

HEWLETT  PACKARD

HP-65

E.E. PAC 1

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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, suggestions, and Users' Library program contributions.

4 Format of User Instructions

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 other 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

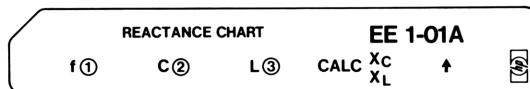
Gently insert the card (printed side up) in the right, lower slot as shown. When the card is part way in, the motor engages it and passes it out the left side of the calculator. Sometimes the motor engages but does not pull the card in. If this happens, push the card a little farther into the machine. 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

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. $C = 100 \text{ pF}$

$$f = 100 \text{ MHz}$$

$$\text{Calculate } L = 25.33 \text{ nH } (2.5330 \times 10^{-8})$$

$$X_C = -15.915 \Omega \left(-1.5915 \times 10^1\right)$$

2. $L = 2.5 \text{ H}$

$$f = 60 \text{ Hz}$$

$$\text{Calculate } C = 2.8145 \mu\text{F} \left(2.8145 \times 10^{-6}\right)$$

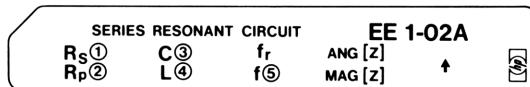
$$X_L = 942.48 \Omega \left(9.4248 \times 10^2\right)$$

3. $C = 0.01 \mu\text{F}$

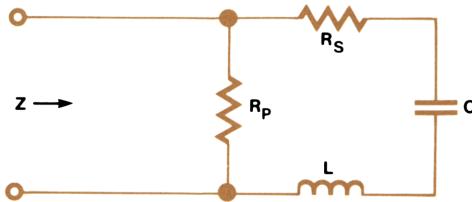
$$L = 160 \mu\text{H}$$

$$\text{Calculate } f = 125.82 \text{ kHz } (1.2582 \times 10^5)$$

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

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

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

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.

12 EE 1-02A**Examples:**

1. $R_p = 10,000 \Omega$

$R_s = 1 \Omega$

$C = 100 \text{ pF}$

$L = 1 \mu\text{H}$

Calculate

$f_r = 1.59 \times 10^7 \text{ Hz} (15\,915\,494.31)$

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. $R_p = 10^{80}$

$R_s = 0$

$C = .159155$

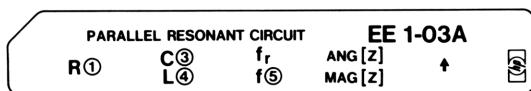
$L = .159155$

Calculate

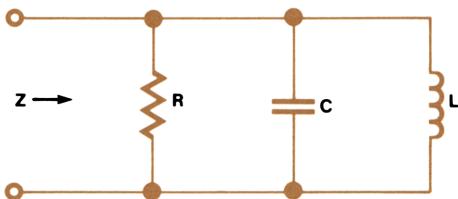
$f_r = 1.0 \text{ Hz} (1.00 \times 10^0)$

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

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

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

Notes:

1. When MAG[Z] or ANG[Z] has been computed, the other may be displayed by pressing **g** **x₂y**.
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** **X**

SWITCH TO RUN

Examples:

1. $R = 100 \Omega$

$C = 100 \text{ pF}$

$L = 10 \mu\text{H}$

Calculate

$f_r = 5.033 \text{ MHz} (5\ 032\ 921.21)$

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. $R = 5000 \Omega$

$C = 1 \mu\text{F}$

$L = 3 \text{ mH}$

Calculate

$f_r = 2905.76 \text{ Hz}$

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

IMPEDANCE OF LADDER NETWORK	EE 1-04A					
R_s	C_s	L_s	f	xz	y	↑
R_p	L_p	C_p				



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

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

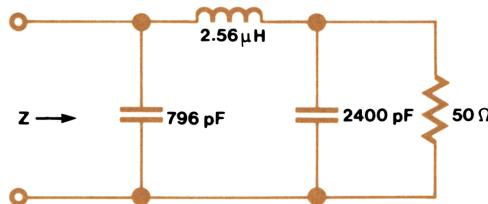
The program converts this admittance to an impedance for display.

Note:

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

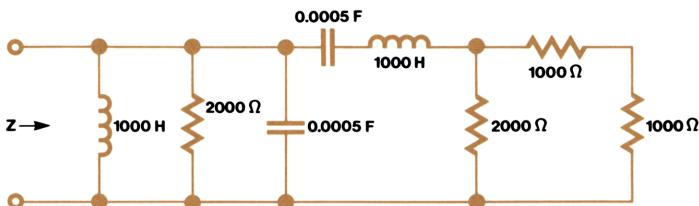
Examples:

1. $f = 4 \text{ MHz}$



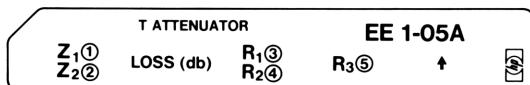
INPUT	Z_{IN}
$R_p = 50$	$50.00 \angle 0.00^\circ$
$C_p = 2400 E-12$	$15.74 \angle -71.66^\circ$
$L_s = 2.56 E-6$	$49.65 \angle 84.28^\circ$
$C_p = 796 E-12$	$497.69 \angle 0.98^\circ \cong 500 \angle 0$

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

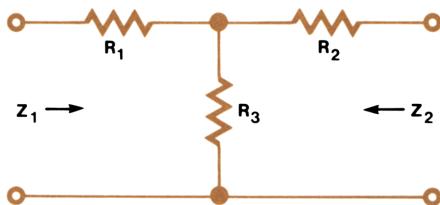


INPUT	Z_{IN}
$R_p = 1000$	$1000 \angle 0^\circ$
$R_s = 1000$	$2000 \angle 0^\circ$
$R_p = 2000$	$1000 \angle 0^\circ$
$L_s = 1000$	$1414 \angle 45^\circ$
$C_s = .0005$	$1414 \angle -45^\circ$
$C_p = .0005$	$894 \angle -63^\circ$
$R_p = 2000$	$707 \angle -45^\circ$
$L_p = 100$	$110 \angle 84^\circ$
(input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

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

$$Z_1 \geq Z_2$$

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)

$R_1 = 43.34 \Omega (4.334 \times 10^1)$

$R_2 = 1.57 \Omega (1.5715 \times 10^0)$

$R_3 = 81.97 \Omega (8.1973 \times 10^1)$

2. $Z_1 = 50 \Omega$

$Z_2 = 50 \Omega$

Loss = 10 dB

Compute

Min Loss = 0 dB

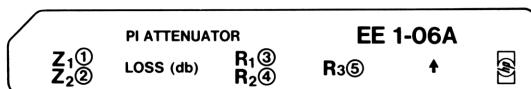
$R_1 = 25.97 \Omega (2.5975 \times 10^1)$

$R_2 = 25.97 \Omega (2.5975 \times 10^1)$

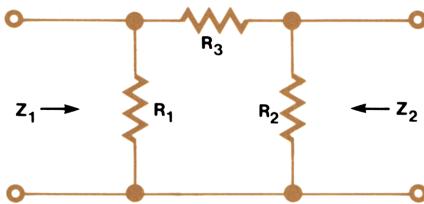
$R_3 = 35.14 \Omega (3.5136 \times 10^1)$

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 $Z_1 \geq Z_2$

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

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

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

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

Examples:

1. $Z_1 = 75 \Omega$

$Z_2 = 50 \Omega$

loss = 6 dB

Compute

Min Loss = 5.72 dB (5.7195×10^0)

$R_1 = 2386.20 \Omega (2.3862 \times 10^3)$

$R_2 = 86.52 \Omega (8.6517 \times 10^1)$

$R_3 = 45.75 \Omega (4.5747 \times 10^1)$

2. $Z_1 = 50 \Omega$

$Z_2 = 50 \Omega$

loss = 10 dB

Compute

Min Loss = 0 dB

$R_1 = 96.25 \Omega (9.6248 \times 10^1)$

$R_2 = 96.25 \Omega (9.6248 \times 10^1)$

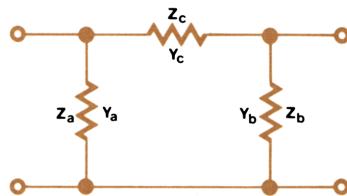
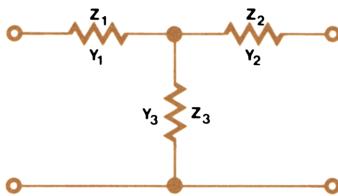
$R_3 = 71.15 \Omega (7.1151 \times 10^1)$

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 $T \rightarrow \pi$ transformation.



$$Z_1 = \frac{Z_a Z_c}{Z_a + Z_b + Z_c}$$

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

$$Z_2 = \frac{Z_b Z_c}{Z_a + Z_b + Z_c}$$

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

$$Z_3 = \frac{Z_a Z_b}{Z_a + Z_b + Z_c}$$

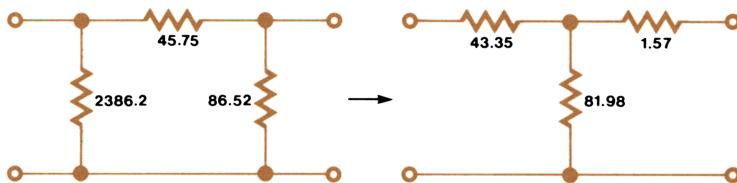
$$Z_b = \left(\frac{Y_2 Y_3}{Y_1 + Y_2 + Y_3} \right)^{-1}$$

Note:

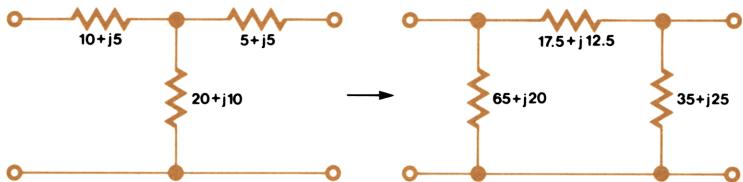
1. It is very important to observe the component designations.
2. Be sure to input zero (do not simply press **CLX**) for X (or R) when Z is purely resistive (or reactive).

