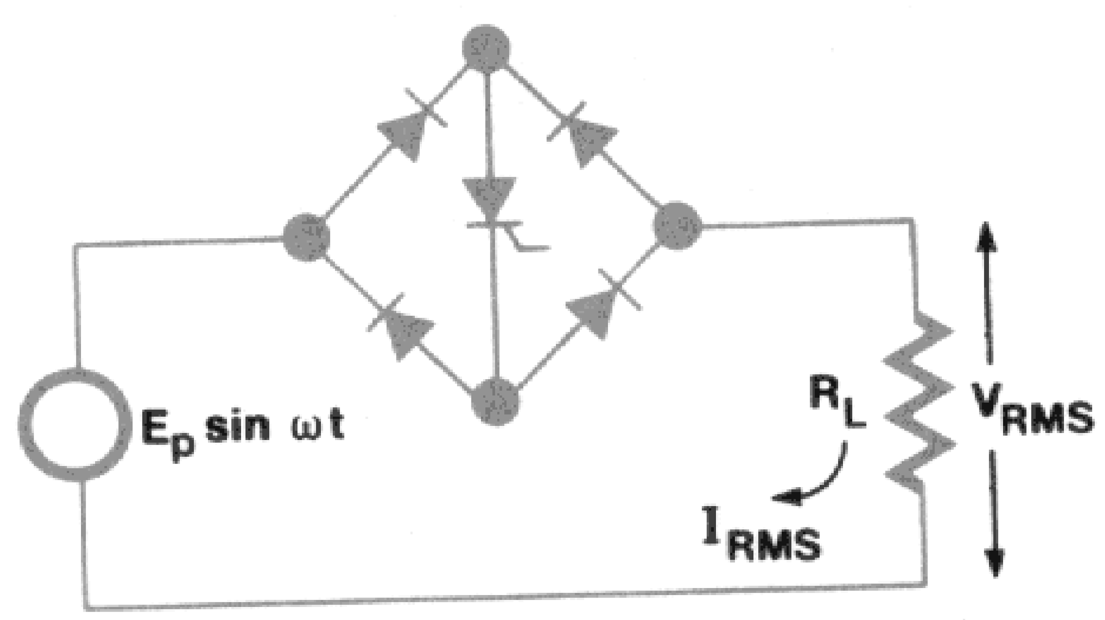
$$V_{p\text{-}p} = \begin{cases} E_p;\ \alpha \leqslant 90^\circ \\ E_p \sin\alpha;\ \alpha > 90^\circ \end{cases}$$

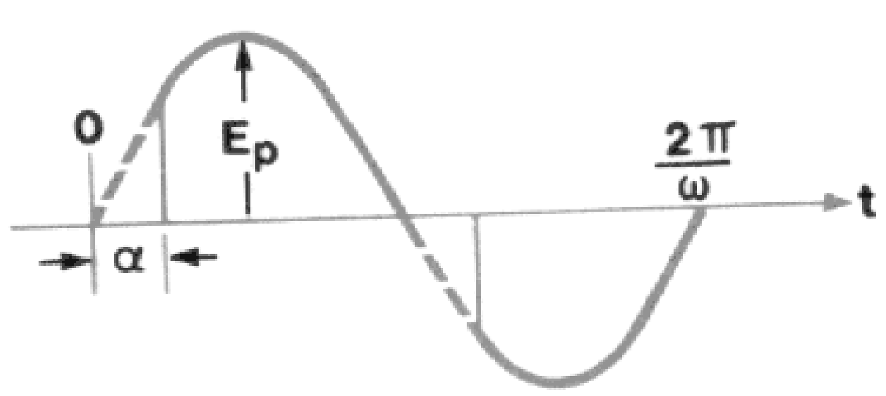
$$V_{RMS} = E_p \sqrt{\frac{2(\pi - \alpha) + \sin 2\alpha}{4\pi}}$$











For these circuits the output is

$$V_{RMS} = E_p \sqrt{\frac{2(\pi - \alpha) + \sin 2\alpha}{4\pi}}$$

Examples:

1. $E_p = 170$
   $\alpha = 30°$

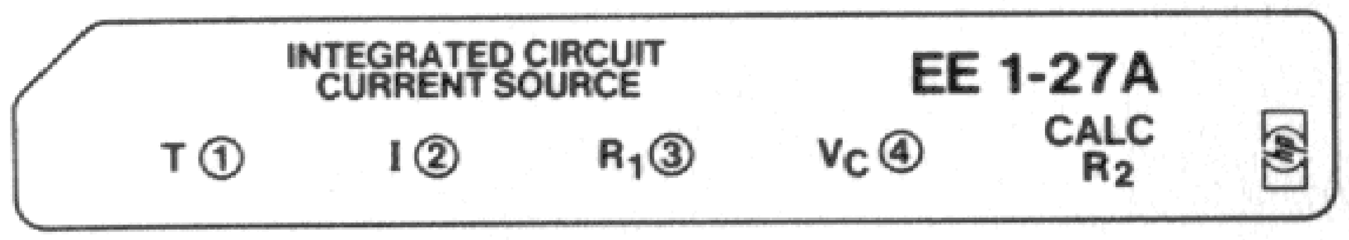
   Compute
   $V_{AVE} = 100.98$
   $V_{p\text{-}p} = 170.00$

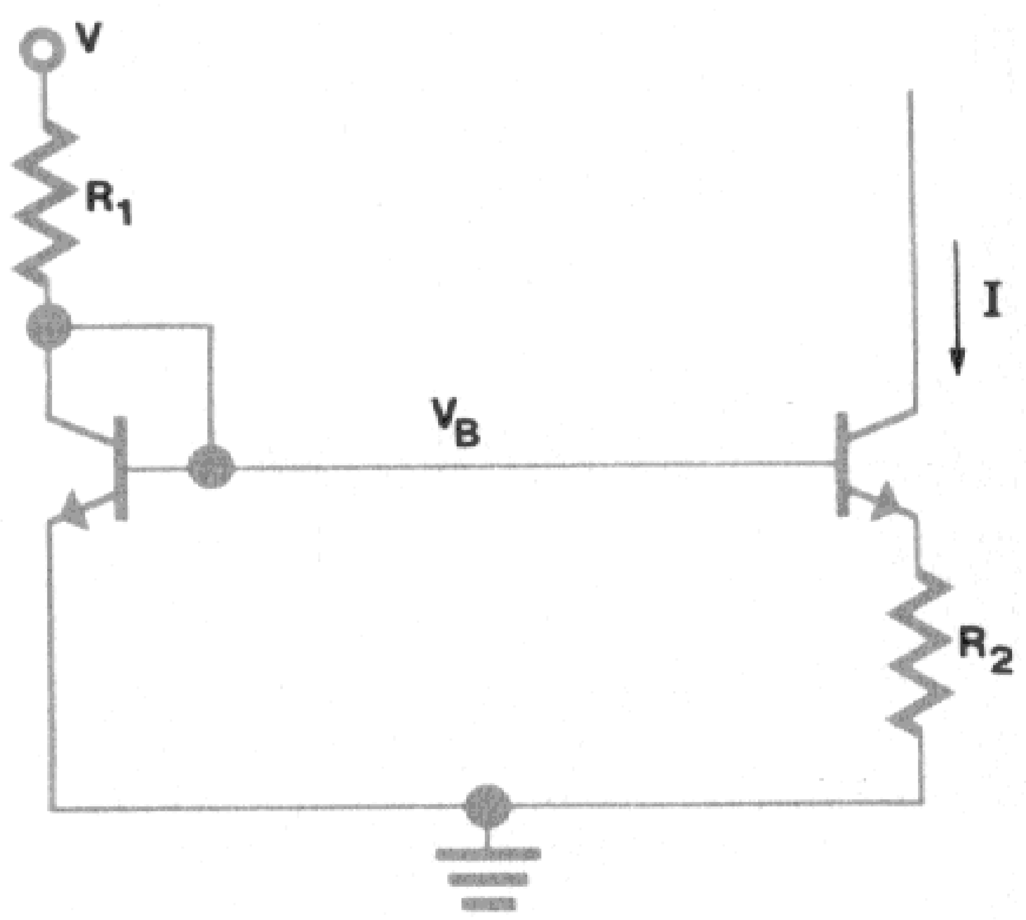
2. $E_p = 170$
   $V_{AVE} = 50$

   Compute
   $\alpha = 94.36$
   Input $\alpha = 94.36$
   Then compute
   $V_{RMS} = 80.79$
   $V_{p\text{-}p} = 169.51$

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	Enter program				
2	Initialize		g	DEG	
3	Inputs (any two)				
	Peak input voltage	E_p, V	A		
	Firing (delay) angle	α, deg.	B		
	Average output voltage	V_{AVE}, V	C		
4	Output remaining one				
	Peak input voltage		E	A	E_p, V
	Firing (delay) angle		E	B	α, deg.
	Average output voltage		E	C	V_{AVE}, V
5	Optional outputs*				
	RMS rectifier output		E	R/S	V_{RMS}, V
	then p-p rectifier output		R/S		$V_{p\text{-}p}$, V
*	E_p and α must be inputs. If one				
	is unknown, it may be com-				
	puted in step 4 and then				
	re-entered in step 3.				

INTEGRATED CIRCUIT CURRENT SOURCE





For this common IC bias circuit, the resistance R_2 can be found from

$$R_2 = \frac{kT_a}{qI} \ln \left[\frac{V_C - V_B}{R_1 I} \right]$$

where

$k = 1.38 \times 10^{-23} \frac{J}{K}$, Boltzman's constant

T_a = absolute temperature of junction in kelvins

$q = 1.6 \times 10^{-19}$ C, the electronic charge

V_B = 0.6 volts, the contact potential for silicon

This program evaluates the above equation given

T, the junction temperature in °C
I, the desired current in amperes
R_1, the desired value for R_1 in ohms
V_C, the supply voltage in volts

Examples:

1. T = 50°C
   I = 10 μA
   R_1 = 10 kΩ
   V = 10V

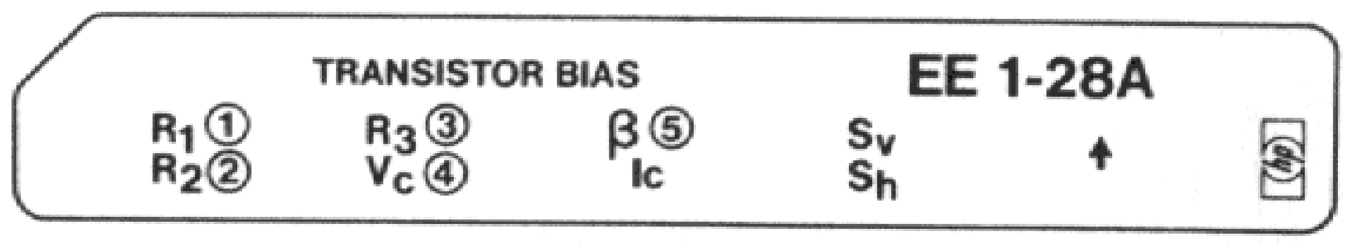
   Compute
   R_2 = 12.7 kΩ (12657.05)

2. T = 100°C
   I = 10 μA
   R_1 = 10 kΩ
   V = 10V

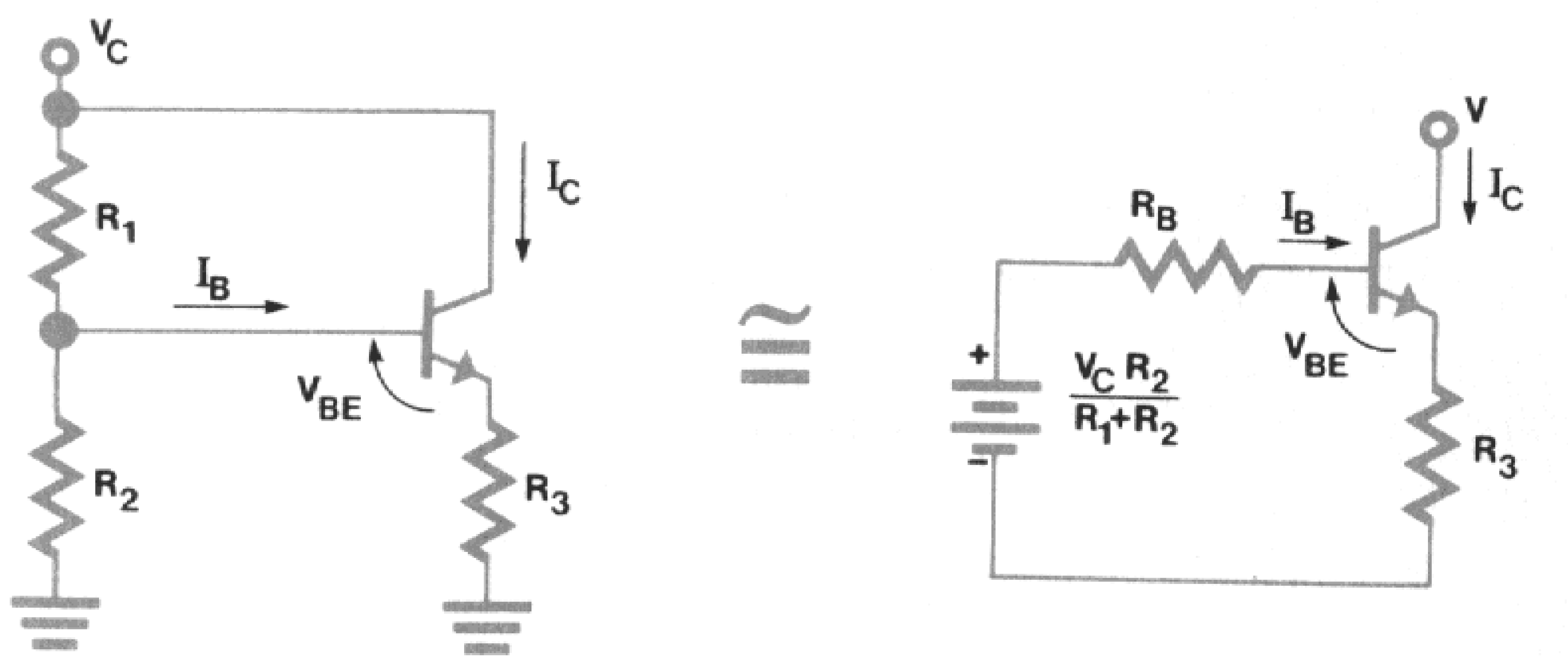
   Compute
   R_2 = 14.6 kΩ (14616.35)

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	Enter program				
2	Initialize		RTN	R/S	
3	Inputs				
	Junction temperature	T, °C	A		
	Desired current	I, A	B		
	Desired value for R_1	R_1, Ω	C		
	Supply voltage	V_C, V	D		
4	Output				
	Required value for R_2		E		R_2, Ω
5	Recall inputs (optional)				
	Junction temperature		RCL	1	T, °C
	Desired current		RCL	2	I, A
	Desired value for R_1		RCL	3	R_1, Ω
	Supply voltage		RCL	4	V_C, V
6	Return to step 2 for new case.				

TRANSISTOR BIAS



This program computes the dc collector current and two sensitivity factors for the circuit shown.