Examples:

1.



2.



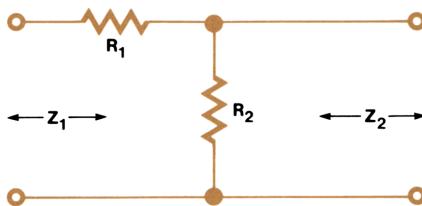
STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
1	Enter program 1			
2	Initialize		RTN R/S	1
3	Input impedances			
	R_a		A	1
	X_a		B	2
	$\Delta \rightarrow Y \quad R_b$		A	2
	$\pi \rightarrow T \quad X_b$		B	3
	R_c		A	3
	X_c		B	
	or			
	R_1		D	1
	X_1		E	2
	R_2		D	2
	$Y \rightarrow \Delta \quad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

MINIMUM-LOSS PAD MATCHING

MINIMUM - LOSS PAD MATCHING	EE 1-08A			
Z₁①	Z₂②	R₁	R₂	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:

$$Z_1 = 1200$$

$$Z_2 = 500$$

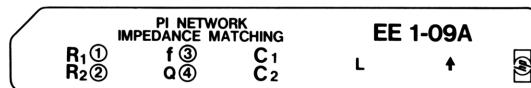
$$\text{Calculate } R_1 = 916.52 \Omega$$

$$R_2 = 654.65 \Omega$$

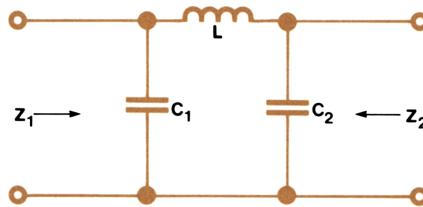
$$\text{loss} = 8.73 \text{ dB}$$

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:

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

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

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

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

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

Examples:

1. $Z_1 = 500 \Omega$

$Z_2 = 50 \Omega$

$Q = 10$

$f = 4 \text{ MHz}$

Compute

$C_1 \cong 796 \text{ pF} (7.9577 \times 10^{-10})$

$C_2 \cong 2400 \text{ pF} (2.4006 \times 10^{-9})$

$L \cong 2.56 \mu\text{H} (2.5639 \times 10^{-6})$

2. $Z_1 = 75 \Omega$

$Z_2 = 50 \Omega$

$Q = 4$

$f = 100 \text{ MHz}$

Compute

$C_1 \cong 84.9 \text{ pF} (8.4883 \times 10^{-11})$

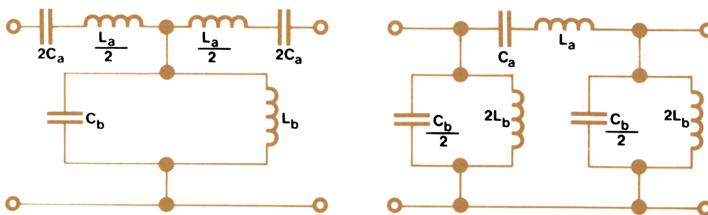
$C_2 \cong 102.3 \text{ pF} (1.0232 \times 10^{-10})$

$L \cong 50.7 \text{ nH} (5.0657 \times 10^{-8})$

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

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.



$$C_a = \frac{f_2 - f_1}{4\pi f_1 f_2 R}$$

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

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

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

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

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

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

for

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

for

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

Note:

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

PRESS **GTO** **2**

SWITCH TO W/PRGM

PRESS **SST** **g** **DEL** **X**

Record modified program on other track of card 2.

SWITCH TO RUN

34 EE 1-10A**Examples:**

1. $f_1 = 300$

$f_2 = 3000$

$R = 50$

Compute

$C_a = 4.775 \mu F (4.775 \times 10^{-6})$

$C_b = 2.358 \mu F (2.358 \times 10^{-6})$

$L_a = 5.895 mH (5.895 \times 10^{-3})$

$L_b = 11.94 mH (1.194 \times 10^{-2})$

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	
13	Output			
	Attenuation		B	A, dB
14	For new case return to step 1			

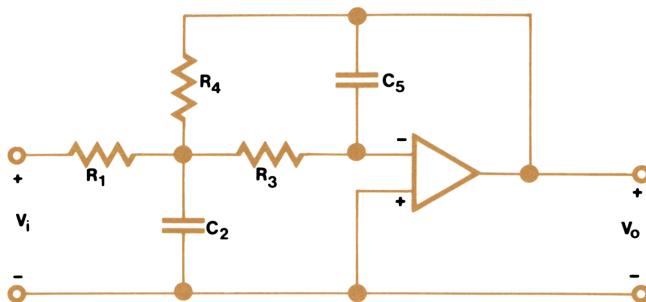
ACTIVE FILTER - LOW PASS

$f_0 \text{ (1)}$	$\alpha \text{ (3)}$	R_1	C_2	EE 1-11A
$G \text{ (2)}$	$C \text{ (4)}$	R_3	R_4	\uparrow



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

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

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. $f_c = 100 \text{ Hz}$

$G = 10$

$\alpha = \sqrt{2}$ (default value)

$C = 0.1 \mu\text{F}$

Compute

$R_1 = 1125.40 \Omega$

$R_3 = 1023.09 \Omega$

$C_2 = 220 \mu\text{F} (2.200\,000 \times 10^{-6})$

$R_4 = 11.254 \text{ k}\Omega (11\,253.95)$

2. $f_c = 10 \text{ Hz}$

$G = 10$

$\alpha = 1$

$C = 1 \mu\text{F}$

Compute

$R_1 = 79.58 \Omega$

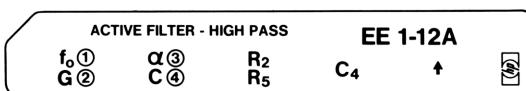
$R_3 = 72.34 \Omega$

$C_2 = 440 \mu\text{F} (4.400\,000 \times 10^{-4})$

$R_4 = 795.77 \Omega$

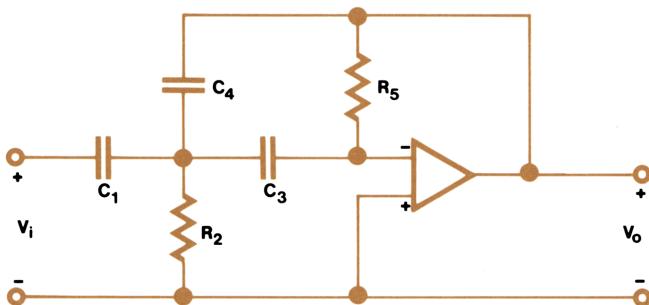
STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
1	Enter program			
2	Initialize		RTN R/S	
3	Inputs Cutoff frequency Overall gain 2 x damping factor Capacitor C_s	(any order) f_c , Hz G α^* C, F		
			E A	
			A	
			E B	
			B	
4	Outputs (any order)			
			E C	R_1, Ω
			C	R_3, Ω
			E D	C_2, F
			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

$$\frac{V_o}{V_i} (s) = - \frac{C_1}{C_4} \frac{s^2}{s^2 + \frac{s}{R_5} \left(\frac{C_1}{C_3 C_4} + \frac{1}{C_4} + \frac{1}{C_3} \right) + \frac{1}{R_2 R_5 C_3 C_4}}$$



Given

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

f_c , the desired corner frequency

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

C = a value for C_1 and C_3 in farads

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

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

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

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

Note:

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

Examples:

1. $f_o = 0.1 \text{ Hz}$

$G = 1$

$\alpha = \sqrt{2} \text{ (default value)}$

$C = 10 \mu\text{F}$

Compute

$R_2 = 75026.36 \Omega$

$R_s = 337618.62 \Omega$

$C_4 = 10 \mu\text{F} (1.000 000 \times 10^{-5})$

2. $f_o = 10 \text{ Hz}$

$G = 10$

$\alpha = 1$

$C = 1 \mu\text{F}$

Compute

$R_2 = 7578.81 \Omega$

$R_s = 334 225.38 \Omega$

$C_4 = 0.1 \mu\text{F} (1.000 000 \times 10^{-7})$

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_s		C	R_s , 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

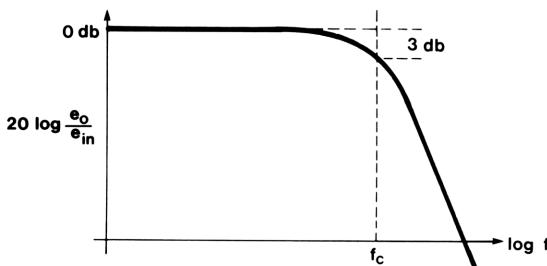
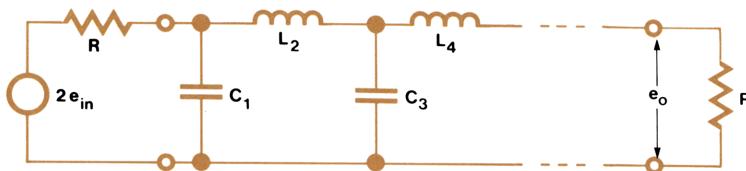
BUTTERWORTH FILTER	EE 1-13A			
n①	R②	f_c③	i,C_i	i,L_i



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.

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

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



Example:

$$n = 6$$

$$R = 50 \Omega$$

$$f_c = 10 \text{ MHz}$$

Compute

$$C_1 = 164.8 \text{ pF} (1.6477 \times 10^{-10})$$

$$L_2 = 1.13 \mu\text{H} (1.1254 \times 10^{-6})$$

$$C_3 = 614.9 \text{ pF} (6.1493 \times 10^{-10})$$

$$L_4 = 1.54 \mu\text{H} (1.5373 \times 10^{-6})$$

$$C_5 = 450.2 \text{ pF} (4.5016 \times 10^{-10})$$

$$L_6 = .412 \mu\text{H} (4.1192 \times 10^{-7})$$

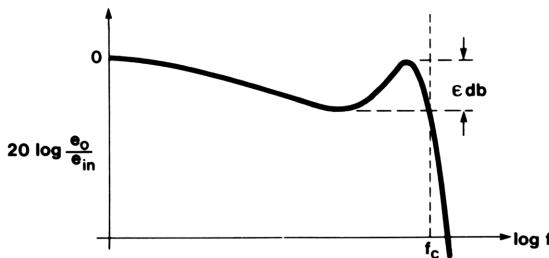
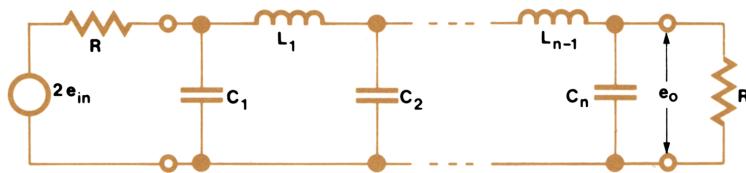
EE1-13A

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

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

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

where

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

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

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

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

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

Example:

$$n = 7$$

$$R = 50 \Omega$$

$$f_c = 3.2 \text{ MHz}$$

$$\epsilon = 0.1 \text{ dB}$$

Compute

$$C_1 = 1175 \text{ pF } (1.175 \times 10^{-9})$$

$$L_2 = 3.538 \mu\text{H } (3.538 \times 10^{-6})$$

$$C_3 = 2086 \text{ pF } (2.086 \times 10^{-9})$$

$$L_4 = 3.913 \mu\text{H } (3.913 \times 10^{-6})$$

$$C_5 = 2086 \text{ pF } (2.086 \times 10^{-9})$$

$$L_6 = 3.538 \mu\text{H } (3.538 \times 10^{-6})$$

$$C_7 = 1175 \text{ pF } (1.175 \times 10^{-9})$$

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

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

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

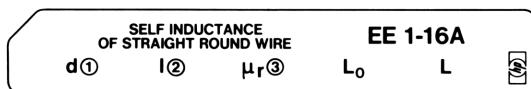
The formula given is accurate only when $L \gg d$ and $W \gg d$, however the error is only -4% for $\frac{W}{d} = 2$ (Terman, *Radio Engineers Handbook*, 1943, Sec. 2, Par. 31).

Examples:

- | | |
|--|---|
| 1. $\epsilon_r = 1$
$d = .01 \text{ cm}$
$L = 10 \text{ cm}$
$W = 1 \text{ cm}$
$C = 88.5 \text{ pF } (8.854 \times 10^1)$ | 3. $\epsilon_r = 1$
$d = .01 \text{ cm}$
$L = 101 \text{ cm}$
$W = 1 \text{ cm}$
$C = 915 \text{ pF } (9.155 \times 10^2)$ |
| 2. $\epsilon_r = 1$
$d = .01 \text{ cm}$
$L = 99 \text{ cm}$
$W = 1 \text{ cm}$
$C = 877 \text{ pF } (8.766 \times 10^2)$ | 4. $\epsilon_r = 1$
$d = .01 \text{ cm}$
$L = 60 \text{ inches (enter as } -60)$
$W = .5 \text{ inch (enter as } -.5)$
$C = 1747 \text{ pF } (1.747 \times 10^3)$ |

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	$d, \text{ cm or in.}^*$	B	$d, \text{ cm}$
	Length	$L, \text{ cm or in.}^*$	C	$L, \text{ cm}$
	Width	$W, \text{ cm or in.}^*$	D	$W, \text{ cm}$
4	Outputs			
	Capacitance		E	$C, \text{ pF}$
	Capacitance with $P = 0$		RCL 5	$C, \text{ pF}$
5	Recall inputs (optional)			
	Relative permittivity		RCL 1	ϵ_r
	Plate spacing		RCL 2	$d, \text{ cm}$
	Length		RCL 3	$L, \text{ cm}$
	Width		RCL 4	$W, \text{ cm}$
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. $d = 0.10 \text{ cm}$ (#18 AWG)

$l = 25 \text{ cm}$

$\mu_r = 1$ (copper)

Compute

$L_o = 0.31 \mu\text{H}$

$L = 0.30 \mu\text{H}$

2. $d = 0.02535 \text{ in.}$ (#22 AWG)

$l = 5 \text{ in.}$

$\mu_r = 1$

Compute

$L_o = 0.15 \mu\text{H}$

$L = 0.14 \mu\text{H}$

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
	Wire length	l, cm or in.*	B	l, cm
	Relative permeability	μ_r **	C	
4	Outputs			
	Low frequency inductance		D	$L_o, \mu\text{H}$
	High frequency inductance		E	$L, \mu\text{H}$
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:

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

where

L = inductance in μH

N = number of turns

R = inside radius of coil 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. $L = 3.5 \mu\text{H}$
 $R = 0.25 \text{ inch}$
 $D = 0.034 \text{ inch (#20 enamel wire)}$
Calculate $N = 24.24 \text{ turns}$

2. $R = 1 \text{ inch}$
 $D = 0.086 \text{ inch}$
 $N = 30 \text{ turns}$
Calculate $L = 25.86 \mu\text{H}$

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				
d_①	I_③	δ	R_s	R	↑
D_②	f_④	Q			

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

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

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

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

where

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

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

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:

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

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

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. $f = 100 \text{ MHz}$

$d = 0.1 \text{ cm}$

Compute $\delta = 0.00066 \text{ cm}$

$$R_s = 2.61 \times 10^{-3} \text{ ohms}$$

$$R = 0.83 \text{ ohms/meter}$$

2. $f = 100 \text{ MHz}$

$d = 0.05 \text{ cm}$

$D = 0.2 \text{ cm}$

$l = 1 \text{ cm}$

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	$d, \text{ cm}$	E A	
	Coil diameter	$D, \text{ cm}$	A	
	Coil length	$l, \text{ cm}$	E B	
	Frequency	$f, \text{ Hz}$	B	
4	Compute desired outputs			
	Skin depth		E C	$\delta, \text{ cm}$
	Q of unshielded coil		C	Q
	Resistance per square		E D	R_s, Ω
	Resistance per meter		D	$R, \Omega/\text{m}$
5	Return to step 3 for new data			

TRANSFORMER DESIGN

TRANSFORMER DESIGN

EE 1-19A

N_p①**f②****A_c③****B_m④****E_p⑤**

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

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

where

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

Example:

$f = 60$ Hz

$W_{\text{out}} = 20$ watts

Compute

$(A_c)_{\text{est.}} = .80$ in.²

Enter

$$E_p = 120 \text{ volts}$$

$$A_c = 1 \text{ in.}^2$$

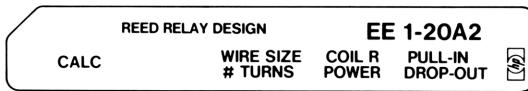
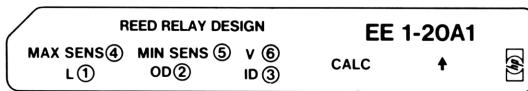
$$B_m = 13,000 \text{ gauss}$$

Compute

$$N_p = 537 \text{ turns (536.92)}$$

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

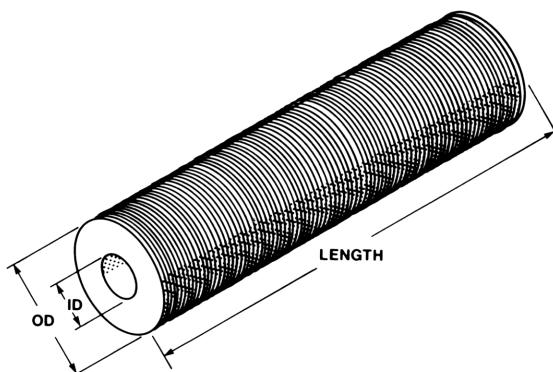
V = operating voltage

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.

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

$$\text{Winding Volume} \quad V_w = .7854 ((OD)^2 - (ID)^2)L$$

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

$$\text{Number of turns} \quad T = 8.57 A e^{.229 WS}$$

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

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

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

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

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

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

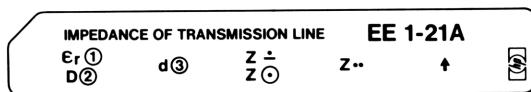
Coil power = 455 mW

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.

$\epsilon_r = 2.3$ (polyethylene)

Compute $Z \odot = 49.38 \Omega$

2. $D = 6$ in.

$d = .0808$ in. (#12 AWG wire)

$\epsilon = 1$ (air)

Compute $Z \cdot \cdot = 599.66 \Omega$

3. $D = 6$ in.

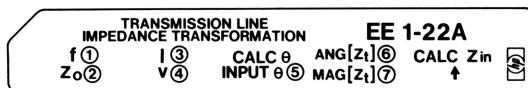
$d = .1285$ in. (#8 AWG wire)

$\epsilon_r = 1$

Compute $Z \div = 313.58 \Omega$

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 }	B	
4	Compute outputs			
	$Z_0 \div$		E C	Z_0 , ohms
	$Z_0 \odot$		C	Z_0 , ohms
	$Z_0 \cdot \cdot$		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
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

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

where

θ = electrical length in degrees

l = physical length in centimeters

f = frequency in Hz

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

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

$$Z_{in} = Z_0 \left[\frac{\frac{Z_t}{Z_0} + j \tan \theta}{1 + j \frac{Z_t}{Z_0} \tan \theta} \right]$$

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 $\theta = 89.99999$ to avoid overflow during execution of LBL E.