It is assumed that $I_B \ll$ current through R_1 and R_2

Given R_1, R_2, R_3, β_{dc}, and V_C, we have

$$I_C = \beta \frac{\frac{R_B}{R_1} V_C - V_{BE}}{R_B + (\beta+1) R_3} = \beta \frac{\frac{R_B}{R_1} V_C - .6}{R_B + (\beta+1) R_3}$$

$$S_V = \frac{\partial I_C}{\partial V_{BE}} = - \frac{\beta}{R_B + (\beta+1) R_3}$$

$$S_h = \frac{\partial I_C}{\partial \beta} = \frac{I_C}{\beta} \left(\frac{\frac{R_B}{R_3} + 1}{\frac{R_B}{R_3} + \beta + 1} \right)$$

where

$\beta = h_{FE}$ = dc current gain

$R_B = \dfrac{R_1 R_2}{R_1 + R_2}$ = parallel combination of R_1 and R_2

$V_{BE} = 0.6V$ = Base-emitter voltage drop for silicon transistor

S_V = Sensitivity of collector current to base-emitter voltage in siemens

S_h = Sensitivity of collector current to current gain in amperes

Examples:

1. $R_1 = 1000\ \Omega$
   $R_2 = 5000\ \Omega$
   $R_3 = 1000\ \Omega$
   $V_C = 10$ volts
   $\beta = 100$

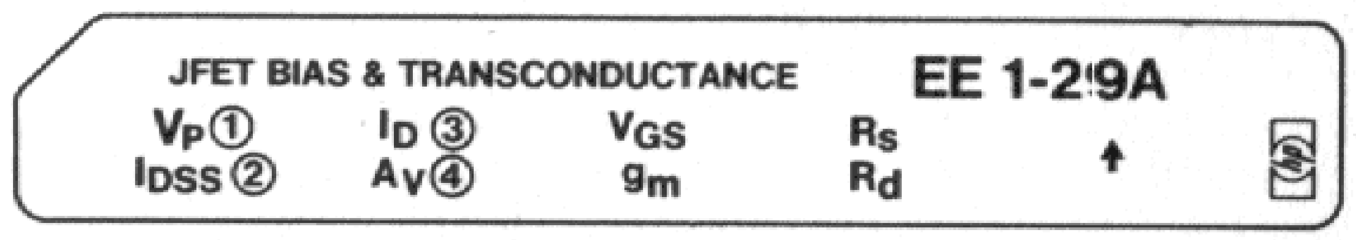
   Compute
   $I_C = 7.6$ mA (7.59×10^{-3})
   $S_V = 0.98$ mS (9.82×10^{-4})
   $S_h = 1.4\ \mu$A (1.37×10^{-6})

2. $R_1 = 200\ \Omega$
   $R_2 = 1000\ \Omega$
   $R_3 = 1000\ \Omega$
   $V_C = 10$ volts
   $\beta = 100$

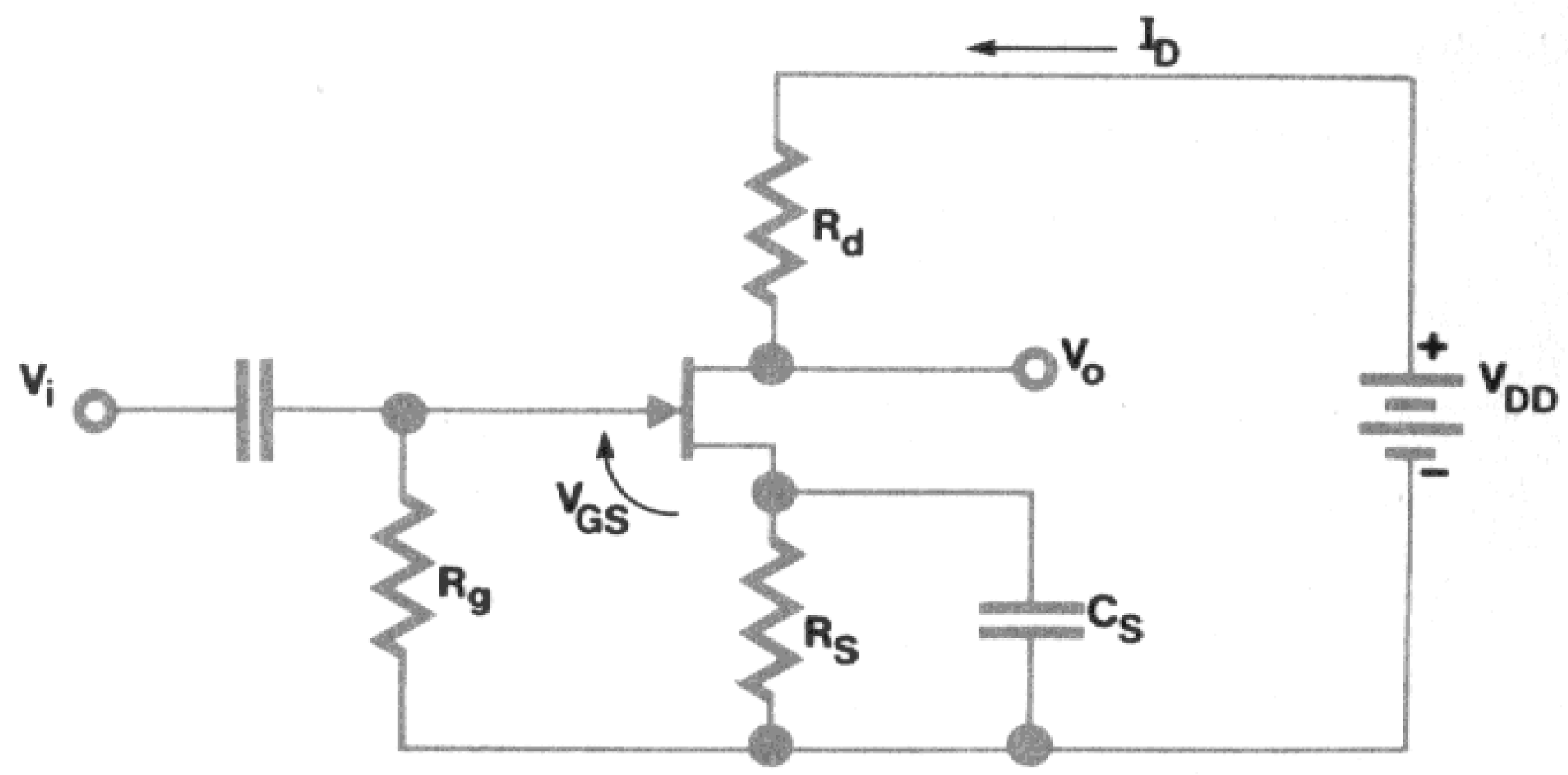
   Compute
   $I_C = 7.6$ mA (7.64×10^{-3})
   $S_V = 0.99$ mS (9.88×10^{-4})
   $S_h = 0.88\ \mu$A (8.82×10^{-7})

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	Enter program				
2	Initialize		RTN	R/S	
3	Inputs				
	Resistor R_1	R_1, Ω	E	A	
	Resistor R_2	R_2, Ω	A		
	Resistor R_3	R_3, Ω	E	B	
	Supply voltage	V_C, V	B		
	dc current gain	β	E	C	
4	Outputs				
	dc collector current		C		I_C, A
	Sensitivity to base voltage		E	D	S_V, S
	Sensitivity to dc gain		D		S_h, A
5	Recall inputs (optional)				
	Resistor R_1		RCL	1	R_1, Ω
	Resistor R_2		RCL	2	R_2, Ω
	Resistor R_3		RCL	3	R_3, Ω
	Supply voltage		RCL	4	V_C, V
	dc current gain		RCL	5	β

JFET BIAS AND TRANSCONDUCTANCE



Given the FET parameters V_P and I_{DSS}, and the desired drain current and voltage gain for the circuit shown, this program computes V_{GS}, g_m, and values for R_d and R_s.



The gate-source voltage necessary for a desired drain current is

$$V_{GS} = V_P \left[1 - \left(\frac{I_D}{I_{DSS}} \right)^{½} \right]$$

where

I_D = drain current in amperes ($I_D > 0$ for n-channel FET)

I_{DSS} = saturation drain current with gate shorted to source in amperes

V_{GS} = gate to source voltage in volts ($V_{GS} < 0$ for n-channel FET)

V_P = pinch-off voltage in volts

Knowing V_{GS}, we can compute the transconductance and the source and drain resistors.

$$g_m = -\frac{2\,I_{DSS}}{V_P}\left(1 - \frac{V_{GS}}{V_P}\right)$$

$$R_s = -\frac{V_{GS}}{I_D}$$

$$R_d = \frac{|A_V|}{|g_m|}$$

where

g_m = transconductance in siemens

$|A_V|$ = magnitude of voltage gain

Examples:

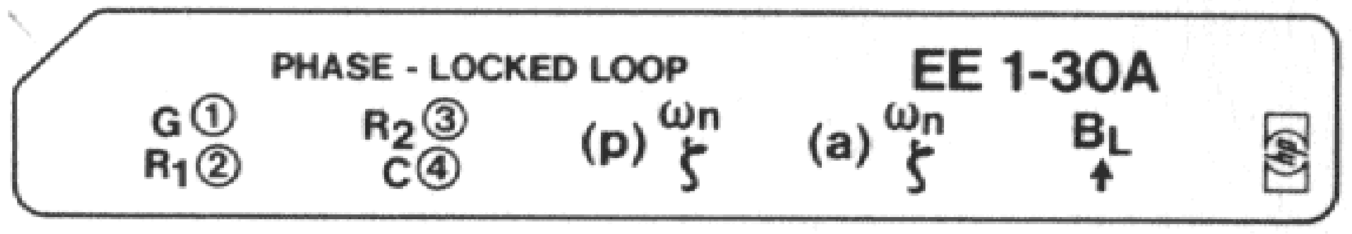
1. $V_P = -2V$
   $I_{DSS} = 1.5$ mA
   $I_D = .7$ mA
   $A_V = 10$

   Compute
   $V_{GS} = -0.63V\ (-6.337 \times 10^{-1})$
   $g_m = 1.025$ mS (1.025×10^{-3})
   $R_s = 905\ \Omega$
   $R_d = 9759\ \Omega$
2. $V_P = 1.5V$
   $I_{DSS} = -1.7$ mA
   $I_D = -.9$mA
   $A_V = 15$

   Compute
   $V_{GS} = 0.409V\ (4.086 \times 10^{-1})$
   $g_m = 1.65$ mS (1.649×10^{-3})
   $R_s = 454\ \Omega$
   $R_d = 9095\ \Omega$

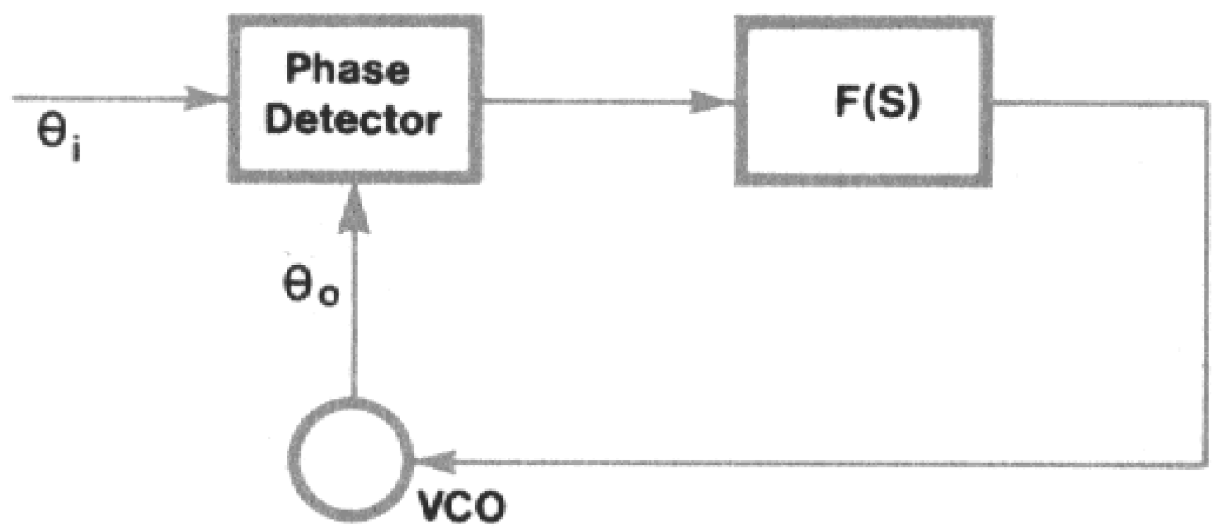
STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	Enter program				
2	Initialize		RTN	R/S	
3	Inputs (any order)				
	Pinch-off voltage	V_P, V	E	A	
	Sat. drain current ($V_{GS} = 0$)	I_{DSS}, A	A		
	Desired drain current	I_D, A	E	B	
	Desired voltage gain	$\|A_V\|$	B		
4	Outputs (any order)				
	Gate-source voltage		E	C	V_{GS}, V
	Transconductance		C		g_m, S
	Source resistor		E	D	R_s, Ω
	Drain resistor		D		R_d, Ω
5	Recall inputs (optional)				
	Pinch-off voltage		RCL	1	V_P, V
	Sat. drain current ($V_{GS} = 0$)		RCL	2	I_{DSS}, A
	Desired drain current		RCL	3	I_D, A
	Desired voltage gain		RCL	4	$\|A_V\|$

PHASE-LOCKED LOOP



This program computes the natural frequency, damping factor, and noise bandwidth for the phase locked loop shown. The transfer function is

$$\frac{\theta_o}{\theta_i}(s) = H(s) = \frac{G\,F(s)}{S + G\,F(s)}$$



where

G = overall loop gain, s^{-1}

θ_o = output phase

θ_i = input phase

$$F(s) = \begin{cases} \dfrac{s\tau_2 + 1}{s(\tau_1 + \tau_2) + 1} & \text{; passive filter transfer function} \\[2ex] \dfrac{s\tau_2 + 1}{s\tau_1} & \text{; active filter transfer function} \end{cases}$$

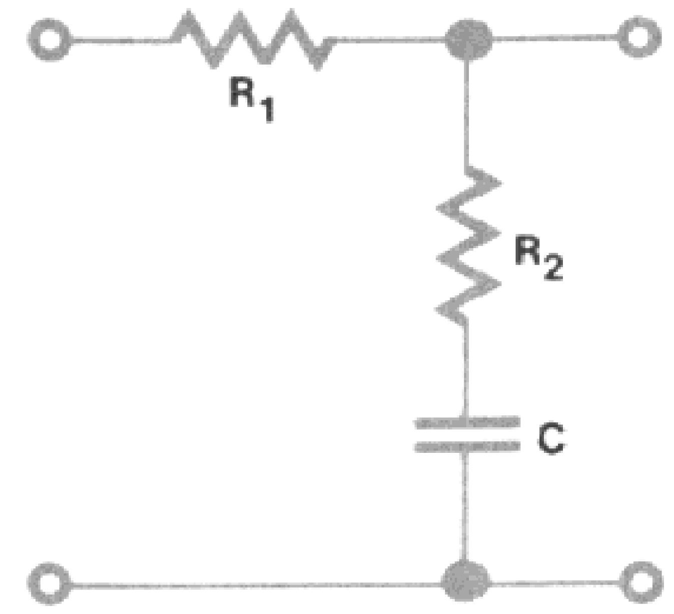
$\tau_1 = R_1\,C$

$\tau_2 = R_2\,C$

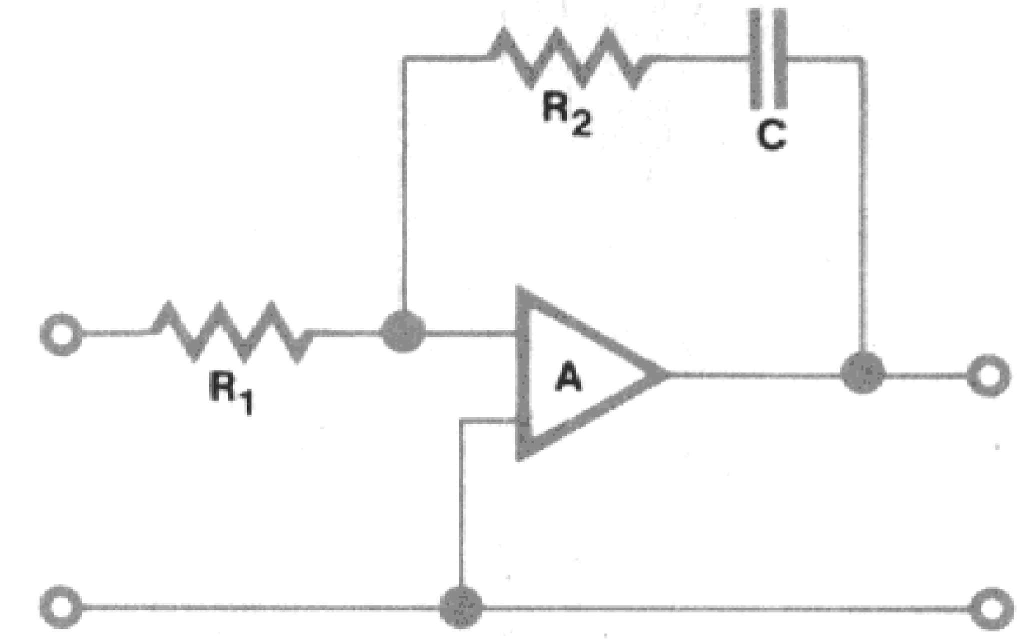
R_1, R_2 = resistances in ohms

C = capacitance in farads

PASSIVE FILTER



ACTIVE FILTER



The natural frequency and damping factor for the two loops are

$$\omega_n = \begin{cases} \sqrt{\dfrac{G}{\tau_1}} & \text{; active} \\[2ex] \sqrt{\dfrac{G}{\tau_1 + \tau_2}} & \text{; passive} \end{cases} \qquad \zeta = \begin{cases} \dfrac{\tau_2}{2}\,\omega_n & \text{; active} \\[2ex] \dfrac{1}{2}\,\omega_n\left(\tau_2 + \dfrac{1}{G}\right) & \text{; passive} \end{cases}$$

The (one-sided) loop noise bandwidth is

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

Note:

Natural frequency and damping factor must be computed before computing loop noise bandwidth.