Examples:

1. $f = 146 \text{ MHz}$

$Z_o = 50 \Omega$

$l = 20 \text{ centimeters}$

$v = .69 \text{ (Teflon)}$

$\text{MAG } [Z_t] = 75 \Omega$

$\text{ANG } [Z_t] = 30^\circ$

Compute $\theta = 50.82^\circ$

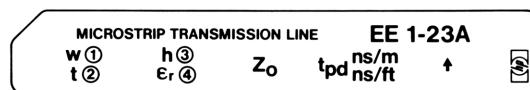
$\text{MAG } [Z_{in}] = 74.12 \Omega \quad \text{ANG } [Z_{in}] = -30.44^\circ$

2. Same data as above except let $\theta = 89.99999^\circ$

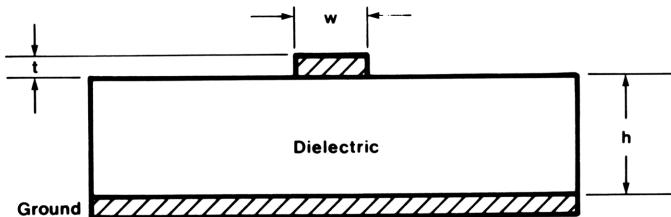
$\text{MAG } [Z_{in}] = 33.33 \Omega \quad \text{ANG } [Z_{in}] = -30.00^\circ$

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

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. $w = 50 \text{ mils}$

$t = 1.5 \text{ mils}$

$h = 30 \text{ mils}$

$\epsilon_r = 4.7$

Compute

$Z_o = 51.52 \Omega$

$t_{pd} = 1.73 \frac{\text{ns}}{\text{ft.}} = 5.68 \frac{\text{ns}}{\text{m}}$

2. $w = 90 \text{ mils}$

$t = 1.5 \text{ mils}$

$h = 60 \text{ mils}$

$\epsilon_r = 4.7$

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 t h } like units	E A	
	Line thickness		A	
	Dielectric thickness		E B	
	Relative permittivity	ϵ_r	B	
4	Outputs			
	Characteristic impedance		C	Z_o, Ω
	Propagation delay		E D	$t_{pd}, \text{ns/m}$
	Propagation delay		D	$t_{pd}, \text{ns/ft.}$
5	Recall inputs (optional)			
	Line width		RCL 1	w t h } like units
	Line thickness		RCL 2	
	Dielectric thickness		RCL 3	
	Relative permittivity		RCL 4	ϵ_r
6	Return to step 2 for new case.			

S \leftrightarrow Y PARAMETER CONVERSIONS \leftrightarrow Y PARAMETER CONVERSION**EE 1-24A1**

r θ CALC

S \leftrightarrow Y PARAMETER CONVERSION**EE 1-24A2**

CALC



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:

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

Compute

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

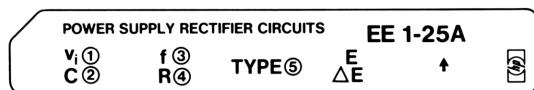
$$2. \quad Y = \begin{bmatrix} 2.35 \angle -34.2 & .391 \angle -147 \\ 4.08 \angle -179 & 1.97 \angle 63.8 \end{bmatrix}$$

Compute

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

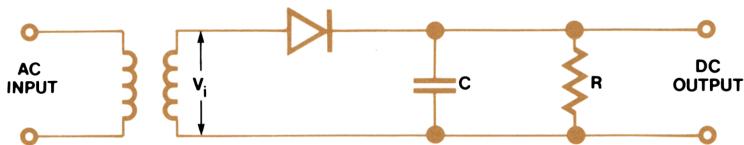
STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
1	Enter program 1			
2	Input s-parameters			
	MAG[s ₁₁]	A		
	ANG[s ₁₁]	B		
	MAG[s ₁₂]	A		
	ANG[s ₁₂]	B		
	MAG[s ₂₁]	A		
	ANG[s ₂₁]	B		
	MAG[s ₂₂]	A		
	ANG[s ₂₂]	B		
3	Output y-parameters			
		C		MAG[y ₁₂]
		R/S		ANG[y ₁₂]
		R/S		MAG[y ₂₁]
		R/S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

POWER SUPPLY RECTIFIER CIRCUITS

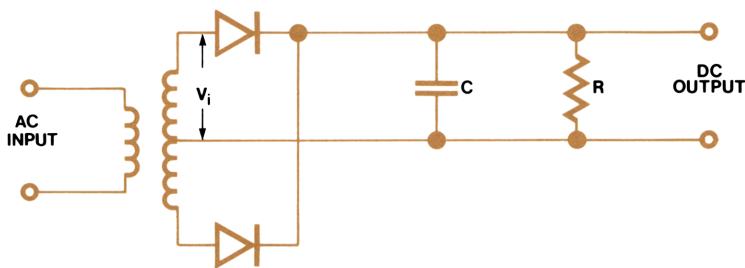


The following three circuits are commonly used to convert AC to DC.

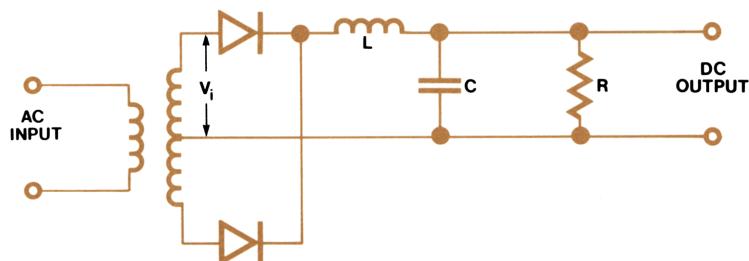
1. half-wave rectifier, capacitive input filter



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) $L \geq R/6\pi f$.

	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

$$V_i = 100 \text{ volts}$$

$$C = 100 \mu\text{F}$$

$$f = 60 \text{ Hz}$$

$$R = 1000 \Omega$$

Compute $\Delta E = 23.57$ volts peak-to-peak

$$E = 129.64 \text{ volts}$$

2. Type 2

Same values as above

Compute $\Delta E = 11.79$ volts

$$E = 135.53 \text{ volts}$$

3. Type 3

Same values as above, plus $L = 2H$

Check $L_{MIN} = .884 < 2$

Compute $\Delta E = 1.06$ volts

$$E = 90.03 \text{ volts}$$

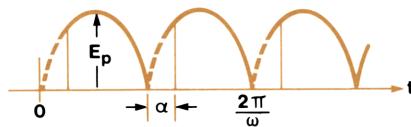
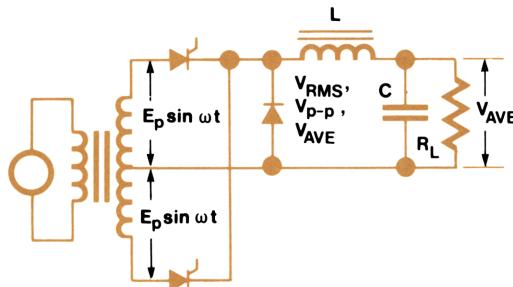
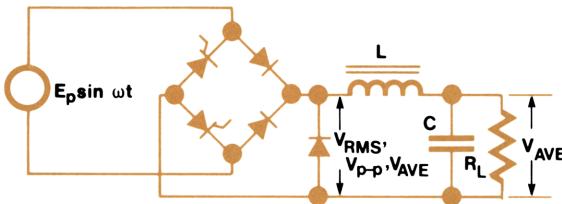
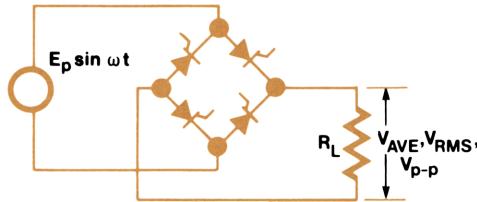
STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
1	Enter program			
2	Initialize		RTN R/S	
3	Inputs (any order)			
	RMS input voltage	V_i , volts	E A	
	Capacitance	C, F	A	
	Frequency	f, Hz	E B	
	Resistance	R, Ω	B	
	Type (1=half wave, 2=full wave, 3=full wave L-C)	Type	C	
4	(Type 3 only)			
	Check L_{MIN}		RCL 7	L_{MIN} , H
	Input $L \geq L_{MIN}$	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

CONTROLLED RECTIFIER CIRCUITS

Ep①**α ②****V_{AVE} ③****EE 1-26A****CALC**

This program computes V_{AVG} , V_{RMS} , and V_{P-P} as functions of E_p and α for the circuits shown. It also computes E_p (or α) given α and V_{AVG} (or E_p and V_{AVG}). 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.

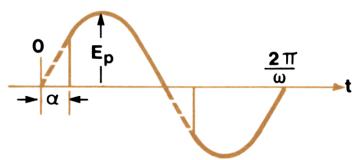
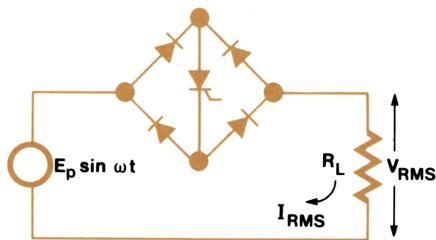
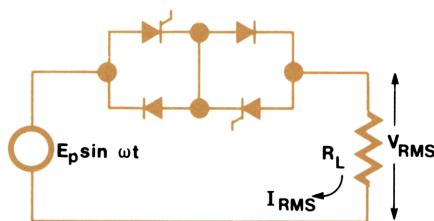
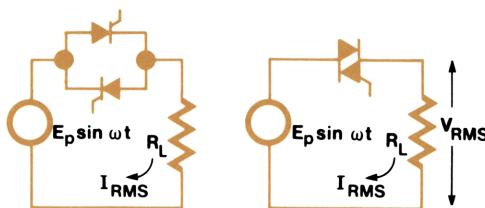


For these circuits the output is

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

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

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



For these circuits the output is

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

Examples:

1. $E_p = 170$
 $\alpha = 30^\circ$

Compute

$V_{AVE} = 100.98$
 $V_{p-p} = 170.00$

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

Compute

$\alpha = 94.36$

Input $\alpha = 94.36$

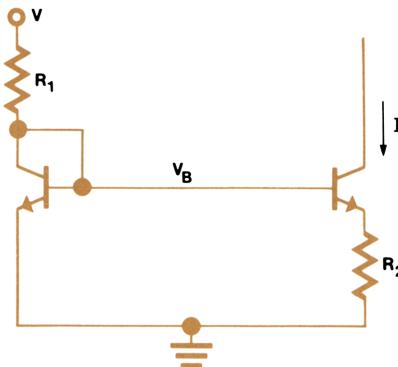
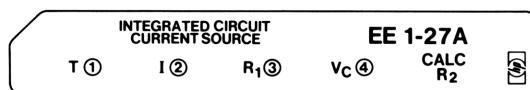
Then compute