Examples:

1. $G = 3.24 \times 10^5\ s^{-1}$

   $R_1 = 9.2\ M\Omega$

   $R_2 = 750\Omega$

   $C = 100\ \mu F$

   Compute

	Passive	Active
ω_n	$18.77\ s^{-1}$	$18.77\ s^{-1}$
ζ	.70	.70
B_L	9.94 Hz	9.94 Hz

2. $G = 1.57 \times 10^7\ s^{-1}$

   $R_1 = 1\ M\Omega$

   $R_2 = 7.1\Omega$

   $C = 1250\ \mu F$

   Compute

	Passive	Active
ω_n	$112.07\ s^{-1}$	$112.07\ s^{-1}$
ζ	.50	.50
B_L	56.04 Hz	56.04 Hz

3. $G = 1.5 \times 10^4\ s^{-1}$

   $R_1 = 1000$

   $R_2 = 75$

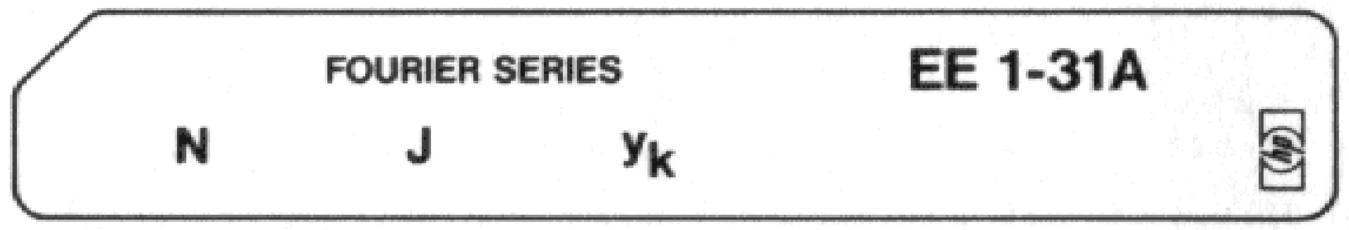
   $C = 10\mu F$

   Compute

	Passive	Active
ω_n	$1181.25\ s^{-1}$	$1225.74\ s^{-1}$
ζ	.48	.46
B_L	591.01 Hz	615.58 Hz

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	Enter program				
2	Initialize		RTN	R/S	0.00
3	Inputs				
	Loop gain	G, s^{-1}	E	A	
	Resistor R_1	R_1, Ω	A		
	Resistor R_2	R_2, Ω	E	B	
	Loop capacitor	C, F	B		
4	Outputs				
	Natural freq. (passive)		E	C	ω_n, s^{-1}
	Damping factor (passive)		C		ζ
	then Loop noise bandwidth		E	E	B_L, Hz
	Natural freq. (active)		E	D	ω_n, s^{-1}
	Damping factor (active)		D		ζ
	then Loop noise bandwidth		E	E	B_L, Hz
5	Recall inputs				
	Loop gain		RCL	1	G, s^{-1}
	Resistor R_1		RCL	2	R_1, Ω
	Resistor R_2		RCL	3	R_2, Ω
	Loop capacitor		RCL	4	C, F
6	Return to step 2 for new case.				

FOURIER SERIES



Any periodic function, f(t), may be expressed as a sum of sines and cosines by the Fourier series

$$f(t) = \frac{a_0}{2} + \sum_{i=1}^{\infty} \left(a_i \cos \frac{i2\pi t}{T} + b_i \sin \frac{i2\pi t}{T} \right)$$

where

$$a_i = \frac{2}{T} \int_0^T f(t) \cos \frac{i2\pi t}{T}\, dt, \qquad i = 0, 1, 2, \ldots$$

$$b_i = \frac{2}{T} \int_0^T f(t) \sin \frac{i2\pi t}{T}\, dt, \qquad i = 1, 2, \ldots$$

and

$$T = \text{period of } f(t)$$

This program computes the Fourier coefficients from discrete versions of the above formulas given a large enough number of samples of a periodic function. Six consecutive sine or cosine coefficients are computed at one time from N equally spaced points.

The discrete formulas for the Fourier coefficients are

$$a_j = \frac{2}{T} \sum_{k=1}^{N} y_k \cos \frac{2\pi kj}{T}, \quad j = J, J+1, \ldots, J+5$$

and

$$b_j = \frac{2}{T} \sum_{k=1}^{N} y_k \sin \frac{2\pi kj}{T}, \quad j = J, J+1, \ldots, J+5$$

where

J = order of first coefficient to be computed

$$y_k = f(t_k)$$

$$t_k = \frac{kT}{N}$$

The value of N should be chosen to be more than twice the highest expected multiple of the fundamental frequency present in the waveform to be analyzed. A low estimate for N will cause energy above one-half the sampling rate to appear at a lower frequency (a phenomenon known as aliasing).

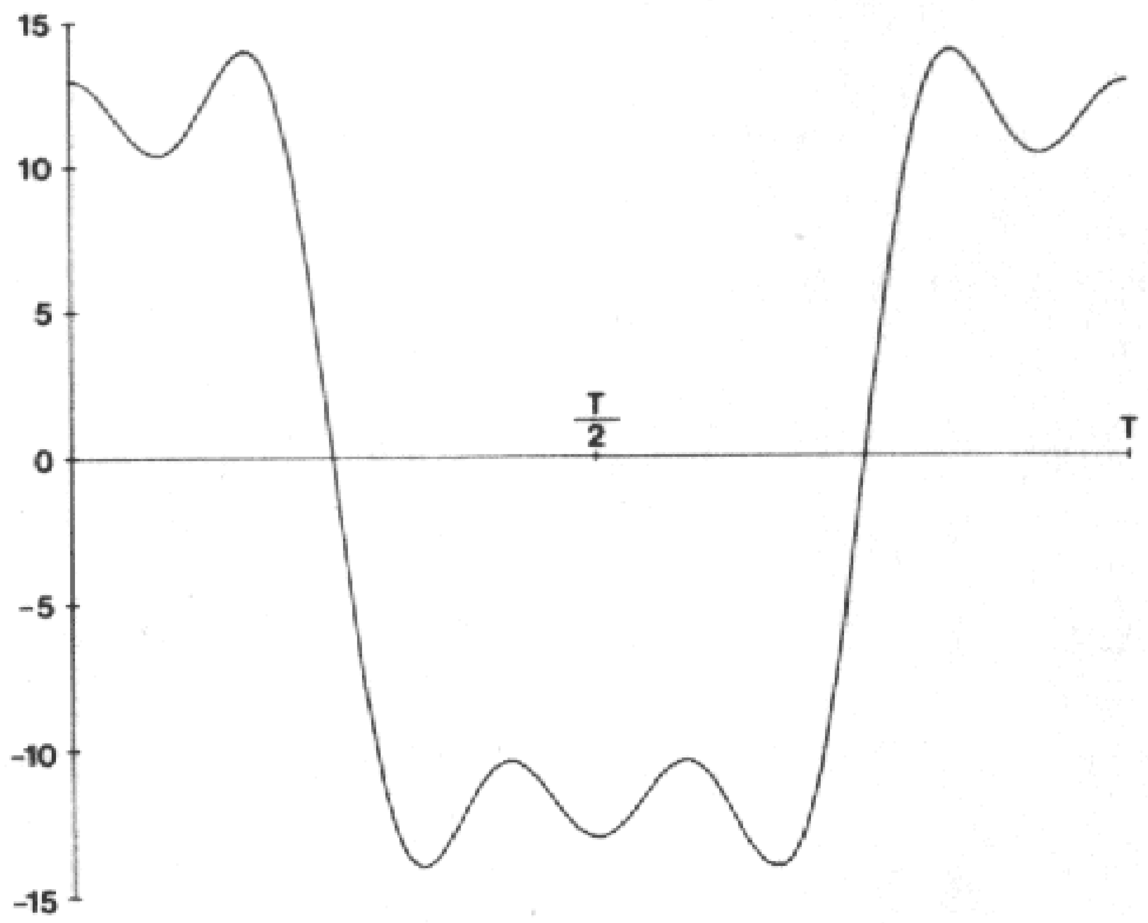
Notes:

1. A single spectral value may be computed by setting flag 1. This feature saves considerable time when only one coefficient is desired.
2. For even functions $(f(x) = f(-x))$, $b_j = 0$, for all values of j.
3. For odd functions $(f(x) = -f(-x))$, $a_j = 0$, for all values of j.
4. For convenience, the program modified to compute sine coefficients may be recorded on the other track of the magnetic card by placing the card into the machine with the uncut end first.

Examples:

1. $N = 12$ $J = 1$

k	$f(t_k)$
1	10.392
2	14.000
3	0.00
4	–14.000
5	–10.392
6	–13.000
7	–10.392
8	–14.000
9	0.00
10	14.000
11	10.392
12	13.000



$$\{a_j \mid j = 1, 2, ..., 6\} = \{15.000, 1.000 \times 10^{-9}, -5.000, -2.700 \times 10^{-8}, 3.000, 0.000 \times 10^{0}\}$$

The function is even, so $\{b_j\} = \{0\}$.

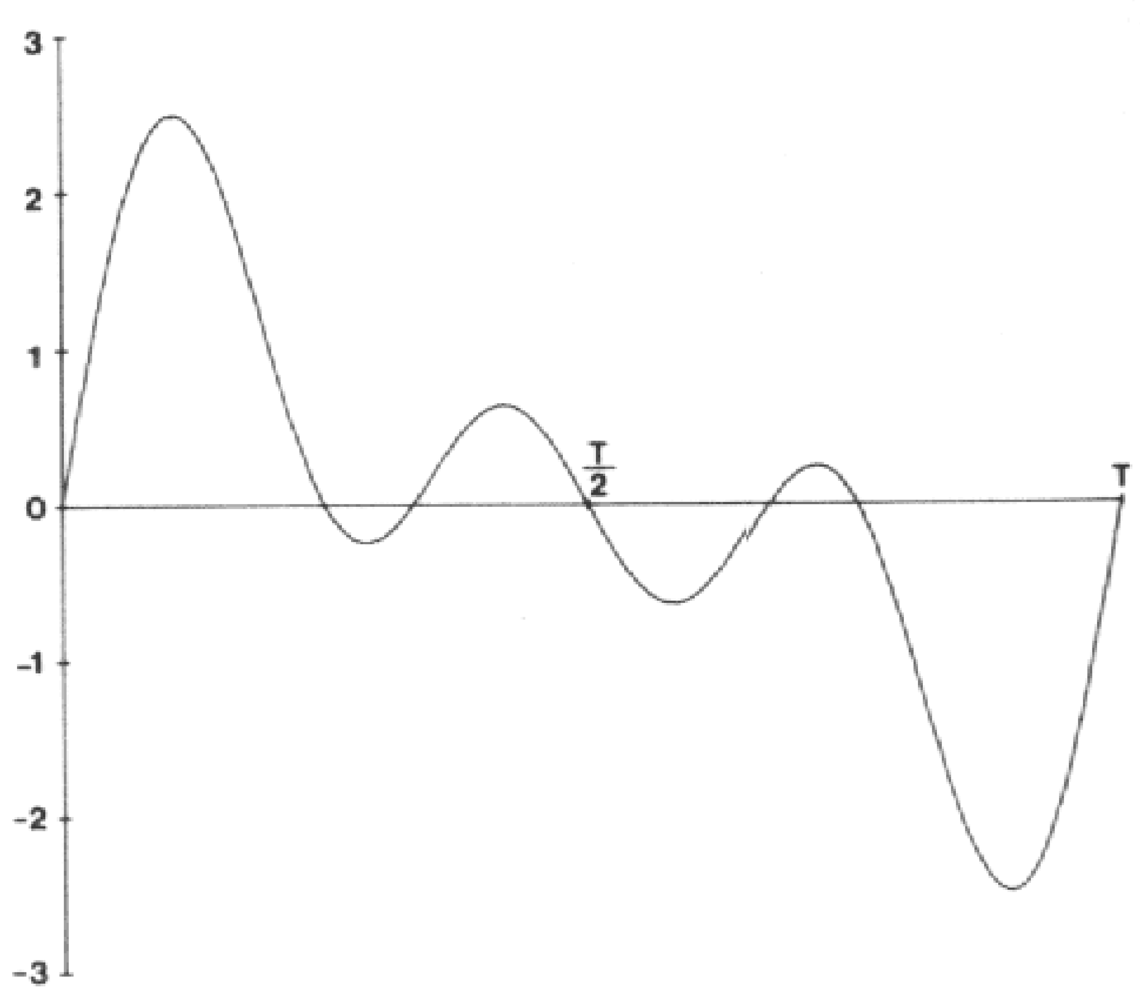
Thus the function is

$$f(t) = 15 \cos \frac{2\pi t}{T} - 5 \cos \frac{6\pi t}{T} + 3 \cos \frac{10\pi t}{T}$$

2. This example requires the modified program

$N = 12$ $J = 1$

k	y_k
1	2.366
2	1.732
3	0
4	0
5	0.634
6	0
7	–0.634
8	0
9	0
10	–1.732
11	–2.366
12	0



The function is odd, so $\{a_j\} = \{0\}$

$$\{b_j \mid j = 1, ... 6\} = \{1.000, 1.000, 1.000, -1.400\text{ E}-9, 1.467\text{ E}-5, -2.500\text{ E}-9\}$$

Thus the function is

$$f(t) = \sin \frac{2\pi t}{T} + \sin \frac{4\pi t}{T} + \sin \frac{6\pi t}{T}$$

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	Enter program				
2	For sine coefficients go to				
	step 10				
3	Input number of points	N	A		N
4	Input order of first coefficient	J	B		1
5	If only one coefficient is desired		f	SF 1	1
6	Input y_k, k = 1, 2, ..., N	y_k	C		2, ..., N + 1
7	Repeat step 6 until display				
	shows N + 1				
8	Display coefficients (If flag 1				
	was set, only a_j or b_j will have		RCL	1	a_j or b_j
	been computed.)		RCL	2	a_{j+1} or b_{j+1}
			RCL	3	a_{j+2} or b_{j+2}
			RCL	4	a_{j+3} or b_{j+3}
			RCL	5	a_{j+4} or b_{j+4}
			RCL	6	a_{j+5} or b_{j+5}
9	For new case, go to step 2				
10	To change to sine coefficients,				
	perform the following steps.				
11	Branch to label 1		GTO	1	
12	Switch to W/PRGM				01
13	Single step twice		SST	SST	05
14	Delete cosine		g	DEL	31
15	Insert sine		SIN		04
16	Record modified program on				00 00
	opposite track (see note 4)				
17	Switch to RUN and go to step 3				