$V_{RMS} = 80.79$

$V_{p-p} = 169.51$

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	$\alpha, \text{deg.}$	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	$\alpha, \text{deg.}$
	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-p}, V
*	E_p and α must be inputs. If one is unknown, it may be computed 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

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

T_a = absolute temperature of junction in kelvins

$q = 1.6 \times 10^{-19} \text{ C}$, 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 $^{\circ}\text{C}$

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. $T = 50^\circ\text{C}$

$I = 10 \mu\text{A}$

$R_1 = 10 \text{ k}\Omega$

$V = 10\text{V}$

Compute

$R_2 = 12.7 \text{ k}\Omega (12657.05)$

2. $T = 100^\circ\text{C}$

$I = 10 \mu\text{A}$

$R_1 = 10 \text{ k}\Omega$

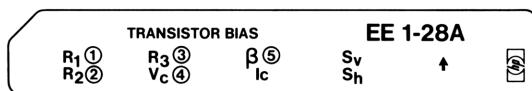
$V = 10\text{V}$

Compute

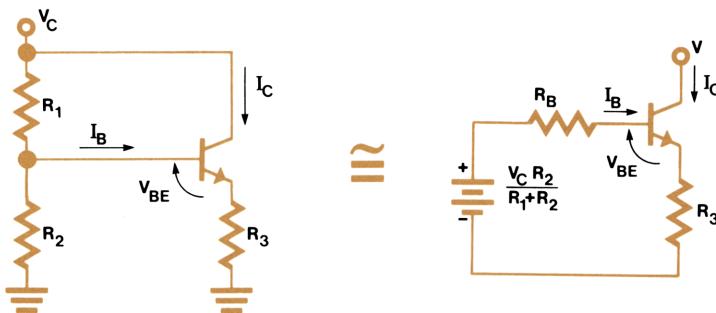
$R_2 = 14.6 \text{ k}\Omega (14616.35)$

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
1	Enter program			
2	Initialize		RTN R/S	
3	Inputs			
	Junction temperature	$T, {}^\circ\text{C}$	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	$T, {}^\circ\text{C}$
	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

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

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

$V_{BE} = 0.6V$ = 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. $R_1 = 1000 \Omega$

$R_2 = 5000 \Omega$

$R_3 = 1000 \Omega$

$V_C = 10 \text{ volts}$

$\beta = 100$

Compute

$I_C = 7.6 \text{ mA } (7.59 \times 10^{-3})$

$S_V = 0.98 \text{ mS } (9.82 \times 10^{-4})$

$S_h = 1.4 \mu\text{A } (1.37 \times 10^{-6})$

2. $R_1 = 200 \Omega$

$R_2 = 1000 \Omega$

$R_3 = 1000 \Omega$

$V_C = 10 \text{ volts}$

$\beta = 100$

Compute

$I_C = 7.6 \text{ mA } (7.64 \times 10^{-3})$

$S_V = 0.99 \text{ mS } (9.88 \times 10^{-4})$

$S_h = 0.88 \mu\text{A } (8.82 \times 10^{-7})$

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

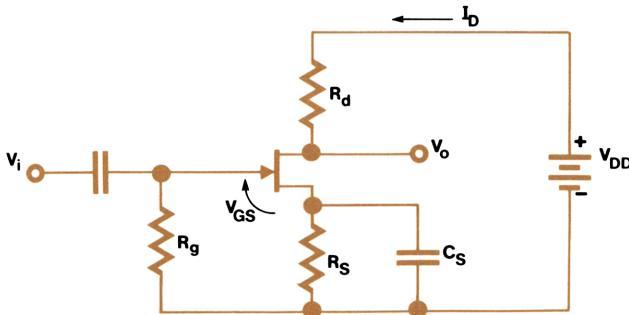
JFET BIAS AND TRANSCONDUCTANCE

JFET BIAS & TRANSCONDUCTANCE
 V_P ① I_D ③ V_{GS}
 I_{DSS} ② A_V ④ g_m

EE 1-29A



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

$$V_{GS} = V_P \left[1 - \left(\frac{I_D}{I_{DSS}} \right)^{\frac{1}{2}} \right]$$

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. $V_P = -2V$

$I_{DSS} = 1.5 \text{ mA}$

$I_D = .7 \text{ mA}$

$A_V = 10$

Compute

$V_{GS} = -0.63V (-6.337 \times 10^{-1})$

$g_m = 1.025 \text{ mS} (1.025 \times 10^{-3})$

$R_s = 905 \Omega$

$R_d = 9759 \Omega$

2. $V_P = 1.5V$

$I_{DSS} = -1.7 \text{ mA}$

$I_D = -.9 \text{ mA}$

$A_V = 15$

Compute

$V_{GS} = 0.409V (4.086 \times 10^{-1})$

$g_m = 1.65 \text{ mS} (1.649 \times 10^{-3})$

$R_s = 454 \Omega$

$R_d = 9095 \Omega$

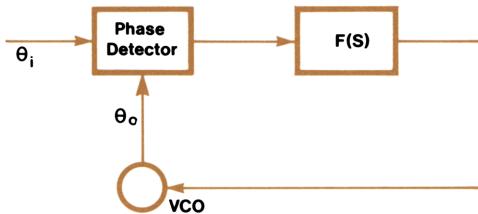
STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
1	Enter program			
2	Initialize		RTN R/S	
3	Inputs (any order)			
	Pinch-off voltage	V _P , V	E A	
	Sat. drain current ($V_{GS} = 0$)	I _{DSS} , A	A	
	Desired drain current	I _D , A	E B	
	Desired voltage gain	Av	B	
4	Outputs (any order)			
	Gate-source 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	Av

PHASE-LOCKED LOOP

PHASE - LOCKED LOOP
 G ① R₂ ③ (p) $\frac{\omega_n}{\zeta}$
 R₁ ② C ④ (a) $\frac{\omega_n}{\zeta}$ B_L


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

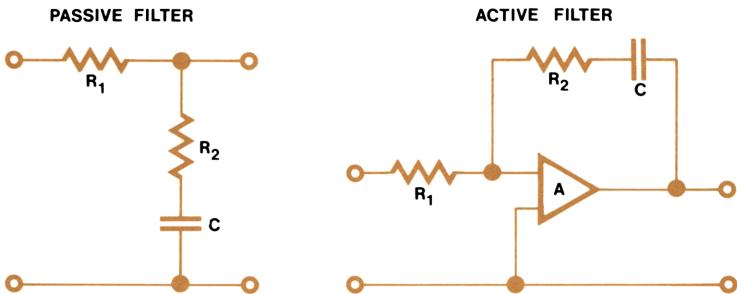
$$F(s) = \begin{cases} \frac{s\tau_2 + 1}{s(\tau_1 + \tau_2) + 1} & ; \text{passive filter transfer function} \\ \frac{s\tau_2 + 1}{s\tau_1} & ; \text{active filter transfer function} \end{cases}$$

$$\tau_1 = R_1 C$$

$$\tau_2 = R_2 C$$

R_1, R_2 = resistances in ohms

C = capacitance in farads



The natural frequency and damping factor for the two loops are

$$\omega_n = \begin{cases} \sqrt{\frac{G}{\tau_1}} & ; \text{active} \\ \sqrt{\frac{G}{\tau_1 + \tau_2}} & ; \text{passive} \end{cases}$$

$$\zeta = \begin{cases} \frac{\tau_2}{2} \omega_n & ; \text{active} \\ \frac{1}{2} \omega_n \left(\tau_2 + \frac{1}{G} \right) & ; \text{passive} \end{cases}$$

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

$R_1 = 9.2 \text{ M}\Omega$

$R_2 = 750\Omega$

$C = 100 \mu\text{F}$

Compute

	Passive	Active
ω_n	18.77 s^{-1}	18.77 s^{-1}
ξ	.70	.70
B_L	9.94 Hz	9.94 Hz

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

$R_1 = 1 \text{ M}\Omega$

$R_2 = 7.1\Omega$

$C = 1250 \mu\text{F}$

Compute

	Passive	Active
ω_n	112.07 s^{-1}	112.07 s^{-1}
ξ	.50	.50
B_L	56.04 Hz	56.04 Hz

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

$R_1 = 1000$

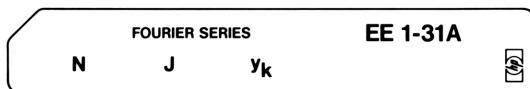
$R_2 = 75$

$C = 10\mu\text{F}$

Compute

	Passive	Active
ω_n	1181.25 s^{-1}	1225.74 s^{-1}
ξ	.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

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

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

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

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

and

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

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).

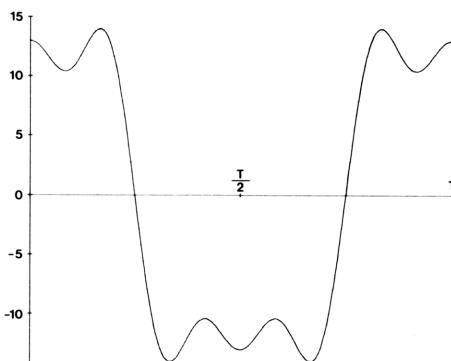
Notes:

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. $N = 12 \quad J = 1$

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



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

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

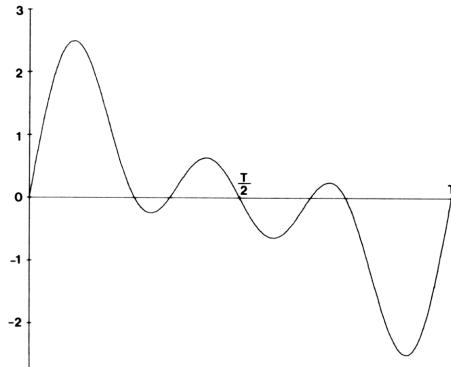
Thus the function is

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

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



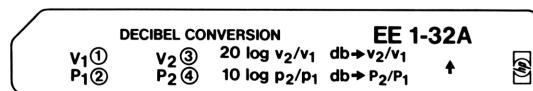
The function is odd, so $\{ a_j \} = \{ 0 \}$

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

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 , $k = 1, 2, \dots, N$	y_k	C	$2, \dots, N + 1$
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 been computed.)		RCL 1 RCL 2 RCL 3 RCL 4 RCL 5 RCL 6	a_j or b_j a_{j+1} or b_{j+1} a_{j+2} or b_{j+2} a_{j+3} or b_{j+3} a_{j+4} or b_{j+4} 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 opposite track (see note 4)			00 00
17	Switch to RUN and go to step 3			

DECIBEL CONVERSION

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. $V_1 = 1\text{ V}$

$V_2 = 2\text{ V}$

Calculate $20 \log \frac{V_2}{V_1} = 6.02\text{ dB}$

2. $P_1 = 3\text{ mW}$

$P_2 = 7\text{ mW}$

Calculate $10 \log \frac{P_2}{P_1} = 3.68\text{ dB}$

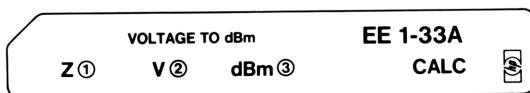
3. $10 \log \frac{P_2}{P_1} = 13.2\text{ dB}$

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

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

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

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

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. $Z = 600 \Omega$

$V = 2V$

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

Cu GAUGE	WIRES AI & ANNEALED AI GAUGE	Cu DIA MILS	EE 1-34A	OHMS 1000 FT	LB 1000 FT
----------	------------------------------------	----------------	----------	-----------------	---------------

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

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

where

DIA = diameter in mils

AWG = Gauge number

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

For copper,

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

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

and for aluminum

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

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

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

$$\frac{\text{ohms}}{1000 \text{ ft}} = 1.588$$

$$\frac{\text{LB}}{1000 \text{ ft}} = 19.77$$
2. No. 34 Cu wire
 Dia = 6.305 mils

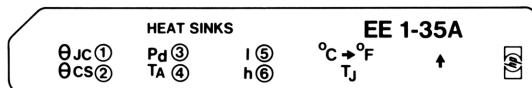
$$\frac{\text{ohms}}{1000 \text{ ft}} = 260.9$$

$$\frac{\text{LB}}{1000 \text{ ft}} = 0.1203$$
3. No. 10 Al wire
 Dia = 101.9 mils

$$\frac{\text{ohms}}{1000 \text{ ft}} = 1.637$$

$$\frac{\text{LB}}{1000 \text{ ft}} = 9.555$$

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")

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

where

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

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, $\frac{^{\circ}\text{C}}{\text{W}}$

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

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

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

Example:

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

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

$$P_d = 10 \text{ W}$$

$$T_A = 25 \text{ } ^{\circ}\text{C}$$

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

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

Compute

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

$$T_J = 208.27 \text{ } ^{\circ}\text{C} = 406.89$$

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	<i>l</i> , cm or in.*	E C	<i>l</i> , cm
	then Height of heat sink	<i>h</i> , cm or in.*	C	θ_{SA} , °C/W
	or			
	Therm. res.-sink to air	θ_{SA} , °C/W	STO 8	
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	<i>l</i> , cm
			RCL 6	<i>h</i> , 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

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REACTANCE CHART

CODE	KEYS	CODE	KEYS	CODE	KEYS
21	DSP	71	x	42	CHS
04	4	35	g	84	R/S
44	CLX	04	$1/x$	23	LBL
33 08	STO 8	84	R/S	01	1
84	R/S	23	LBL	34 04	RCL 4
23	LBL	12	B	34 03	RCL 3
00	0	35	g	71	x
33 01	STO 1	83	DSZ	84	R/S
02	2	33 02	STO 2	23	LBL
71	x	84	R/S	15	E
35	g	34 05	RCL 5	01	1
02	π	34 03	RCL 3	33 08	STO 8
71	x	81	\div	84	R/S
33 04	STO 4	84	R/S	35 01	g NOP
41	\uparrow	23	LBL	35 01	g NOP
71	x	13	C	35 01	g NOP
35	g	35	g	35 01	g NOP
04	$1/x$	83	DSZ	35 01	g NOP
33 05	STO 5	33 03	STO 3	35 01	g NOP
84	R/S	84	R/S	35 01	g NOP
23	LBL	34 05	RCL 5	35 01	g NOP
11	A	34 02	RCL 2	35 01	g NOP
35	g	81	\div	35 01	g NOP
83	DSZ	84	R/S	35 01	g NOP
22	GTO	23	LBL	35 01	g NOP
00	0	14	D	35 01	g NOP
34 02	RCL 2	35	g	35 01	g NOP
34 03	RCL 3	83	DSZ	35 01	g NOP
71	x	22	GTO	35 01	g NOP
31	f	01	1	35 01	g NOP
09	\sqrt{x}	34 04	RCL 4		
02	2	34 02	RCL 2		
71	x	71	x		
35	g	35	g		
02	π	04	$1/x$		

R₁	f	R₄	$2\pi f$	R₇	
R₂	C	R₅	$(4\pi^2 f^2)^{-1}$	R₈	DSZ
R₃	L	R₆		R₉	

SERIES RESONANT CIRCUIT

CODE	KEYS	CODE	KEYS	CODE	KEYS
32	f ⁻¹	02	2	01	1
51	SF 1	71	x	51	—
84	R/S	35	g	31	f
23	LBL	04	1/x	01	R→P
11	A	22	GTO	35 09	g R↑
32	f ⁻¹	00	0	35 00	g LST X
61	TF 1	23	LBL	31	f
33 02	STO 2	15	E	01	R→P
84	R/S	31	f	35 07	g x↔y
33 01	STO 1	51	SF 1	35 08	g R↓
22	GTO	84	R/S	81	÷
00	0	23	LBL	34 02	RCL 2
23	LBL	14	D	71	x
12	B	34 04	RCL 4	35 08	g R↓
32	f ⁻¹	34 05	RCL 5	35 07	g x↔y
61	TF 1	02	2	51	—
33 04	STO 4	71	x	35 09	g R↑
84	R/S	35	g	31	f
33 03	STO 3	02	π	61	TF 1
22	GTO	71	x	22	GTO
00	0	71	x	01	1
23	LBL	35 00	g LST X	84	R/S
13	C	34 03	RCL 3	23	LBL
32	f ⁻¹	71	x	01	1
61	TF 1	71	x	35 07	g x↔y
33 05	STO 5	34 02	RCL 2	22	GTO
84	R/S	35 00	g LST X	00	0
34 03	RCL 3	42	CHS	35 01	g NOP
34 04	RCL 4	71	x	35 01	g NOP
71	x	35 00	g LST X	35 01	g NOP
31	f	34 01	RCL 1		
09	√x	71	x		
35	g	61	+		
02	π	35 00	g LST X		
71	x	35 09	g R↑		

R₁	R _s	R₄	L	R₇
R₂	R _p	R₅	f	R₈
R₃	C	R₆		R₉ Used

PARALLEL RESONANT CIRCUIT

CODE	KEYS	CODE	KEYS	CODE	KEYS
32	f ⁻¹	09	\sqrt{x}	81	÷
51	SF 1	02	2	33	STO
24	RTN	71	x	81	÷
23	LBL	35	g	07	7
11	A	02	π	35 07	g x \leftrightarrow y
33 01	STO 1	71	x	09	9
84	R/S	35	g	00	0
23	LBL	04	$^1/x$	51	—
12	B	22	GTO	42	CHS
32	f ⁻¹	00	0	34 07	RCL 7
61	TF 1	23	LBL	32	f ⁻¹
33 04	STO 4	15	E	61	TF 1
84	R/S	31	f	22	GTO
33 03	STO 3	51	SF 1	00	0
22	GTO	24	RTN	35 07	g x \leftrightarrow y
00	0	23	LBL	24	RTN
23	LBL	14	D	23	LBL
13	C	34 04	RCL 4	01	1
33 05	STO 5	34 06	RCL 6	34 02	RCL 2
41	↑	71	x	34 05	RCL 5
41	↑	33 07	STO 7	61	+
02	2	01	1	84	R/S
71	x	35 07	g x \leftrightarrow y	13	C
35	g	34 06	RCL 6	14	D
02	π	71	x	84	R/S
71	x	34 03	RCL 3	35 07	g x \leftrightarrow y
33 06	STO 6	71	x	84	R/S
32	f ⁻¹	51	—	22	GTO
61	TF 1	34 01	RCL 1	01	1
35 01	g NOP	71	x	35 01	g NOP
24	RTN	34 07	RCL 7		
34 03	RCL 3	35 07	g x \leftrightarrow y		
34 04	RCL 4	31	f		
71	x	01	R \rightarrow P		
31	f	34 01	RCL 1		

R₁	R	R₄	L	R₇	Temporary
R₂	Δf	R₅	f	R₈	
R₃	C	R₆	$\omega = 2\pi f$	R₉	Used

IMPEDANCE OF LADDER NETWORK

CODE	KEYS	CODE	KEYS	CODE	KEYS
31	f	23	LBL	23	LBL
42	STK	00	0	01	1
31	f	32	f^{-1}	33 06	STO 6
43	REG	51	SF 1	35 07	$g x \leftrightarrow y$
84	R/S	84	R/S	33 07	STO 7
23	LBL	23	LBL	34 02	RCL 2
11	A	15	E	34 01	RCL 1
33 04	STO 4	31	f	31	f
35 07	$g x \leftrightarrow y$	51	SF 1	61	TF 1
33 05	STO 5	84	R/S	11	A
31	f	23	LBL	35 01	$g \text{ NOP}$
01	$R \rightarrow P$	11	A	34 06	RCL 6
32	f^{-1}	32	f^{-1}	61	+
09	\sqrt{x}	61	TF 1	35 07	$g x \leftrightarrow y$
34 05	RCL 5	35	g	34 07	RCL 7
42	CHS	04	$\frac{1}{x}$	61	+
35 07	$g x \leftrightarrow y$	00	0	35 07	$g x \leftrightarrow y$
81	\div	35 07	$g x \leftrightarrow y$	31	f
34 04	RCL 4	22	GTO	61	TF 1
35 00	$g \text{ NOP}$	01	1	11	A
81	\div	23	LBL	35 01	$g \text{ NOP}$
24	RTN	12	B	33 01	STO 1
23	LBL	34 03	RCL 3	35 07	$g x \leftrightarrow y$
14	D	71	x	33 02	STO 2
32	f^{-1}	35	g	35 07	$g x \leftrightarrow y$
61	TF 1	04	$\frac{1}{x}$	11	A
35 07	$g x \leftrightarrow y$	42	CHS	31	f
22	GTO	00	0	01	$R \rightarrow P$
00	0	22	GTO	22	GTO
02	2	01	1	00	0
71	x	23	LBL		
35	g	13	C		
02	π	34 03	RCL 3		
71	x	71	x		
33 03	STO 3	00	0		