DECIBEL CONVERSION

DECIBEL CONVERSION				EE 1-32A
V_1 ①	V_2 ③	$20 \log V_2/V_1$	db→V_2/V_1	↑
P_1 ②	P_2 ④	$10 \log P_2/P_1$	db→P_2/P_1	

This program converts voltage or power ratios to decibels and vice versa.

$$dB = 10 \log \frac{P_2}{P_1} = 20 \log \frac{V_2}{V_1}$$

$$\frac{P_2}{P_1} = 10^{\frac{dB}{10}}$$

$$\frac{V_2}{V_1} = 10^{\frac{dB}{20}}$$

Examples:

1. $V_1 = 1\,V$
   $V_2 = 2\,V$
   Calculate $20 \log \frac{V_2}{V_1} = 6.02$ dB

2. $P_1 = 3$ mW
   $P_2 = 7$ mW
   Calculate $10 \log \frac{P_2}{P_1} = 3.68$ dB

3. $10 \log \frac{P_2}{P_1} = 13.2$ dB

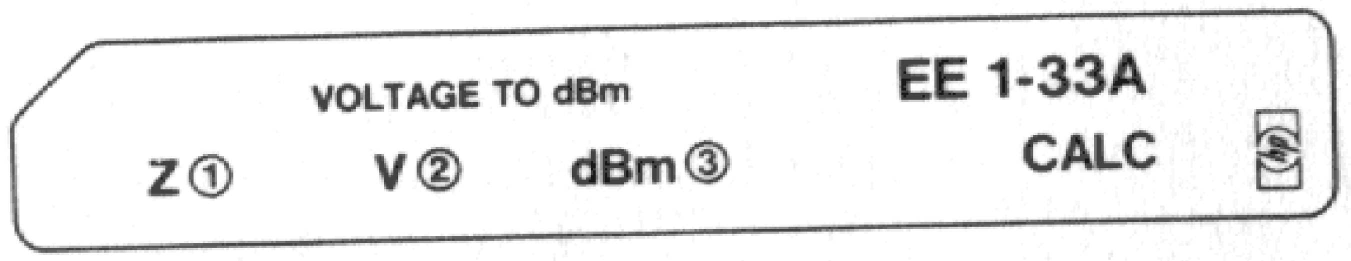
   Calculate $\frac{P_2}{P_1} = 20.89$

4. $20 \log \frac{V_2}{V_1} = 10$ dB

   Calculate $\frac{V_2}{V_1} = 3.16$

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	Enter program				
2	Input Data				
	Power P_1	P_1	A		
	Power P_2	P_2	B		
	or				
	Voltage V_1	V_1	E	A	
	Voltage V_2	V_2	E	B	
3	Compute decibels				
	Power, $10 \log (P_2/P_1)$		C		dB
	Voltage, $20 \log (V_2/V_1)$		E	C	dB
4	Convert dB to ratio				
	Voltage ratio in dB	dB	E	D	V_2/V_1
	Power ratio in dB	dB	D		P_2/P_1
5	Recall inputs				
	V_1		RCL	1	V_1
	P_1		RCL	2	P_1
	V_2		RCL	3	V_2
	P_2		RCL	4	P_2
6	Change appropriate inputs or				
	for new case go to 2.				

VOLTAGE TO dBm



The power level of radio-frequency energy is often expressed in decibels above one milliwatt. This program finds the missing value in the following expression when any two are given

$$\text{dBm} = 10 \log \frac{\frac{V^2}{Z}}{10^{-3}} = 10 \log \frac{V^2}{Z} + 30$$

where

Z = impedance level in ohms

V = voltage in volts

dBm = decibels above one milliwatt

when any two are given.

Examples:

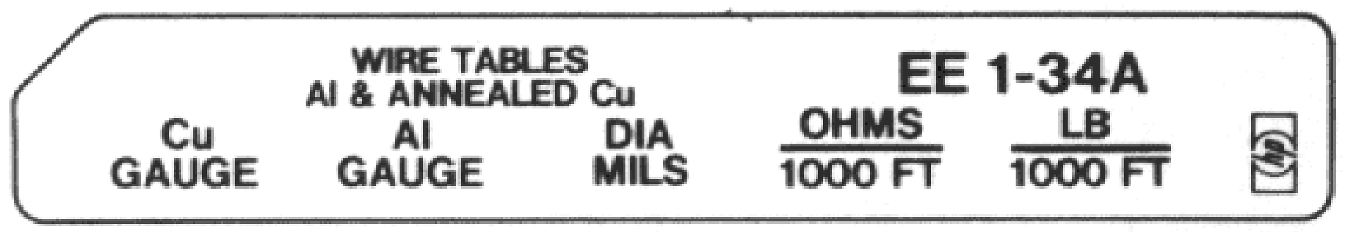
1. $Z = 50\ \Omega$
   dBm = 0
   Calculate $V = 0.2236$ volts

2. $Z = 600\ \Omega$
   $V = 0.7746$ V
   Calculate dBm = 0.00004

3. $Z = 600\ \Omega$
   $V = 2$V
   Calculate dBm = 8.24

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	Enter program				
2	Input knowns (any 2)				
	Impedance	Z, ohms	A		
	Voltage	V, V	B		
	dB above 1 mW	dBm	C		
3	Calculate unknown				
	Impedance		E	A	Z, ohms
	Voltage		E	B	V, V
	dB above 1 mW		E	C	dBm
4	Recall inputs				
	Impedance		RCL	1	Z, ohms
	Voltage		RCL	2	V, V
	dB above 1 mW		RCL	3	dBm
5	Change appropriate inputs in				
	step 2.				

WIRE TABLES AL AND ANNEALED CU



This program converts AWG gauge number to mils. It also computes the weight and resistance of 1000 feet of wire.

The diameter of American Wire Gauge (AWG) is given by

$$DIA = \frac{460}{(92)^{\frac{AWG+3}{39}}}$$

where

DIA = diameter in mils

AWG = Gauge number

The weight and resistance of 1000 feet of wire depend on the material.

For copper,

$$R = \frac{10371}{(DIA)^2}$$

$$W = 0.003\ 026\ 9\ (DIA)^2$$

and for aluminum

$$R = \frac{17002}{(DIA)^2}$$

$$W = 0.000\ 920\ 3\ (DIA)^2$$

where

R = resistance of 1000 ft. of wire in ohms

W = weight of 1000 ft. of wire in pounds

Note: Values calculated by this program may differ slightly from those in published wire tables due to table round-off errors.

Examples:

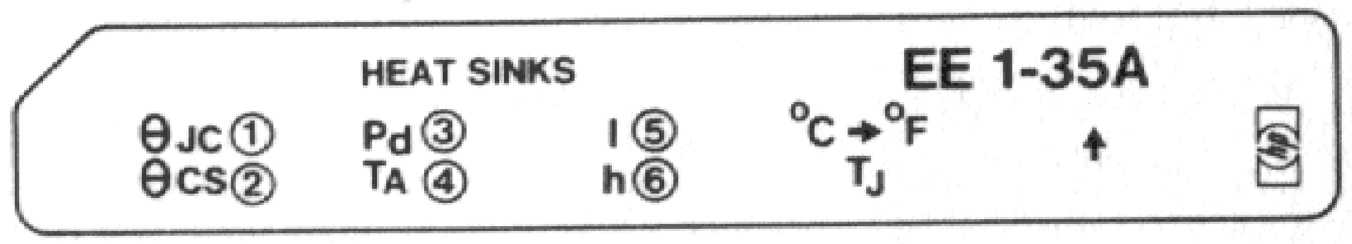
1. No. 12 Cu wire
   Dia = 80.81 mils (8.081×10^1)
   $\frac{\text{ohms}}{1000\text{ ft}} = 1.588\ (1.588 \times 10^0)$
   $\frac{\text{LB}}{1000\text{ ft}} = 19.77\ (1.977 \times 10^1)$

2. No. 34 Cu wire
   Dia = 6.305 mils (6.305×10^0)
   $\frac{\text{ohms}}{1000\text{ ft}} = 260.9\ (2.609 \times 10^2)$
   $\frac{\text{LB}}{1000\text{ ft}} = 0.1203\ (1.203 \times 10^{-1})$

3. No. 10 Al wire
   Dia = 101.9 mils (1.019×10^2)
   $\frac{\text{ohms}}{1000\text{ ft}} = 1.637\ (1.637 \times 10^0)$
   $\frac{\text{LB}}{1000\text{ ft}} = 9.555\ (9.555 \times 10^0)$

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	Enter program				
2	Input gauge for				
	Copper wire	AWG	A		
	Aluminum wire	AWG	B		
3	Calculate desired values				
	Wire diameter		C		Dia, mils
	Resistance of 1000 ft		D		R, ohms
	Weight of 1000 ft		E		W, pounds
4	Recall Input (optional)				
			RCL	1	AWG
5	For new case repeat steps 2				
	and 3.				

HEAT SINKS



The thermal resistance, sink to air, of a 1/8" thick unpainted aluminum sheet has been found to be approximately (see the Motorola Application Note, "Power Transistor Heat Sinks")

$$\theta_{SA} \cong 78.59 \times \left(\frac{1}{l\,h}\right)^{.472}$$

where

θ_{SA} = thermal resistance, sink to air, $\frac{^\circ C}{W}$

l = length of heat sink, cm or in.

h = height of heat sink, cm or in.

The temperature at the junction of a transistor is given by

$$T_J = T_A + P_d\,(\theta_{JC} + \theta_{CS} + \theta_{SA})$$

where

T_J = junction temperature, °C

T_A = ambient temperature, °C

P_d = power dissipated by transistor, watts

θ_{JC} = thermal resistance, junction to case, $\frac{^\circ C}{W}$

θ_{CS} = thermal resistance, case to sink, $\frac{^\circ C}{W}$

θ_{SA} = thermal resistance, sink to air, $\frac{^\circ C}{W}$

This program evaluates the above equations to determine T_J from the other parameters.

Example:

$$\theta_{JC} = 10\ \frac{^\circ C}{W}$$

$$\theta_{CS} = .4\ \frac{^\circ C}{W}$$

$$P_d = 10\ W$$

$$T_A = 25\ ^\circ C$$

$$l = 4 \text{ inches}$$

$$h = 5 \text{ inches}$$

Compute

$$\theta_{SA} = 7.93\ \frac{^\circ C}{W}$$

$$T_J = 208.27\ ^\circ C = 406.89$$

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	Enter program				
2	Initialize		RTN	R/S	
3	Inputs				
	Therm. res.-junction to case	θ_{JC}, °C/W	E	A	
	Therm. res.-case to sink	θ_{CS}, °C/W	A		
	Power dissipated	P_d, W	E	B	
	Ambient temperature	T_A, °C	B		
	either				
	Length of heat sink	l, cm or in.*	E	C	l, cm
	then Height of heat sink	h, cm or in.*	C		θ_{SA}, °C/W
	or				
	Therm. res.-sink to air	θ_{SA}, °C/W	STO	~~8~~ 9	
4	Outputs				
	Junction temperature		D		T_J, °C
	Junction temperature		E	D	T_J, °F
5	Recall data (optional)				
			RCL	1	θ_{JC}, °C/W
			RCL	2	θ_{CS}, °C/W
			RCL	3	P_d, W
			RCL	4	T_A, °C
			RCL	5	l, cm
			RCL	6	h, cm
			RCL	7	T_J, °C
			RCL	9	θ_{SA}, °C/W
6	Return to step 2 for new case				
*	Input inches negatively.				

PROGRAM LISTINGS

REACTANCE CHART

CODE	KEYS
21	DSP
04	4
44	CLX
33 08	STO 8
84	R/S
23	LBL
00	0
33 01	STO 1
02	2
71	x
35	g
02	π
71	x
33 04	STO 4
41	↑
71	x
35	g
04	$^1/x$
33 05	STO 5
84	R/S
23	LBL
11	A
35	g
83	DSZ
22	GTO
00	0
34 02	RCL 2
34 03	RCL 3
71	x
31	f
09	$\sqrt{x}$
02	2
71	x
35	g
02	π

CODE	KEYS
71	x
35	g
04	$^1/x$
84	R/S
23	LBL
12	B
35	g
83	DSZ
33 02	STO 2
84	R/S
34 05	RCL 5
34 03	RCL 3
81	÷
84	R/S
23	LBL
13	C
35	g
83	DSZ
33 03	STO 3
84	R/S
34 05	RCL 5
34 02	RCL 2
81	÷
84	R/S
23	LBL
14	D
35	g
83	DSZ
22	GTO
01	1
34 04	RCL 4
34 02	RCL 2
71	x
35	g
04	$^1/x$

CODE	KEYS
42	CHS
84	R/S
23	LBL
01	1
34 04	RCL 4
34 03	RCL 3
71	x
84	R/S
23	LBL
15	E
01	1
33 08	STO 8
84	R/S
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP

R_1	f	R_4	$2\pi f$	R_7	
R_2	C	R_5	$(4\pi^2 f^2)^{-1}$	R_8	DSZ
R_3	L	R_6		R_9	

SERIES RESONANT CIRCUIT

CODE	KEYS
32	f^{-1}
51	SF 1
84	R/S
23	LBL
11	A
32	f^{-1}
61	TF 1
33 02	STO 2
84	R/S
33 01	STO 1
22	GTO
00	0
23	LBL
12	B
32	f^{-1}
61	TF 1
33 04	STO 4
84	R/S
33 03	STO 3
22	GTO
00	0
23	LBL
13	C
32	f^{-1}
61	TF 1
33 05	STO 5
84	R/S
34 03	RCL 3
34 04	RCL 4
71	x
31	f
09	$\sqrt{x}$
35	g
02	π
71	x

CODE	KEYS
02	2
71	x
35	g
04	$^1/x$
22	GTO
00	0
23	LBL
15	E
31	f
51	SF 1
84	R/S
23	LBL
14	D
34 04	RCL 4
34 05	RCL 5
02	2
71	x
35	g
02	π
71	x
71	x
35 00	g LST X
34 03	RCL 3
71	x
71	x
34 02	RCL 2
35 00	g LST X
42	CHS
71	x
35 00	g LST X
34 01	RCL 1
71	x
61	+
35 00	g LST X
35 09	g R↑

CODE	KEYS
01	1
51	−
31	f
01	R→P
35 09	g R↑
35 00	g LST X
31	f
01	R→P
35 07	g x⇄y
35 08	g R↓
81	÷
34 02	RCL 2
71	x
35 08	g R↓
35 07	g x⇄y
51	−
35 09	g R↑
31	f
61	TF 1
22	GTO
01	1
84	R/S
23	LBL
01	1
35 07	g x⇄y
22	GTO
00	0
35 01	g NOP
35 01	g NOP
35 01	g NOP

R_1	R_s	R_4	L	R_7	
R_2	R_p	R_5	f	R_8	
R_3	C	R_6		R_9	Used

PARALLEL RESONANT CIRCUIT

CODE	KEYS
32	f^{-1}
51	SF 1
24	RTN
23	LBL
11	A
33 01	STO 1
84	R/S
23	LBL
12	B
32	f^{-1}
61	TF 1
33 04	STO 4
84	R/S
33 03	STO 3
22	GTO
00	0
23	LBL
13	C
33 05	STO 5
41	↑
41	↑
02	2
71	x
35	g
02	π
71	x
33 06	STO 6
32	f^{-1}
61	TF 1
35 01	g NOP
24	RTN
34 03	RCL 3
34 04	RCL 4
71	x
31	f

CODE	KEYS
09	$\sqrt{x}$
02	2
71	x
35	g
02	π
71	x
35	g
04	$^1/x$
22	GTO
00	0
23	LBL
15	E
31	f
51	SF 1
24	RTN
23	LBL
14	D
34 04	RCL 4
34 06	RCL 6
71	x
33 07	STO 7
01	1
35 07	g x⇄y
34 06	RCL 6
71	x
34 03	RCL 3
71	x
51	–
34 01	RCL 1
71	x
34 07	RCL 7
35 07	g x⇄y
31	f
01	R→P
34 01	RCL 1

CODE	KEYS
81	÷
33	STO
81	÷
07	7
35 07	g x⇄y
09	9
00	0
51	–
42	CHS
34 07	RCL 7
35 07	g x⇄y
31	f
61	TF 1
22	GTO
00	0
35 07	g x⇄y
24	RTN
23	LBL
01	1
34 02	RCL 2
34 05	RCL 5
61	+
84	R/S
13	C
14	D
84	R/S
35 07	g x⇄y
84	R/S
22	GTO
01	1

R_1	R	R_4	L	R_7	Temporary
R_2	Δf	R_5	f	R_8	
R_3	C	R_6	$\omega = 2\pi f$	R_9	Used

IMPEDANCE OF LADDER NETWORK

CODE	KEYS
31	f
42	STK
31	f
43	REG
84	R/S
23	LBL
11	A
33 04	STO 4
35 07	g x⇄y
33 05	STO 5
31	f
01	R→P
32	f^{-1}
09	$\sqrt{x}$
34 05	RCL 5
42	CHS
35 07	g x⇄y
81	÷
34 04	RCL 4
35 00	g LST x
81	÷
24	RTN
23	LBL
14	D
32	f^{-1}
61	TF 1
35 07	g x⇄y
22	GTO
00	0
02	2
71	x
35	g
02	π
71	x
33 03	STO 3

CODE	KEYS
23	LBL
00	0
32	f^{-1}
51	SF 1
84	R/S
23	LBL
15	E
31	f
51	SF 1
84	R/S
23	LBL
11	A
32	f^{-1}
61	TF 1
35	g
04	$^1/x$
00	0
35 07	g x⇄y
22	GTO
01	1
23	LBL
12	B
34 03	RCL 3
71	x
35	g
04	$^1/x$
42	CHS
00	0
22	GTO
01	1
23	LBL
13	C
34 03	RCL 3
71	x
00	0

CODE	KEYS
23	LBL
01	1
33 06	STO 6
35 07	g x⇄y
33 07	STO 7
34 02	RCL 2
34 01	RCL 1
31	f
61	TF 1
11	A
35 01	g NOP
34 06	RCL 6
61	+
35 07	g x⇄y
34 07	RCL 7
61	+
35 07	g x⇄y
31	f
61	TF 1
11	A
35 01	g NOP
33 01	STO 1
35 07	g x⇄y
33 02	STO 2
35 07	g x⇄y
11	A
31	f
01	R→P
22	GTO
00	0

R_1	Re $[Y_{in}]$	R_4	Used	R_7	Used
R_2	Im $[Y_{in}]$	R_5	Used	R_8	
R_3	$\omega = 2\pi f$	R_6	Used	R_9	

T ATTENUATOR

CODE	KEYS
21	DSP
04	4
32	f^{-1}
51	SF 1
23	LBL
11	A
32	f^{-1}
61	TF 1
33 02	STO 2
84	R/S
33 01	STO 1
32	f^{-1}
51	SF 1
84	R/S
23	LBL
12	B
01	1
00	0
81	÷
01	1
00	0
35 07	g x⇄y
35	g
05	y^x
33 07	STO 7
34 01	RCL 1
34 02	RCL 2
71	x
71	x
31	f
09	$\sqrt{x}$
02	2
71	x
34 07	RCL 7
01	1

CODE	KEYS
51	–
33 08	STO 8
81	÷
33 05	STO 5
34 01	RCL 1
34 07	RCL 7
01	1
61	+
33 07	STO 7
71	x
34 08	RCL 8
81	÷
34 05	RCL 5
51	–
33 03	STO 3
34 02	RCL 2
34 07	RCL 7
71	x
34 08	RCL 8
81	÷
34 05	RCL 5
51	–
33 04	STO 4
34 01	RCL 1
34 02	RCL 2
81	÷
33 06	STO 6
01	1
51	–
31	f
09	$\sqrt{x}$
34 06	RCL 6
31	f
09	$\sqrt{x}$
61	+

CODE	KEYS
41	↑
71	x
31	f
08	LOG
01	1
00	0
71	x
33 06	STO 6
84	R/S
23	LBL
13	C
32	f^{-1}
61	TF 1
34 04	RCL 4
84	R/S
34 03	RCL 3
32	f^{-1}
51	SF 1
84	R/S
23	LBL
14	D
34 05	RCL 5
84	R/S
23	LBL
15	E
31	f
51	SF 1
84	R/S
35 01	g NOP
35 01	g NOP

R_1	Z_1	R_4	R_2	R_7	N, N + 1
R_2	Z_2	R_5	R_3	R_8	N – 1
R_3	R_1	R_6	Min Loss	R_9	

PI ATTENUATOR

CODE	KEYS
21	DSP
04	4
32	f^{-1}
61	TF 1
33 02	STO 2
84	R/S
33 01	STO 1
32	f^{-1}
51	SF 1
84	R/S
23	LBL
12	B
01	1
00	0
81	÷
01	1
00	0
35 07	g x⇄y
35	g
05	y^x
33 07	STO 7
01	1
51	–
33 08	STO 8
83	•
05	5
71	x
34 01	RCL 1
34 02	RCL 2
71	x
34 07	RCL 7
81	÷
31	f
09	$\sqrt{x}$
71	x

CODE	KEYS
33 05	STO 5
35	g
04	$1/x$
33 06	STO 6
34 08	RCL 8
02	2
61	+
34 08	RCL 8
81	÷
33 08	STO 8
34 01	RCL 1
81	÷
34 06	RCL 6
51	–
35	g
04	$1/x$
33 03	STO 3
34 08	RCL 8
34 02	RCL 2
81	÷
34 06	RCL 6
51	–
35	g
04	$1/x$
33 04	STO 4
34 01	RCL 1
34 02	RCL 2
81	÷
33 06	STO 6
01	1
51	–
31	g
09	$\sqrt{x}$
34 06	RCL 6
31	g

CODE	KEYS
09	$\sqrt{x}$
61	+
41	↑
71	x
31	f
08	LOG
01	1
00	0
71	x
33 06	STO 6
84	R/S
23	LBL
13	C
32	f^{-1}
61	TF 1
34 04	RCL 4
84	R/S
34 03	RCL 3
32	f^{-1}
51	SF 1
84	R/S
23	LBL
14	D
34 05	RCL 5
84	R/S
23	LBL
15	E
31	f
51	SF 1
84	R/S

R_1	Z_1	R_4	R_2	R_7	N
R_2	Z_2	R_5	R_3	R_8	Used
R_3	R_1	R_6	Min Loss	R_9	$1/R_3$

WYE-DELTA OR DELTA-WYE TRANSFORMATION (CARD 1)

CODE	KEYS
01	1
33 08	STO 8
23	LBL
01	1
21	DSP
83	.
00	0
34 08	RCL 8
84	R/S
23	LBL
14	D
23	LBL
11	A
34 02	RCL 2
33 01	STO 1
34 03	RCL 3
33 02	STO 2
35 08	g R↓
35 08	g R↓
33 03	STO 3
22	GTO
01	1
23	LBL
15	E
34 03	RCL 3
13	C
33 03	STO 3
35 08	g R↓
23	LBL
12	B
34 05	RCL 5
33 04	STO 4
34 06	RCL 6
33 05	STO 5
35 08	g R↓

CODE	KEYS
35 08	g R↓
33 06	STO 6
03	3
34 08	RCL 8
35 23	g x=y
22	GTO
02	2
01	1
61	+
33 08	STO 8
22	GTO
01	1
23	LBL
13	C
31	f
01	R→P
35	g
04	$^1/x$
35 07	g x⇄y
42	CHS
35 07	g x⇄y
32	f^{-1}
01	R→P
24	RTN
23	LBL
02	2
34 04	RCL 4
34 05	RCL 5
61	+
34 06	RCL 6
61	+
34 01	RCL 1
34 02	RCL 2
61	+
34 03	RCL 3

CODE	KEYS
61	+
31	f
01	R→P
33 07	STO 7
35 07	g x⇄y
33 08	STO 8
34 04	RCL 4
34 01	RCL 1
31	f
01	R→P
33 01	STO 1
35 07	g x⇄y
33 04	STO 4
34 05	RCL 5
34 02	RCL 2
31	f
01	R→P
33 02	STO 2
35 07	g x⇄y
33 05	STO 5
34 06	RCL 6
34 03	RCL 3
31	f
01	R→P
33 03	STO 3
35 07	g x⇄y
33 06	STO 6
21	DSP
04	4
84	R/S

R_1	Used	R_4	Used	R_7	Used
R_2	Used	R_5	Used	R_8	Used
R_3	Used	R_6	Used	R_9	Used

WYE-DELTA OR DELTA-WYE TRANSFORMATION (CARD 2)

CODE	KEYS
23	LBL
11	A
34 04	RCL 4
34 06	RCL 6
34 01	RCL 1
34 03	RCL 3
13	C
84	R/S
23	LBL
12	B
35 07	g x⇄y
84	R/S
23	LBL
11	A
34 05	RCL 5
34 06	RCL 6
34 02	RCL 2
34 03	RCL 3
13	C
84	R/S
23	LBL
12	B
35 07	g x≥y
84	R/S
23	LBL
11	A
34 04	RCL 4
34 05	RCL 5
34 01	RCL 1
34 02	RCL 2
13	C
84	R/S
23	LBL
12	B
35 07	g x⇄y

CODE	KEYS
84	R/S
23	LBL
13	C
71	×
34 07	RCL 7
81	÷
35 08	g R↓
61	+
34 08	RCL 8
51	–
35 09	g R↑
31	f
61	TF 1
22	GTO
01	1
32	f^{-1}
01	R→P
24	RTN
23	LBL
01	1
35	g
04	$^1/x$
35 07	g x⇄y
42	CHS
35 07	g x⇄y
32	f^{-1}
01	R→P
24	RTN
23	LBL
14	D
32	f^{-1}
51	SF 1
84	R/S
23	LBL
15	E

CODE	KEYS
31	f
51	SF 1
84	R/S
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP

R_1	Used	R_4	Used	R_7	Used
R_2	Used	R_5	Used	R_8	Used
R_3	Used	R_6	Used	R_9	Used

MINIMUM LOSS PAD MATCHING

CODE	KEYS
23	LBL
11	A
33 01	STO 1
84	R/S
23	LBL
12	B
33 02	STO 2
84	R/S
23	LBL
13	C
15	E
34 04	RCL 4
84	R/S
23	LBL
14	D
15	E
34 05	RCL 5
84	R/S
23	LBL
15	E
34 01	RCL 1
34 02	RCL 2
81	÷
31	f
09	$\sqrt{x}$
35 00	g LST X
01	1
51	–
31	f
09	$\sqrt{x}$
61	+
31	f
08	LOG
02	2
00	0

CODE	KEYS
71	x
33 03	STO 3
01	1
34 02	RCL 2
34 01	RCL 1
81	÷
51	–
31	f
09	$\sqrt{x}$
33 04	STO 4
35	g
04	$^1/x$
33 05	STO 5
34 01	RCL 1
33	STO
71	x
04	4
34 02	RCL 2
33	STO
71	x
05	5
34 03	RCL 3
24	RTN
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP

CODE	KEYS
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP

R_1	Z_1	R_4	R_1	R_7	
R_2	Z_2	R_5	R_2	R_8	
R_3	Loss	R_6		R_9	

PI NETWORK IMPEDANCE MATCHING

CODE	KEYS
31	f
42	STK
21	DSP
04	4
23	LBL
01	1
32	f^{-1}
51	SF 1
24	RTN
84	R/S
23	LBL
11	A
32	f^{-1}
61	TF 1
33 02	STO 2
84	R/S
33 01	STO 1
22	GTO
01	1
23	LBL
12	B
32	f^{-1}
61	TF 1
33 04	STO 4
84	R/S
33 03	STO 3
22	GTO
01	1
23	LBL
13	C
34 04	RCL 4
34 01	RCL 1
81	÷
31	f
61	TF 1

CODE	KEYS
22	GTO
00	0
34 02	RCL 2
34 01	RCL 1
81	÷
34 04	RCL 4
41	↑
71	x
01	1
61	+
33 05	STO 5
71	x
01	1
51	–
31	f
09	$\sqrt{x}$
34 02	RCL 2
81	÷
33 06	STO 6
22	GTO
00	0
23	LBL
14	D
13	C
34 02	RCL 2
34 06	RCL 6
71	x
34 04	RCL 4
81	÷
01	1
61	+
34 04	RCL 4
34 01	RCL 1
71	x
34 05	RCL 5

CODE	KEYS
81	÷
71	x
23	LBL
00	0
35	g
02	π
02	2
71	x
34 03	RCL 3
71	x
81	÷
22	GTO
01	1
23	LBL
15	E
31	f
51	SF 1
84	R/S
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP

R_1	R_1	R_4	Q	R_7	
R_2	R_2	R_5	Used	R_8	
R_3	f	R_6	Used	R_9	

BAND PASS FILTER DESIGN (CARD 1)

CODE	KEYS
21	DSP
03	3
32	f^{-1}
51	SF 1
84	R/S
23	LBL
11	A
32	f^{-1}
61	TF 1
33 02	STO 2
84	R/S
33 01	STO 1
32	f^{-1}
51	SF 1
84	R/S
23	LBL
12	B
31	f
61	TF 1
22	GTO
01	1
34 02	RCL 2
34 01	RCL 1
51	–
33 06	STO 6
34 01	RCL 1
34 02	RCL 2
71	x
04	4
71	x
35	g
02	π
71	x
33 07	STO 7
34 03	RCL 3

CODE	KEYS
71	x
81	÷
33 04	STO 4
34 03	RCL 3
34 06	RCL 6
35	g
02	π
71	x
33 08	STO 8
71	x
35	g
04	$1/x$
33 05	STO 5
34 03	RCL 3
34 06	RCL 6
71	x
34 07	RCL 7
81	÷
33 07	STO 7
34 03	RCL 3
34 08	RCL 8
81	÷
33 06	STO 6
00	0
21	DSP
03	3
84	R/S
23	LBL
01	1
33 03	STO 3
32	f^{-1}
51	SF 1
84	R/S
23	LBL
13	C

CODE	KEYS
32	f^{-1}
61	TF 1
34 05	RCL 5
84	R/S
34 04	RCL 4
32	f^{-1}
51	SF 1
84	R/S
23	LBL
14	D
32	f^{-1}
61	TF 1
34 07	RCL 7
84	R/S
34 06	RCL 6
32	f^{-1}
51	SF 1
84	R/S
23	LBL
15	E
31	f
51	SF 1
84	R/S
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP

R_1	f_1, f_L	**R_4**	C_a	**R_7**	$4\pi f_1 f_2, L_b$
R_2	f_2, f_U	**R_5**	C_b	**R_8**	$\pi(f_2 - f_1)$
R_3	R, Δf	**R_6**	$f_2 - f_1, L_a$	**R_9**	

BAND PASS FILTER DESIGN (CARD 2)