R₁ Re [Y _{in}]	R₄ Used	R₇ Used
R₂ Im [Y _{in}]	R₅ Used	R₈
R₃ $\omega = 2\pi f$	R₆ Used	R₉

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	\div
01	1
00	0
35 07	$g \ x \leftrightarrow y$
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	\div
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	\div
34 05	RCL 5
51	—
33 03	STO 3
34 02	RCL 2
34 07	RCL 7
71	x
34 08	RCL 8
81	\div
34 05	RCL 5
51	—
33 04	STO 4
34 01	RCL 1
34 02	RCL 2
81	\div
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	\uparrow
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	CODE	KEYS	CODE	KEYS
21	DSP	33 05	STO 5	09	\sqrt{x}
04	4	35	g	61	+
32	f^{-1}	04	$1/x$	41	\uparrow
61	TF 1	33 06	STO 6	71	x
33 02	STO 2	34 08	RCL 8	31	f
84	R/S	02	2	08	LOG
33 01	STO 1	61	+	01	1
32	f^{-1}	34 08	RCL 8	00	0
51	SF 1	81	\div	71	x
84	R/S	33 08	STO 8	33 06	STO 6
23	LBL	34 01	RCL 1	84	R/S
12	B	81	\div	23	LBL
01	1	34 06	RCL 6	13	C
00	0	51	—	32	f^{-1}
81	\div	35	g	61	TF 1
01	1	04	$1/x$	34 04	RCL 4
00	0	33 03	STO 3	84	R/S
35 07	$g \leftrightarrow y$	34 08	RCL 8	34 03	RCL 3
35	g	34 02	RCL 2	32	f^{-1}
05	y^x	81	\div	51	SF 1
33 07	STO 7	34 06	RCL 6	84	R/S
01	1	51	—	23	LBL
51	—	35	g	14	D
33 08	STO 8	04	$1/x$	34 05	RCL 5
83	.	33 04	STO 4	84	R/S
05	5	34 01	RCL 1	23	LBL
71	x	34 02	RCL 2	15	E
34 01	RCL 1	81	\div	31	f
34 02	RCL 2	33 06	STO 6	51	SF 1
71	x	01	1	84	R/S
34 07	RCL 7	51	—		
81	\div	31	g		
31	f	09	\sqrt{x}		
09	\sqrt{x}	34 06	RCL 6		
71	x	31	g		

R₁	Z ₁	R₄	R ₂	R₇	N
R₂	Z ₂	R₅	R ₃	R₈	Used
R₃	R ₁	R₆	Min Loss	R₉	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	CODE	KEYS	CODE	KEYS
23	LBL	84	R/S	31	f
11	A	23	LBL	51	SF 1
34 04	RCL 4	13	C	84	R/S
34 06	RCL 6	71	x	35 01	g NOP
34 01	RCL 1	34 07	RCL 7	35 01	g NOP
34 03	RCL 3	81	÷	35 01	g NOP
13	C	35 08	g R↓	35 01	g NOP
84	R/S	61	+	35 01	g NOP
23	LBL	34 08	RCL 8	35 01	g NOP
12	B	51	—	35 01	g NOP
35 07	g x↔y	35 09	g R↑	35 01	g NOP
84	R/S	31	f	35 01	g NOP
23	LBL	61	TF 1	35 01	g NOP
11	A	22	GTO	35 01	g NOP
34 05	RCL 5	01	1	35 01	g NOP
34 06	RCL 6	32	f ⁻¹	35 01	g NOP
34 02	RCL 2	01	R→P	35 01	g NOP
34 03	RCL 3	24	RTN	35 01	g NOP
13	C	23	LBL	35 01	g NOP
84	R/S	01	1	35 01	g NOP
23	LBL	35	g	35 01	g NOP
12	B	04	¹ /x	35 01	g NOP
35 07	g x≥y	35 07	g x↔y	35 01	g NOP
84	R/S	42	CHS	35 01	g NOP
23	LBL	35 07	g x↔y	35 01	g NOP
11	A	32	f ⁻¹	35 01	g NOP
34 04	RCL 4	01	R→P	35 01	g NOP
34 05	RCL 5	24	RTN	35 01	g NOP
34 01	RCL 1	23	LBL	35 01	g NOP
34 02	RCL 2	14	D	35 01	g NOP
13	C	32	f ⁻¹		
84	R/S	51	SF 1		
23	LBL	84	R/S		
12	B	23	LBL		
35 07	g x↔y	15	E		

R₁	Used	R₄	Used	R₇	Used
R₂	Used	R₅	Used	R₈	Used
R₃	Used	R₆	Used	R₉	Used

MINIMUM LOSS PAD MATCHING

CODE	KEYS	CODE	KEYS	CODE	KEYS
23	LBL	71	x	35 01	g NOP
11	A	33 03	STO 3	35 01	g NOP
33 01	STO 1	01	1	35 01	g NOP
84	R/S	34 02	RCL 2	35 01	g NOP
23	LBL	34 01	RCL 1	35 01	g NOP
12	B	81	÷	35 01	g NOP
33 02	STO 2	51	—	35 01	g NOP
84	R/S	31	f	35 01	g NOP
23	LBL	09	\sqrt{x}	35 01	g NOP
13	C	33 04	STO 4	35 01	g NOP
15	E	35	g	35 01	g NOP
34 04	RCL 4	04	${}^1/x$	35 01	g NOP
84	R/S	33 05	STO 5	35 01	g NOP
23	LBL	34 01	RCL 1	35 01	g NOP
14	D	33	STO	35 01	g NOP
15	E	71	x	35 01	g NOP
34 05	RCL 5	04	4	35 01	g NOP
84	R/S	34 02	RCL 2	35 01	g NOP
23	LBL	33	STO	35 01	g NOP
15	E	71	x	35 01	g NOP
34 01	RCL 1	05	5	35 01	g NOP
34 02	RCL 2	34 03	RCL 3	35 01	g NOP
81	÷	24	RTN	35 01	g NOP
31	f	35 01	g NOP	35 01	g NOP
09	\sqrt{x}	35 01	g NOP	35 01	g NOP
35 00	g LST X	35 01	g NOP	35 01	g NOP
01	1	35 01	g NOP	35 01	g NOP
51	—	35 01	g NOP	35 01	g NOP
31	f	35 01	g NOP	35 01	g NOP
09	\sqrt{x}	35 01	g NOP	35 01	g NOP
61	+	35 01	g NOP	35 01	g NOP
31	f	35 01	g NOP	35 01	g NOP
08	LOG	35 01	g NOP	35 01	g NOP
02	2	35 01	g NOP		
00	0	35 01	g NOP		

R₁	Z₁	R₄	R₁	R₇
R₂	Z₂	R₅	R₂	R₈
R₃	Loss	R₆		R₉

PI NETWORK IMPEDANCE MATCHING

CODE	KEYS	CODE	KEYS	CODE	KEYS
31	f	22	GTO	81	÷
42	STK	00	0	71	x
21	DSP	34 02	RCL 2	23	LBL
04	4	34 01	RCL 1	00	0
23	LBL	81	÷	35	g
01	1	34 04	RCL 4	02	π
32	f^{-1}	41	↑	02	2
51	SF 1	71	x	71	x
24	RTN	01	1	34 03	RCL 3
84	R/S	61	+	71	x
23	LBL	33 05	STO 5	81	÷
11	A	71	x	22	GTO
32	f^{-1}	01	1	01	1
61	TF 1	51	—	23	LBL
33 02	STO 2	31	f	15	E
84	R/S	09	\sqrt{x}	31	f
33 01	STO 1	34 02	RCL 2	51	SF 1
22	GTO	81	÷	84	R/S
01	1	33 06	STO 6	35 01	g NOP
23	LBL	22	GTO	35 01	g NOP
12	B	00	0	35 01	g NOP
32	f^{-1}	23	LBL	35 01	g NOP
61	TF 1	14	D	35 01	g NOP
33 04	STO 4	13	C	35 01	g NOP
84	R/S	34 02	RCL 2	35 01	g NOP
33 03	STO 3	34 06	RCL 6	35 01	g NOP
22	GTO	71	x	35 01	g NOP
01	1	34 04	RCL 4	35 01	g NOP
23	LBL	81	÷	35 01	g NOP
13	C	01	1	35 01	g NOP
34 04	RCL 4	61	+	35 01	g NOP
34 01	RCL 1	34 04	RCL 4	35 01	g NOP
81	÷	34 01	RCL 1	35 01	g NOP
31	f	71	x	35 01	g NOP
61	TF 1	34 05	RCL 5	35 01	g NOP

R₁	R ₁	R₄	Q	R₇
R₂	R ₂	R₅	Used	R₈
R₃	f	R₆	Used	R₉

BAND PASS FILTER DESIGN (CARD 1)