CODE	KEYS
34 02	RCL 2
34 01	RCL 1
35 24	g x>y
00	0
81	÷
21	DSP
83	·
02	2
84	R/S
23	LBL
12	B
34 01	RCL 1
02	2
71	x
35	g
02	π
71	x
41	↑
71	x
33 08	STO 8
34 04	RCL 4
71	x
34 06	RCL 6
71	x
01	1
51	–
01	1
34 08	RCL 8
34 05	RCL 5
71	x
34 07	RCL 7
71	x
51	–
71	x
34 08	RCL 8

CODE	KEYS
04	4
71	x
34 04	RCL 4
71	x
34 07	RCL 7
71	x
81	÷
34 01	RCL 1
34 03	RCL 3
23	LBL
02	2
61	+
33 01	STO 1
35 08	g R↓
00	0
35 07	g x⇄y
35 24	g x>y
22	GTO
01	1
35 23	g x=y
00	0
84	R/S
01	1
42	CHS
35 07	g x⇄y
35 24	g x>y
00	0
84	R/S
42	CHS
14	D
51	–
15	E
84	R/S
23	LBL
01	1

CODE	KEYS
14	D
61	+
23	LBL
15	E
31	f
09	$\sqrt{x}$
61	+
31	f
07	LN
01	1
32	f^{-1}
07	LN
31	f
08	LOG
04	4
00	0
71	x
71	x
24	RTN
23	LBL
14	D
31	f
09	$\sqrt{x}$
41	↑
71	x
35 00	g LST X
35 07	g x⇄y
01	1
24	RTN
35 01	g NOP

R_1	f_L	**R_4**	C_a	**R_7**	L_b
R_2	f_U	**R_5**	C_b	**R_8**	ω^2
R_3	Δf	**R_6**	L_a	**R_9**	Used

ACTIVE FILTER—LOW PASS

CODE	KEYS
02	2
31	f
09	$\sqrt{x}$
33 03	STO 3
31	f
42	STK
23	LBL
00	0
32	f^{-1}
51	SF 1
21	DSP
83	·
02	2
24	RTN
23	LBL
11	A
31	f
61	TF 1
33 01	STO 1
22	GTO
00	0
61	+
33 02	STO 2
22	GTO
00	0
23	LBL
12	B
31	f
61	TF 1
33 03	STO 3
22	GTO
00	0
61	+
33 04	STO 4
22	GTO

CODE	KEYS
05	5
23	LBL
13	C
31	f
61	TF 1
22	GTO
01	1
14	D
35 07	g x⇄y
81	÷
22	GTO
00	0
23	LBL
02	2
32	f^{-1}
51	SF 1
14	D
34 03	RCL 3
71	x
35	g
02	π
71	x
34 01	RCL 1
71	x
81	÷
23	LBL
05	5
21	DSP
06	6
84	R/S
23	LBL
14	D
31	f
61	TF 1
22	GTO

CODE	KEYS
02	2
34 02	RCL 2
01	1
61	+
34 03	RCL 3
04	4
81	÷
35	g
02	π
81	÷
34 01	RCL 1
81	÷
34 04	RCL 4
81	÷
22	GTO
00	0
23	LBL
01	1
32	f^{-1}
51	SF 1
14	D
34 02	RCL 2
81	÷
22	GTO
00	0
23	LBL
15	E
31	f
51	SF 1
84	R/S

R_1	f_c	R_4	C	R_7	
R_2	G	R_5		R_8	
R_3	α	R_6		R_9	

ACTIVE FILTER—HIGH PASS

CODE	KEYS
02	2
31	f
09	$\sqrt{x}$
33 03	STO 3
31	f
42	STK
23	LBL
00	0
32	f^{-1}
51	SF 1
21	DSP
83	·
02	2
84	R/S
23	LBL
11	A
31	f
61	TF 1
33 01	STO 1
22	GTO
00	0
61	+
33 02	STO 2
22	GTO
00	0
23	LBL
12	B
31	f
61	TF 1
33 03	STO 3
22	GTO
00	0
61	+
33 04	STO 4
22	GTO

CODE	KEYS
05	5
23	LBL
13	C
31	f
61	TF 1
22	GTO
01	1
02	2
34 02	RCL 2
71	x
01	1
61	+
34 03	RCL 3
02	2
71	x
35	g
02	π
71	x
34 01	RCL 1
71	x
34 04	RCL 4
71	x
81	÷
22	GTO
00	0
23	LBL
01	1
34 03	RCL 3
02	2
35	g
02	π
71	x
34 01	RCL 1
71	x
34 04	RCL 4

CODE	KEYS
71	x
01	1
34 02	RCL 2
81	÷
02	2
61	+
71	x
81	÷
22	GTO
00	0
23	LBL
14	D
34 04	RCL 4
34 02	RCL 2
81	÷
23	LBL
05	5
21	DSP
06	6
32	f^{-1}
51	SF 1
84	R/S
23	LBL
15	E
31	f
51	SF 1
84	R/S
35 01	g NOP
35 01	g NOP
35 01	g NOP

R_1	f_o	R_4	C	R_7	
R_2	G	R_5		R_8	
R_3	α	R_6		R_9	

BUTTERWORTH FILTER

CODE	KEYS
33 01	STO 1
35	g
42	RAD
01	1
33 04	STO 4
02	2
33 05	STO 5
34 01	RCL 1
84	R/S
23	LBL
12	B
33 02	STO 2
84	R/S
23	LBL
13	C
33 03	STO 3
84	R/S
23	LBL
14	D
34 04	RCL 4
02	2
71	x
01	1
51	–
35	g
02	π
71	x
34 01	RCL 1
02	2
71	x
81	÷
31	f
04	SIN
34 02	RCL 2
34 03	RCL 3

CODE	KEYS
71	x
35	g
02	π
71	x
81	÷
33 06	STO 6
34 01	RCL 1
34 04	RCL 4
33 08	STO 8
35 24	g x>y
00	0
81	÷
02	2
61	+
33 04	STO 4
21	DSP
02	2
34 08	RCL 8
84	R/S
21	DSP
04	4
34 06	RCL 6
84	R/S
23	LBL
15	E
34 05	RCL 5
02	2
71	x
01	1
51	–
35	g
02	π
71	x
34 01	RCL 1
02	2

CODE	KEYS
71	x
81	÷
31	f
04	SIN
34 02	RCL 2
71	x
35	g
02	π
34 03	RCL 3
71	x
81	÷
33 07	STO 7
34 01	RCL 1
34 05	RCL 5
33 08	STO 8
35 24	g x>y
00	0
81	÷
02	2
61	+
33 05	STO 5
21	DSP
02	2
34 08	RCL 8
84	R/S
21	DSP
04	4
34 07	RCL 7
84	R/S
35 01	g NOP

R_1	n	R_4	Used	R_7	L_i
R_2	R	R_5	Used	R_8	Used
R_3	f_c	R_6	C_i	R_9	Used

CHEBYSHEV FILTER (CARD 1)

CODE	KEYS
23	LBL
11	A
33 01	STO 1
84	R/S
23	LBL
12	B
33 02	STO 2
84	R/S
23	LBL
13	C
33 03	STO 3
84	R/S
23	LBL
14	D
33 04	STO 4
84	R/S
23	LBL
15	E
01	1
33 05	STO 5
31	f
51	SF 1
35	g
42	RAD
21	DSP
03	3
34 03	RCL 3
02	2
71	x
35	g
02	π
71	x
33 03	STO 3
34 04	RCL 4
01	1

CODE	KEYS
32	f^{-1}
07	LN
31	f
08	LOG
04	4
00	0
71	x
81	÷
32	f^{-1}
07	LN
33 07	STO 7
35 00	g LST X
42	CHS
32	f^{-1}
07	LN
51	–
35 00	g LST X
34 07	RCL 7
61	+
81	÷
35	g
04	$1/x$
31	f
07	LN
34 01	RCL 1
02	2
71	x
81	÷
32	f^{-1}
07	LN
35 00	g LST X
42	CHS
32	f^{-1}
07	LN
51	–

CODE	KEYS
02	2
81	÷
33 06	STO 6
35	g
02	π
34 01	RCL 1
02	2
71	x
81	÷
31	f
04	SIN
33 08	STO 8
02	2
71	x
34 06	RCL 6
81	÷
33 07	STO 7
34 03	RCL 3
34 02	RCL 2
71	x
81	÷
33 04	STO 4
00	0
84	R/S
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP

R_1	n	R_4	ϵ_{dB}, C_1	R_7	G_i
R_2	R	R_5	i	R_8	a_i
R_3	f_c, ω_c	R_6	γ	R_9	Used

CHEBYSHEV FILTER (CARD 2)

CODE	KEYS
23	LBL
11	A
21	DSP
83	•
00	0
34 01	RCL 1
34 05	RCL 5
35 24	g x>y
00	0
81	÷
84	R/S
23	LBL
12	B
31	f
61	TF 1
22	GTO
01	1
31	f
81	TF 2
22	GTO
03	3
31	f
71	SF 2
15	E
34 03	RCL 3
34 02	RCL 2
71	x
23	LBL
02	2
21	DSP
03	3
81	÷
34 05	RCL 5
01	1
61	+

CODE	KEYS
33 05	STO 5
35 07	g x⇄y
84	R/S
23	LBL
01	1
32	f^{-1}
51	–
31	f
71	SF 2
34 04	RCL 4
01	1
22	GTO
02	2
23	LBL
03	3
32	f^{-1}
71	SF 1
15	E
34 02	RCL 2
71	x
34 03	RCL 3
22	GTO
02	2
23	LBL
15	E
34 08	RCL 8
04	4
71	x
34 05	RCL 5
02	2
71	x
01	1
51	–
35	g
02	π

CODE	KEYS
71	x
34 01	RCL 1
02	2
71	x
81	÷
31	f
04	SIN
33 08	STO 8
71	x
34 05	RCL 5
01	1
51	–
35	g
02	π
71	x
34 01	RCL 1
81	÷
31	f
04	SIN
41	↑
71	x
34 06	RCL 6
41	↑
71	x
61	+
34 07	RCL 7
71	x
81	÷
33 07	STO 7
24	RTN

R_1	n	R_4	C_i	R_7	G_i
R_2	R	R_5	i	R_8	a_i
R_3	ω_C	R_6	γ	R_9	Used

CAPACITANCE OF PARALLEL PLATES

CODE	KEYS
02	2
83	•
05	5
04	4
42	CHS
33 06	STO 6
84	R/S
23	LBL
11	A
33 01	STO 1
84	R/S
23	LBL
12	B
00	0
35 07	g x⇄y
35 24	g x>y
33 02	STO 2
84	R/S
34 06	RCL 6
71	x
33 02	STO 2
84	R/S
23	LBL
13	C
00	0
35 07	g x⇄y
35 24	g x>y
33 03	STO 3
84	R/S
34 06	RCL 6
71	x
33 03	STO 3
84	R/S
23	LBL
14	D

CODE	KEYS
00	0
35 07	g x⇄y
35 24	g x>y
33 04	STO 4
84	R/S
34 06	RCL 6
71	x
33 04	STO 4
84	R/S
23	LBL
15	E
34 01	RCL 1
34 02	RCL 2
81	÷
34 03	RCL 3
71	x
34 04	RCL 4
71	x
83	•
00	0
08	8
08	8
05	5
04	4
01	1
09	9
71	x
33 05	STO 5
34 03	RCL 3
34 04	RCL 4
43	EEX
02	2
71	x
35 24	g x>y
34 05	RCL 5

CODE	KEYS
84	R/S
34 04	RCL 4
35	g
02	π
02	2
71	x
71	x
34 02	RCL 2
81	÷
31	f
07	LN
01	1
61	+
34 02	RCL 2
34 04	RCL 4
81	÷
35	g
02	π
81	÷
71	x
01	1
61	+
34 05	RCL 5
71	x
84	R/S
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP

R_1	ϵ_r	R_4	W	R_7	
R_2	d	R_5	C with P = 0	R_8	
R_3	L	R_6	−2.54	R_9	Used

SELF INDUCTANCE OF STRAIGHT ROUND WIRE

CODE	KEYS
02	2
83	•
05	5
04	4
42	CHS
33 04	STO 4
01	1
33 03	STO 3
44	CLX
84	R/S
23	LBL
11	A
00	0
35 07	g x⇄y
35 24	g x>y
33 01	STO 1
84	R/S
34 04	RCL 4
71	x
33 01	STO 1
84	R/S
23	LBL
12	B
00	0
35 07	g x⇄y
35 24	g x>y
33 02	STO 2
84	R/S
34 04	RCL 4
71	x
33 02	STO 2
84	R/S
23	LBL
13	C
33 03	STO 3

CODE	KEYS
84	R/S
23	LBL
14	D
15	E
83	•
00	0
00	0
02	2
34 03	RCL 3
71	x
34 02	RCL 2
71	x
04	4
81	÷
61	+
84	R/S
23	LBL
15	E
04	4
34 02	RCL 2
71	x
34 01	RCL 1
81	÷
31	f
07	LN
01	1
51	–
34 02	RCL 2
71	x
83	•
00	0
00	0
02	2
71	x
24	RTN

CODE	KEYS
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP

R_1	d	R_4	-2.54	R_7	
R_2	l	R_5		R_8	
R_3	μ_r	R_6		R_9	Used

INDUCTANCE OF A SINGLE-LAYER CLOSE-WOUND COIL

CODE	KEYS
81	÷
71	x
31	f
09	$\sqrt{x}$
31	f
01	R→P
35 09	g R↑
61	+
84	R/S
23	LBL
15	E
34 02	RCL 2
34 04	RCL 4
71	x
33 06	STO 6
01	1
33 08	STO 8
84	R/S
23	LBL
11	A
35	g
83	DSZ
33 01	STO 1
84	R/S
04	4
83	•
05	5
34 03	RCL 3
41	↑
71	x
81	÷
34 04	RCL 4
71	x
34 06	RCL 6
01	1

CODE	KEYS
00	0
34 03	RCL 3
22	GTO
00	0
23	LBL
12	B
35	g
83	DSZ
33 02	STO 2
84	R/S
34 03	RCL 3
34 01	RCL 1
34 04	RCL 4
81	÷
71	x
09	9
34 03	RCL 3
81	÷
51	–
34 01	RCL 1
71	x
01	1
00	0
81	÷
84	R/S
23	LBL
14	D
35	g
83	DSZ
33 04	STO 4
84	R/S
34 03	RCL 3
34 01	RCL 1
71	x
41	↑

CODE	KEYS
71	x
09	9
34 01	RCL 1
71	x
01	1
00	0
34 02	RCL 2
71	x
34 03	RCL 3
71	x
61	+
81	÷
84	R/S
23	LBL
13	C
35	g
83	DSZ
33 03	STO 3
84	R/S
05	5
34 06	RCL 6
71	x
34 01	RCL 1
41	↑
71	x
81	÷
34 04	RCL 4
09	9
34 01	RCL 1
35 01	g NOP

R_1	R	R_4	L	R_7	
R_2	D	R_5		R_8	DSZ
R_3	N	R_6	DL	R_9	Used

SKIN EFFECT AND COIL Q

CODE	KEYS
32	f^{-1}
51	SF 1
84	R/S
23	LBL
11	A
32	f^{-1}
61	TF 1
33 02	STO 2
84	R/S
33 01	STO 1
22	GTO
00	0
23	LBL
12	B
32	f^{-1}
61	TF 1
33 04	STO 4
84	R/S
33 03	STO 3
22	GTO
00	0
23	LBL
15	E
31	f
51	SF 1
84	R/S
23	LBL
13	C
06	6
83	·
06	6
00	0
08	8
34 04	RCL 4
31	f

CODE	KEYS
09	$\sqrt{x}$
81	÷
31	f
61	TF 1
22	GTO
00	0
35 00	g LST X
34 02	RCL 2
71	x
34 03	RCL 3
34 02	RCL 2
81	÷
31	f
08	LOG
01	1
83	·
02	2
71	x
83	·
03	3
08	8
61	+
35	g
42	RAD
31	f
04	SIN
01	1
83	·
01	1
08	8
61	+
83 ~~02~~	~~2~~ ·
00 ~~05~~	~~5~~ 0
02 ~~83~~	~~·~~ 2
05 ~~05~~	~~5~~ 5

CODE	KEYS
06 ~~09~~	~~9~~ 6
71	x
71	x
84	R/S
23	LBL
14	D
02	2
83	·
06	6
01	1
43	EEX
42	CHS
07	7
34 04	RCL 4
31	f
09	$\sqrt{x}$
71	x
31	f
61	TF 1
22	GTO
00	0
43	EEX
02	2
71	x
35	g
02	π
81	÷
34 01	RCL 1
81	÷
84	R/S

R_1	d	R_4	f	R_7	
R_2	D	R_5		R_8	
R_3	l	R_6		R_9	Used

TRANSFORMER DESIGN

CODE	KEYS
84	R/S
01	1
33 08	STO 8
03	3
04	4
09	9
43	EEX
04	4
33 07	STO 7
84	R/S
33 06	STO 6
34 02	RCL 2
81	÷
31	f
09	$\sqrt{x}$
83	·
07	7
02	2
33 08	STO 8
81	÷
22	GTO
00	0
23	LBL
11	A
35	g
83	DSZ
33 01	STO 1
22	GTO
00	0
34 02	RCL 2
23	LBL
02	2
34 03	RCL 3
71	x
23	LBL

CODE	KEYS
03	3
34 04	RCL 4
71	x
23	LBL
04	4
34 05	RCL 5
34 07	RCL 7
71	x
35 07	g x⇄y
81	÷
22	GTO
00	0
23	LBL
12	B
35	g
83	DSZ
33 02	STO 2
22	GTO
00	0
34 01	RCL 1
22	GTO
02	2
23	LBL
13	C
35	g
83	DSZ
33 03	STO 3
22	GTO
00	0
34 01	RCL 1
34 02	RCL 2
71	x
22	GTO
03	3
23	LBL

CODE	KEYS
14	D
35	g
83	DSZ
33 04	STO 4
22	GTO
00	0
34 01	RCL 1
34 02	RCL 2
71	x
34 03	RCL 3
71	x
22	GTO
04	4
23	LBL
15	E
35	g
83	DSZ
33 05	STO 5
22	GTO
00	0
34 01	RCL 1
34 02	RCL 2
71	x
34 03	RCL 3
71	x
34 04	RCL 4
71	x
34 07	RCL 7
81	÷
35 01	g NOP

R_1	N_p	R_4	B_m	R_7	temporary
R_2	f	R_5	E_p	R_8	.72, DSZ
R_3	A_c	R_6	W_{out}	R_9	

REED RELAY DESIGN (CARD 1)

CODE	KEYS
02	2
83	•
05	5
04	4
33 07	STO 7
00	0
33 08	STO 8
84	R/S
23	LBL
11	A
35	g
83	DSZ
33 01	STO 1
84	R/S
33 04	STO 4
84	R/S
23	LBL
12	B
35	g
83	DSZ
33 02	STO 2
84	R/S
33 05	STO 5
84	R/S
23	LBL
13	C
35	g
83	DSZ
33 03	STO 3
84	R/S
33 06	STO 6
00	0
34 01	RCL 1
35 24	g x>y
34 07	RCL 7

CODE	KEYS
81	÷
35	g
06	ABS
33 01	STO
44	CLX
34 02	RCL 2
35 24	g x>y
34 07	RCL 7
81	÷
35	g
06	ABS
33 02	STO 2
44	CLX
34 03	RCL 3
35 24	g x>y
34 07	RCL 7
81	÷
35	g
06	ABS
33 03	STO 3
34 06	RCL 6
84	R/S
23	LBL
15	E
01	1
33 08	STO 8
35 08	g R↓
24	RTN
23	LBL
14	D
34 02	RCL 2
34 03	RCL 3
51	–
34 01	RCL 1
71	x

CODE	KEYS
02	2
81	÷
33 07	STO 7
34 06	RCL 6
34 02	RCL 2
34 03	RCL 3
61	+
33 02	STO 2
81	÷
02	2
83	•
06	6
43	EEX
05	5
71	x
02	2
83	•
03	3
05	5
06	6
02	2
34 04	RCL 4
71	x
81	÷
31	f
07	LN
04	4
41	↑
00	0
84	R/S

R_1	L, WS	R_4	S_{max}	R_7	A
R_2	OD, OD + ID	R_5	S_{min}	R_8	T, DSZ
R_3	ID	R_6	V	R_9	Used

REED RELAY DESIGN (CARD 2)

CODE	KEYS
35 08	g R↓
71	x
83	•
05	5
61	+
31	f
83	INT
33 01	STO 1
00	0
84	R/S
23	LBL
13	C
21	DSP
83	•
00	0
34 01	RCL 1
83	•
02	2
02	2
09	9
71	x
32	f^{-1}
07	LN
08	8
83	•
05	5
07	7
71	x
34 07	RCL 7
71	x
33 08	STO 8
34 01	RCL 1
84	R/S
34 08	RCL 8
84	R/S

CODE	KEYS
23	LBL
14	D
83	•
02	2
03	3
01	1
02	2
34 01	RCL 1
71	x
32	f^{-1}
07	LN
83	•
00	0
04	4
09	9
06	6
71	x
01	1
02	2
43	EEX
03	3
81	÷
34 08	RCL 8
71	x
35	g
02	π
71	x
34 02	RCL 2
71	x
33 03	STO 3
84	R/S
34 06	RCL 6
32	f^{-1}
09	$\sqrt{x}$
34 03	RCL 3

CODE	KEYS
81	÷
01	1
43	EEX
03	3
71	x
84	R/S
23	LBL
15	E
21	DSP
83	•
02	2
34 04	RCL 4
01	1
83	•
01	1
71	x
34 08	RCL 8
81	÷
34 03	RCL 3
71	x
84	R/S
34 05	RCL 5
83	•
03	3
71	x
34 08	RCL 8
81	÷
34 03	RCL 3
71	x
84	R/S

R_1	L, WS	R_4	S_{max}	R_7	A
R_2	OD + ID	R_5	S_{min}	R_8	T
R_3	ID, R_c	R_6	V	R_9	

IMPEDANCE OF TRANSMISSION LINE

CODE	KEYS
01	1
33 01	STO 1
01	1
03	3
08	8
83	·
00	0
06	6
33 04	STO 4
84	R/S
23	LBL
11	A
35	g
83	DSZ
33 02	STO 2
84	R/S
33 01	STO 1
84	R/S
23	LBL
12	B
33 03	STO 3
84	R/S
23	LBL
13	C
35	g
83	DSZ
22	GTO
01	1
34 02	RCL 2
04	4
71	x
23	LBL
00	0
34 03	RCL 3
81	÷

CODE	KEYS
31	f
08	LOG
34 04	RCL 4
71	x
34 01	RCL 1
31	f
09	$\sqrt{x}$
81	÷
84	R/S
23	LBL
01	1
34 02	RCL 2
22	GTO
00	0
23	LBL
14	D
34 02	RCL 2
34 03	RCL 3
81	÷
41	↑
41	↑
71	x
01	1
51	–
31	f
09	$\sqrt{x}$
61	+
31	f
08	LOG
34 04	RCL 4
02	2
71	x
71	x
34 01	RCL 1
31	f

CODE	KEYS
09	$\sqrt{x}$
81	÷
84	R/S
23	LBL
15	E
01	1
33 08	STO 8
35 08	g R↓
84	R/S
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP

R_1	ϵ_r	R_4	138.06	R_7	
R_2	D	R_5		R_8	DSZ
R_3	d	R_6		R_9	

TRANSMISSION LINE IMPEDANCE TRANSFORMATION

CODE	KEYS
32	f^{-1}
51	SF 1
84	R/S
23	LBL
11	A
32	f^{-1}
61	TF 1
33 02	STO 2
84	R/S
33 01	STO 1
22	GTO
00	0
23	LBL
12	B
32	f^{-1}
61	TF 1
33 04	STO 4
84	R/S
33 03	STO 3
22	GTO
00	0
23	LBL
13	C
32	f^{-1}
61	TF 1
33 05	STO 5
84	R/S
34 01	RCL 1
34 03	RCL 3
71	x
01	1
83	·
02	2
00	0
00	0

CODE	KEYS
08	8
03	3
43	EEX
42	CHS
08	8
71	x
34 04	RCL 4
81	÷
33 05	STO 5
22	GTO
00	0
23	LBL
14	D
32	f^{-1}
61	TF 1
33 07	STO 7
84	R/S
33 06	STO 6
22	GTO
00	0
23	LBL
15	E
31	f
51	SF 1
84	R/S
23	LBL
15	E
34 06	RCL 6
34 07	RCL 7
32	f^{-1}
01	R→P
33 08	STO 8
34 05	RCL 5
31	f
06	TAN

CODE	KEYS
71	x
34 02	RCL 2
35 00	g LST X
71	x
35 00	g LST X
35 09	g R↑
71	x
35 07	g x⇄y
35 00	g LST X
61	+
35 07	g x⇄y
34 02	RCL 2
35 07	g x⇄y
51	–
35 07	g x⇄y
34 08	RCL 8
31	f
01	R→P
35 07	g x⇄y
35 09	g R↑
35 09	g R↑
31	f
01	R→P
35 08	g R↓
51	–
35 07	g x⇄y
35 09	g R↑
81	÷
34 02	RCL 2
71	x

R_1	f	R_4	v	R_7	MAG[Z]
R_2	Z_0	R_5	θ	R_8	Used
R_3	l	R_6	ANG[Z]	R_9	Used

MICROSTRIP TRANSMISSION LINE

CODE	KEYS
00	0
33 08	STO 8
84	R/S
23	LBL
11	A
35	g
83	DSZ
33 02	STO 2
24	RTN
33 01	STO 1
24	RTN
23	LBL
12	B
35	g
83	DSZ
33 04	STO 4
24	RTN
33 03	STO 3
24	RTN
23	LBL
13	C
05	5
83	·
09	9
08	8
34 03	RCL 3
71	x
34 01	RCL 1
83	·
08	8
71	x
34 02	RCL 2
61	+
81	÷
31	f

CODE	KEYS
07	LN
08	8
07	7
71	x
34 04	RCL 4
01	1
83	·
04	4
01	1
61	+
31	f
09	$\sqrt{x}$
81	÷
24	RTN
23	LBL
14	D
83	·
04	4
07	7
05	5
34 04	RCL 4
71	x
83	·
06	6
07	7
61	+
31	f
09	$\sqrt{x}$
01	1
83	·
00	0
01	1
07	7
71	x
35	g

CODE	KEYS
83	DSZ
24	RTN
35 01	g NOP
83	·
03	3
00	0
04	4
08	8
81	÷
24	RTN
23	LBL
15	E
01	1
33 08	STO 8
35 08	g R↓
24	RTN
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP

R_1	w	R_4	ϵ_r	R_7	
R_2	t	R_5		R_8	DSZ
R_3	h	R_6		R_9	

S⇄Y PARAMETER CONVERSION (CARD 1)

CODE	KEYS
34 02	RCL 2
33 01	STO 1
34 03	RCL 3
33 02	STO 2
34 04	RCL 4
33 03	STO 3
35 09	g R↑
33 04	STO 4
84	R/S
23	LBL
12	B
34 06	RCL 6
33 05	STO 5
34 07	RCL 7
33 06	STO 6
34 08	RCL 8
33 07	STO 7
35 09	g R↑
34 04	RCL 4
32	f^{-1}
01	R→P
33 04	STO 4
35 08	g R↓
33 08	STO 8
84	R/S
23	LBL
13	C
15	E
34 06	RCL 6
34 02	RCL 2
14	D
15	E
34 07	RCL 7
34 03	RCL 3
14	D

CODE	KEYS
23	LBL
15	E
34 05	RCL 5
34 04	RCL 4
01	1
61	+
71	x
34 08	RCL 8
34 01	RCL 1
01	1
61	+
71	x
61	+
34 02	RCL 2
34 07	RCL 7
71	x
51	–
34 06	RCL 6
34 03	RCL 3
71	x
51	–
34 01	RCL 1
01	1
61	+
34 04	RCL 4
01	1
61	+
71	x
34 05	RCL 5
34 08	RCL 8
71	x
51	–
34 02	RCL 2
34 03	RCL 3
71	x

CODE	KEYS
51	–
34 06	RCL 6
34 07	RCL 7
71	x
61	+
31	f
01	R→P
35 07	g x⇄y
24	RTN
23	LBL
14	D
31	f
01	R→P
35 09	g R↑
81	÷
02	2
71	x
84	R/S
35 08	g R↓
35 07	g x⇄y
51	–
01	1
42	CHS
32	f^{-1}
01	R→P
31	f
01	R→P
35 08	g R↓
84	R/S
24	RTN

R_1	Re $[s_{11}]$	R_4	Re $[s_{22}]$	R_7	temporary
R_2	temporary	R_5	Im $[s_{11}]$	R_8	Im $[s_{22}]$
R_3	temporary	R_6	temporary	R_9	temporary, ± 1

S⇄Y PARAMETER CONVERSION (CARD 2)

CODE	KEYS
33	STO
09	9
35 07	g x⇄y
34 02	RCL 2
34 03	RCL 3
71	x
34 06	RCL 6
34 07	RCL 7
71	x
51	–
34 02	RCL 2
34 07	RCL 7
71	x
34 03	RCL 3
35 09	g R↑
33 03	STO 3
35 08	g R↓
34 06	RCL 6
71	x
61	+
33 07	STO 7
35 07	g x⇄y
33 06	STO 6
34	RCL
09	9
33 02	STO 2
01	1
33	STO
09	9
15	E
01	1
42	CHS
33	STO
09	9
23	LBL

CODE	KEYS
15	E
34 05	RCL 5
34	RCL
09	9
42	CHS
34 04	RCL 4
51	–
71	x
34 08	RCL 8
34	RCL
09	9
34 01	RCL 1
51	–
71	x
61	+
34 07	RCL 7
61	+
34	RCL
09	9
34 01	RCL 1
51	–
34	RCL
09	9
34 04	RCL 4
61	+
71	x
34 05	RCL 5
34 08	RCL 8
71	x
61	+
34 06	RCL 6
61	+
31	f
01	R→P
34 03	RCL 3

CODE	KEYS
81	÷
84	R/S
35 07	g x⇄y
34 02	RCL 2
51	–
01	1
32	f^{-1}
01	R→P
31	f
01	R→P
35 08	g R↓
84	R/S
24	RTN
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP

R_1	Re $[s_{11}]$	R_4	Re $[s_{22}]$	R_7	temporary
R_2	temporary	R_5	Im $[s_{11}]$	R_8	Im $[s_{22}]$
R_3	temporary	R_6	temporary	R_9	temporary, ± 1

POWER SUPPLY RECTIFIER CIRCUITS

CODE	KEYS
31	f
43	REG
84	R/S
23	LBL
11	A
35	g
83	DSZ
33 02	STO 2
84	R/S
33 01	STO 1
84	R/S
23	LBL
12	B
35	g
83	DSZ
33 04	STO 4
84	R/S
33 03	STO 3
84	R/S
23	LBL
13	C
33 05	STO 5
34 04	RCL 4
06	6
81	÷
35	g
02	π
81	÷
34 03	RCL 3
81	÷
33 07	STO 7
34 05	RCL 5
84	R/S
23	LBL
15	E

CODE	KEYS
01	1
33 08	STO 8
35 08	g R↓
84	R/S
23	LBL
14	D
34 01	RCL 1
02	2
31	f
09	$\sqrt{x}$
71	x
33 06	STO 6
34 06	RCL 6
34 05	RCL 5
03	3
35 23	g x=y
22	GTO
01	1
35 08	g R↓
81	÷
34 02	RCL 2
81	÷
34 03	RCL 3
81	÷
34 04	RCL 4
81	÷
33	STO
09	9
02	2
81	÷
51	–
34	RCL
09	9
22	GTO
02	2

CODE	KEYS
23	LBL
01	1
34 06	RCL 6
02	2
71	x
35	g
02	π
81	÷
35 00	g LST X
34 03	RCL 3
71	x
41	↑
71	x
01	1
02	2
34 02	RCL 2
71	x
71	x
34 07	RCL 7
71	x
81	÷
23	LBL
02	2
35	g
83	DSZ
35 01	g NOP
84	R/S
35 07	g x⇄y
84	R/S
35 01	g NOP

R_1	V_i	R_4	R	R_7	L_{MIN} or L
R_2	C	R_5	Type	R_8	DSZ
R_3	f	R_6	$\sqrt{2}\ V_i$	R_9	Temporary

CONTROLLED RECTIFIER CIRCUITS

CODE	KEYS
35	g
41	DEG
31	f
43	REG
84	R/S
23	LBL
11	A
35	g
83	DSZ
33 01	STO 1
24	RTN
34 03	RCL 3
14	D
81	÷
24	RTN
23	LBL
12	B
35	g
83	DSZ
33 02	STO 2
24	RTN
34 03	RCL 3
34 01	RCL 1
81	÷
35	g
02	π
71	x
01	1
51	—
32	f^{-1}
05	COS
24	RTN
23	LBL
13	C
35	g

CODE	KEYS
83	DSZ
33 03	STO 3
24	RTN
34 01	RCL 1
14	D
71	x
24	RTN
23	LBL
14	D
01	1
34 02	RCL 2
31	f
05	COS
61	+
35	g
02	π
81	÷
24	RTN
23	LBL
15	E
01	1
33 08	STO 8
84	R/S
34 01	RCL 1
34 02	RCL 2
35	g
02	π
71	x
09	9
00	0
81	÷
35	g
42	RAD
31	f
04	SIN

CODE	KEYS
35 00	g LST X
51	—
35	g
02	π
33 08	STO 8
02	2
71	x
61	+
35 00	g LST X
02	2
71	x
35 07	g x⇄y
81	÷
31	f
09	$\sqrt{x}$
81	÷
35	g
41	DEG
84	R/S
09	9
00	0
34 02	RCL 2
35 22	g x≤y
35 01	g NOP
35 07	g x⇄y
31	f
04	SIN
34 01	RCL 1
71	x
84	R/S

R_1	E_p	R_4		R_7	
R_2	α	R_5		R_8	DSZ
R_3	V_{AVE}	R_6		R_9	Used

INTEGRATED CIRCUIT CURRENT SOURCE

CODE	KEYS
31	f
42	STK
31	f
43	REG
84	R/S
23	LBL
11	A
33 01	STO 1
84	R/S
23	LBL
12	B
33 02	STO 2
84	R/S
23	LBL
13	C
33 03	STO 3
84	R/S
23	LBL
14	D
33 04	STO 4
84	R/S
23	LBL
15	E
34 04	RCL 4
83	•
06	6
51	—
34 03	RCL 3
81	÷
34 02	RCL 2
81	÷
31	f
07	LN
34 01	RCL 1
02	2

CODE	KEYS
07	7
03	3
61	+
71	x
34 02	RCL 2
81	÷
08	8
83	•
06	6
02	2
05	5
43	EEX
42	CHS
05	5
71	x
84	R/S
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP

CODE	KEYS
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP

R_1	T	R_4	V_C	R_7	
R_2	I	R_5		R_8	
R_3	R_1	R_6		R_9	

TRANSISTOR BIAS

CODE	KEYS
21	DSP
02	2
31	f
42	STK
23	LBL
00	0
32	f^{-1}
51	SF 1
24	RTN
84	R/S
23	LBL
11	A
32	f^{-1}
61	TF 1
33 02	STO 2
22	GTO
01	1
35 07	g x⇄y
33 01	STO 1
22	GTO
01	1
23	LBL
12	B
32	f^{-1}
61	TF 1
33 04	STO 4
84	R/S
33 03	STO 3
22	GTO
01	1
23	LBL
13	C
31	f
61	TF 1
33 05	STO 5

CODE	KEYS
22	GTO
00	0
34 06	RCL 6
34 01	RCL 1
81	÷
34 04	RCL 4
71	x
83	•
06	6
51	—
34 05	RCL 5
71	x
23	LBL
02	2
34 05	RCL 5
01	1
61	+
34 03	RCL 3
71	x
34 06	RCL 6
61	+
81	÷
22	GTO
00	0
23	LBL
14	D
34 05	RCL 5
31	f
61	TF 1
22	GTO
02	2
13	C
34 05	RCL 5
81	÷
34 03	RCL 3

CODE	KEYS
34 06	RCL 6
61	+
71	x
22	GTO
02	2
23	LBL
15	E
31	f
51	SF 1
84	R/S
23	LBL
01	1
33 07	STO 7
34 01	RCL 1
34 02	RCL 2
71	x
34 01	RCL 1
34 02	RCL 2
61	+
00	0
35 23	g x=y
34 07	RCL 7
22	GTO
00	0
61	+
61	+
81	÷
33 06	STO 6
34 07	RCL 7
35 01	g NOP

R_1	R_1	R_4	V_C	R_7	Used
R_2	R_2	R_5	β	R_8	
R_3	R_3	R_6	R_B	R_9	Used

JFET BIAS AND TRANSCONDUCTANCE

CODE	KEYS
21	DSP
02	2
44	CLX
84	R/S
23	LBL
11	A
35	g
83	DSZ
33 02	STO 2
84	R/S
33 01	STO 1
84	R/S
23	LBL
12	B
35	g
83	DSZ
33 04	STO 4
84	R/S
33 03	STO 3
84	R/S
23	LBL
13	C
35	g
83	DSZ
22	GTO
01	1
01	1
34 03	RCL 3
34 02	RCL 2
81	÷
31	f
09	$\sqrt{x}$
51	—
34 01	RCL 1
71	x

CODE	KEYS
21	DSP
03	3
24	RTN
23	LBL
01	1
15	E
13	C
34 01	RCL 1
81	÷
01	1
51	—
02	2
71	x
34 02	RCL 2
71	x
34 01	RCL 1
81	÷
21	DSP
03	3
84	R/S
23	LBL
14	D
35	g
83	DSZ
22	GTO
02	2
15	E
13	C
34 03	RCL 3
81	÷
42	CHS
21	DSP
83	•
00	0
84	R/S

CODE	KEYS
23	LBL
02	2
15	E
13	C
34 01	RCL 1
81	÷
01	1
51	—
02	2
71	x
34 02	RCL 2
71	x
34 01	RCL 1
81	÷
34 04	RCL 4
35 07	g x⇄y
81	÷
35	g
06	ABS
21	DSP
83	•
00	0
84	R/S
23	LBL
15	E
01	1
33 08	STO 8
35 08	g R↓
24	RTN
35 01	g NOP

R_1	V_P	R_4	A_V	R_7	
R_2	I_{DSS}	R_5		R_8	DSZ
R_3	I_D	R_6		R_9	

PHASE–LOCKED LOOP

CODE	KEYS
00	0
33 08	STO 8
84	R/S
23	LBL
11	A
35	g
83	DSZ
33 02	STO 2
84	R/S
33 01	STO 1
84	R/S
23	LBL
12	B
35	g
83	DSZ
33 04	STO 4
84	R/S
33 03	STO 3
84	R/S
23	LBL
13	C
34 01	RCL 1
34 02	RCL 2
34 03	RCL 3
61	+
34 04	RCL 4
71	x
81	÷
31	f
09	$\sqrt{x}$
33 05	STO 5
02	2
81	÷
34 03	RCL 3
34 04	RCL 4

CODE	KEYS
71	x
34 01	RCL 1
35	g
04	$^1/_x$
61	+
71	x
33 06	STO 6
35	g
83	DSZ
24	RTN
35 01	g NOP
34 05	RCL 5
24	RTN
23	LBL
14	D
34 01	RCL 1
34 02	RCL 2
34 04	RCL 4
71	x
81	÷
31	f
09	$\sqrt{x}$
33 05	STO 5
02	2
81	÷
34 04	RCL 4
34 03	RCL 3
71	x
71	x
33 06	STO 6
35	g
83	DSZ
24	RTN
35 01	g NOP
34 05	RCL 5

CODE	KEYS
24	RTN
23	LBL
15	E
35	g
83	DSZ
22	GTO
01	1
34 05	RCL 5
34 06	RCL 6
41	↑
41	↑
04	4
71	x
35	g
04	$^1/_x$
61	+
71	x
02	2
81	÷
84	R/S
23	LBL
01	1
01	1
33 08	STO 8
35 08	g R↓
84	R/S
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP

R_1	G	R_4	C	R_7	
R_2	R_1	R_5	ω_n	R_8	DSZ
R_3	R_2	R_6	ζ	R_9	

FOURIER SERIES

CODE	KEYS
35	g
42	RAD
31	f
43	REG
33	STO
09	9
24	RTN
23	LBL
12	B
42	CHS
33 08	STO 8
01	1
33 07	STO 7
24	RTN
23	LBL
13	C
34	RCL
09	9
81	÷
35 07	g x⇄y
35 00	g LST X
81	÷
02	2
71	x
35	g
02	π
71	x
41	↑
15	E
33	STO
61	+
01	1
31	f
61	TF 1
22	GTO

CODE	KEYS
02	2
15	E
33	STO
61	+
02	2
15	E
33	STO
61	+
03	3
15	E
33	STO
61	+
04	4
15	E
33	STO
61	+
05	5
15	E
33	STO
61	+
06	6
23	LBL
02	2
06	6
31	f
61	TF 1
44	CLX
01	1
33	STO
61	+
08	8
34 07	RCL 7
01	1
61	+
33 07	STO 7

CODE	KEYS
24	RTN
23	LBL
15	E
44	CLX
34 08	RCL 8
42	CHS
35	g
83	DSZ
35 07	g x⇄y
71	x
35 00	g LST X
35 07	g x⇄y
34	RCL
09	9
35 08	g R↓
23	LBL
01	1
31	f
05	COS
35 09	g R↑
33	STO
09	9
44	CLX
61	+
35 09	g R↑
71	x
02	2
71	x
24	RTN
35 01	g NOP

R_1	C_1	R_4	C_4	R_7	k
R_2	C_2	R_5	C_5	R_8	J, j
R_3	C_3	R_6	C_6	R_9	N

DECIBEL CONVERSION

CODE	KEYS
23	LBL
11	A
35	g
83	DSZ
33 02	STO 2
84	R/S
33 01	STO 1
84	R/S
23	LBL
12	B
35	g
83	DSZ
33 04	STO 4
84	R/S
33 03	STO 3
84	R/S
23	LBL
13	C
35	g
83	DSZ
22	GTO
00	0
34 03	RCL 3
34 01	RCL 1
81	÷
31	f
08	LOG
02	2
00	0
71	x
84	R/S
23	LBL
00	0
34 04	RCL 4
34 02	RCL 2

CODE	KEYS
81	÷
31	f
08	LOG
01	1
00	0
71	x
84	R/S
23	LBL
14	D
01	1
00	0
81	÷
32	f^{-1}
08	LOG
31	f
09	$\sqrt{x}$
35	g
83	DSZ
35 00	g LST X
84	R/S
84	R/S
23	LBL
15	E
01	1
33 08	STO 8
35 08	g R↓
84	R/S
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP

CODE	KEYS
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP

R_1	V_1	R_4	P_2	R_7	
R_2	P_1	R_5		R_8	DSZ
R_3	V_2	R_6		R_9	

VOLTAGE TO dBm

CODE	KEYS
23	LBL
11	A
35	g
83	DSZ
33 01	STO 1
84	R/S
03	3
00	0
34 03	RCL 3
51	—
01	1
00	0
81	÷
32	f^{-1}
08	LOG
34 02	RCL 2
41	↑
71	x
71	x
84	R/S
23	LBL
12	B
35	g
83	DSZ
33 02	STO 2
84	R/S
34 03	RCL 3
03	3
00	0
51	—
01	1
00	0
81	÷
32	f^{-1}
08	LOG

CODE	KEYS
34 01	RCL 1
71	x
31	f
09	$\sqrt{x}$
84	R/S
23	LBL
13	C
35	g
83	DSZ
33 03	STO 3
84	R/S
34 02	RCL 2
41	↑
71	x
34 01	RCL 1
81	÷
31	f
08	LOG
03	3
61	+
01	1
00	0
71	x
84	R/S
23	LBL
15	E
01	1
33 08	STO 8
84	R/S
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP

CODE	KEYS
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP

R_1	Z	R_4		R_7	
R_2	V	R_5		R_8	DSZ
R_3	dBm	R_6		R_9	

WIRE TABLES Al AND ANNEALED Cu

CODE	KEYS
23	LBL
11	A
21	DSP
83	·
00	0
33 01	STO 1
01	1
00	0
03	3
07	7
01	1
33 02	STO 2
83	·
00	0
00	0
03	3
00	0
02	2
06	6
09	9
33 03	STO 3
34 01	RCL 1
24	RTN
23	LBL
12	B
21	DSP
83	·
00	0
33 01	STO 1
01	1
07	7
00	0
00	0
02	2
33 02	STO 2

CODE	KEYS
83	·
00	0
00	0
00	0
09	9
02	2
00	0
03	3
33 03	STO 3
34 01	RCL 1
24	RTN
23	LBL
13	C
21	DSP
03	3
83	·
04	4
06	6
41	↑
41	↑
83	·
00	0
00	0
05	5
81	÷
34 01	RCL 1
03	3
61	+
03	3
09	9
81	÷
35	g
05	y^x
81	÷
43	EEX

CODE	KEYS
03	3
71	x
24	RTN
23	LBL
14	D
13	C
34 02	RCL 2
35 07	g x⇄y
41	↑
71	x
81	÷
24	RTN
23	LBL
15	E
13	C
41	↑
71	x
34 03	RCL 3
71	x
24	RTN
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP
35 01	g NOP

R_1	AWG	R_4		R_7	
R_2	Resistivity	R_5		R_8	
R_3	Density	R_6		R_9	

HEAT SINKS

CODE	KEYS
21	DSP
04	4
31	f
43	REG
84	R/S
23	LBL
11	A
35	g
83	DSZ
33 02	STO 2
84	R/S
33 01	STO 1
84	R/S
23	LBL
12	B
35	g
83	DSZ
33 04	STO 4
84	R/S
33 03	STO 3
84	R/S
23	LBL
13	C
00	0
35 07	g x⇄y
35 24	g x>y
22	GTO
00	0
02	2
83	·
05	5
04	4
42	CHS
71	x
23	LBL

CODE	KEYS
00	0
35	g
83	DSZ
22	GTO
01	1
33 05	STO 5
84	R/S
23	LBL
01	1
33 06	STO 6
34 05	RCL 5
71	x
83	·
04	4
07	7
02	2
42	CHS
35	g
05	y^x
07	7
08	8
83	·
05	5
09	9
71	x
33	STO
09	9
84	R/S
23	LBL
14	D
35	g
83	DSZ
22	GTO
02	2
01	1

CODE	KEYS
83	·
08	8
71	x
03	3
02	2
61	+
84	R/S
23	LBL
02	2
34	RCL
09	9
34 01	RCL 1
61	+
34 02	RCL 2
61	+
34 03	RCL 3
71	x
34 04	RCL 4
61	+
33 07	STO 7
84	R/S
23	LBL
15	E
01	1
33 08	STO 8
35 08	g R↓
84	R/S
35 01	g NOP
35 01	g NOP
35 01	g NOP

R_1	θ_{JC}	R_4	T_A	R_7	T_J
R_2	θ_{CS}	R_5	l	R_8	DSZ
R_3	P_d	R_6	h	R_9	θ_{SA}