CODE	KEYS	CODE	KEYS	CODE	KEYS
21	DSP	71	x	32	f^{-1}
03	3	81	\div	61	TF 1
32	f^{-1}	33 04	STO 4	34 05	RCL 5
51	SF 1	34 03	RCL 3	84	R/S
84	R/S	34 06	RCL 6	34 04	RCL 4
23	LBL	35	g	32	f^{-1}
11	A	02	π	51	SF 1
32	f^{-1}	71	x	84	R/S
61	TF 1	33 08	STO 8	23	LBL
33 02	STO 2	71	x	14	D
84	R/S	35	g	32	f^{-1}
33 01	STO 1	04	$1/x$	61	TF 1
32	f^{-1}	33 05	STO 5	34 07	RCL 7
51	SF 1	34 03	RCL 3	84	R/S
84	R/S	34 06	RCL 6	34 06	RCL 6
23	LBL	71	x	32	f^{-1}
12	B	34 07	RCL 7	51	SF 1
31	f	81	\div	84	R/S
61	TF 1	33 07	STO 7	23	LBL
22	GTO	34 03	RCL 3	15	E
01	1	34 08	RCL 8	31	f
34 02	RCL 2	81	\div	51	SF 1
34 01	RCL 1	33 06	STO 6	84	R/S
51	-	00	0	35 01	g NOP
33 06	STO 6	21	DSP	35 01	g NOP
34 01	RCL 1	03	3	35 01	g NOP
34 02	RCL 2	84	R/S	35 01	g NOP
71	x	23	LBL	35 01	g NOP
04	4	01	1	35 01	g NOP
71	x	33 03	STO 3	35 01	g NOP
35	g	32	f^{-1}	35 01	g NOP
02	π	51	SF 1		
71	x	84	R/S		
33 07	STO 7	23	LBL		
34 03	RCL 3	13	C		

R₁	f_1, f_L	R₄	C_a	R₇	$4\pi f_1 f_2, L_b$
R₂	f_2, f_U	R₅	C_b	R₈	$\pi(f_2 - f_1)$
R₃	$R, \Delta f$	R₆	$f_2 - f_1, L_a$	R₉	

BAND PASS FILTER DESIGN (CARD 2)

CODE	KEYS	CODE	KEYS	CODE	KEYS
34 02	RCL 2	04	4	14	D
34 01	RCL 1	71	x	61	+
35 24	g x>y	34 04	RCL 4	23	LBL
00	0	71	x	15	E
81	÷	34 07	RCL 7	31	f
21	DSP	71	x	09	\sqrt{x}
83	.	81	÷	61	+
02	2	34 01	RCL 1	31	f
84	R/S	34 03	RCL 3	07	LN
23	LBL	23	LBL	01	1
12	B	02	2	32	f^{-1}
34 01	RCL 1	61	+	07	LN
02	2	33 01	STO 1	31	f
71	x	35 08	g R↓	08	LOG
35	g	00	0	04	4
02	π	35 07	g x↔y	00	0
71	x	35 24	g x>y	71	x
41	↑	22	GTO	71	x
71	x	01	1	24	RTN
33 08	STO 8	35 23	g x=y	23	LBL
34 04	RCL 4	00	0	14	D
71	x	84	R/S	31	f
34 06	RCL 6	01	1	09	\sqrt{x}
71	x	42	CHS	41	↑
01	1	35 07	g x↔y	71	x
51	—	35 24	g x>y	35 00	g LST X
01	1	00	0	35 07	g x↔y
34 08	RCL 8	84	R/S	01	1
34 05	RCL 5	42	CHS	24	RTN
71	x	14	D	35 01	g NOP
34 07	RCL 7	51	—		
71	x	15	E		
51	—	84	R/S		
71	x	23	LBL		
34 08	RCL 8	01	1		

R₁	f_L	R₄	C_a	R₇	L_b
R₂	f_U	R₅	C_b	R₈	ω^2
R₃	Δf	R₆	L_a	R₉	Used

ACTIVE FILTER—LOW PASS

CODE	KEYS	CODE	KEYS	CODE	KEYS
02	2	05	5	02	2
31	f	23	LBL	34 02	RCL 2
09	\sqrt{x}	13	C	01	1
33 03	STO 3	31	f	61	+
31	f	61	TF 1	34 03	RCL 3
42	STK	22	GTO	04	4
23	LBL	01	1	81	\div
00	0	14	D	35	g
32	f^{-1}	35 07	$g \leftrightarrow y$	02	π
51	SF 1	81	\div	81	\div
21	DSP	22	GTO	34 01	RCL 1
83	.	00	0	81	\div
02	2	23	LBL	34 04	RCL 4
24	RTN	02	2	81	\div
23	LBL	32	f^{-1}	22	GTO
11	A	51	SF 1	00	0
31	f	14	D	23	LBL
61	TF 1	34 03	RCL 3	01	1
33 01	STO 1	71	x	32	f^{-1}
22	GTO	35	g	51	SF 1
00	0	02	π	14	D
61	+	71	x	34 02	RCL 2
33 02	STO 2	34 01	RCL 1	81	\div
22	GTO	71	x	22	GTO
00	0	81	\div	00	0
23	LBL	23	LBL	23	LBL
12	B	05	5	15	E
31	f	21	DSP	31	f
61	TF 1	06	6	51	SF 1
33 03	STO 3	84	R/S	84	R/S
22	GTO	23	LBL		
00	0	14	D		
61	+	31	f		
33 04	STO 4	61	TF 1		
22	GTO	22	GTO		

R₁	f _c	R₄	C	R₇
R₂	G	R₅		R₈
R₃	α	R₆		R₉

ACTIVE FILTER-HIGH PASS

CODE	KEYS	CODE	KEYS	CODE	KEYS
02	2	05	5	71	x
31	f	23	LBL	01	1
09	\sqrt{x}	13	C	34 02	RCL 2
33 03	STO 3	31	f	81	\div
31	f	61	TF 1	02	2
42	STK	22	GTO	61	+
23	LBL	01	1	71	x
00	0	02	2	81	\div
32	f^{-1}	34 02	RCL 2	22	GTO
51	SF 1	71	x	00	0
21	DSP	01	1	23	LBL
83	.	61	+	14	D
02	2	34 03	RCL 3	34 04	RCL 4
84	R/S	02	2	34 02	RCL 2
23	LBL	71	x	81	\div
11	A	35	g	23	LBL
31	f	02	π	05	5
61	TF 1	71	x	21	DSP
33 01	STO 1	34 01	RCL 1	06	6
22	GTO	71	x	32	f^{-1}
00	0	34 04	RCL 4	51	SF 1
61	+	71	x	84	R/S
33 02	STO 2	81	\div	23	LBL
22	GTO	22	GTO	15	E
00	0	00	0	31	f
23	LBL	23	LBL	51	SF 1
12	B	01	1	84	R/S
31	f	34 03	RCL 3	35 01	g NOP
61	TF 1	02	2	35 01	g NOP
33 03	STO 3	35	g	35 01	g NOP
22	GTO	02	π		
00	0	71	x		
61	+	34 01	RCL 1		
33 04	STO 4	71	x		
22	GTO	34 04	RCL 4		

R₁	f_0	R₄	C	R₇
R₂	G	R₅		R₈
R₃	α	R₆		R₉

BUTTERWORTH FILTER

CODE	KEYS	CODE	KEYS	CODE	KEYS
33 01	STO 1	71	x	71	x
35	g	35	g	81	÷
42	RAD	02	π	31	f
01	1	71	x	04	SIN
33 04	STO 4	81	÷	34 02	RCL 2
02	2	33 06	STO 6	71	x
33 05	STO 5	34 01	RCL 1	35	g
34 01	RCL 1	34 04	RCL 4	02	π
84	R/S	33 08	STO 8	34 03	RCL 3
23	LBL	35 24	g x>y	71	x
12	B	00	0	81	÷
33 02	STO 2	81	÷	33 07	STO 7
84	R/S	02	2	34 01	RCL 1
23	LBL	61	+	34 05	RCL 5
13	C	33 04	STO 4	33 08	STO 8
33 03	STO 3	21	DSP	35 24	g x>y
84	R/S	02	2	00	0
23	LBL	34 08	RCL 8	81	÷
14	D	84	R/S	02	2
34 04	RCL 4	21	DSP	61	+
02	2	04	4	33 05	STO 5
71	x	34 06	RCL 6	21	DSP
01	1	84	R/S	02	2
51	—	23	LBL	34 08	RCL 8
35	g	15	E	84	R/S
02	π	34 05	RCL 5	21	DSP
71	x	02	2	04	4
34 01	RCL 1	71	x	34 07	RCL 7
02	2	01	1	84	R/S
71	x	51	—	35 01	g NOP
81	÷	35	g		
31	f	02	π		
04	SIN	71	x		
34 02	RCL 2	34 01	RCL 1		
34 03	RCL 3	02	2		

R₁	n	R₄	Used	R₇	L _i
R₂	R	R₅	Used	R₈	Used
R₃	f _c	R₆	C _i	R₉	Used

CHEBYSHEV FILTER (CARD 1)

CODE	KEYS	CODE	KEYS	CODE	KEYS
23	LBL	32	f ⁻¹	02	2
11	A	07	LN	81	÷
33 01	STO 1	31	f	33 06	STO 6
84	R/S	08	LOG	35	g
23	LBL	04	4	02	π
12	B	00	0	34 01	RCL 1
33 02	STO 2	71	x	02	2
84	R/S	81	÷	71	x
23	LBL	32	f ⁻¹	81	÷
13	C	07	LN	31	f
33 03	STO 3	33 07	STO 7	04	SIN
84	R/S	35 00	g LST X	33 08	STO 8
23	LBL	42	CHS	02	2
14	D	32	f ⁻¹	71	x
33 04	STO 4	07	LN	34 06	RCL 6
84	R/S	51	—	81	÷
23	LBL	35 00	g LST X	33 07	STO 7
15	E	34 07	RCL 7	34 03	RCL 3
01	1	61	+	34 02	RCL 2
33 05	STO 5	81	÷	71	x
31	f	35	g	81	÷
51	SF 1	04	1/x	33 04	STO 4
35	g	31	f	00	0
42	RAD	07	LN	84	R/S
21	DSP	34 01	RCL 1	35 01	g NOP
03	3	02	2	35 01	g NOP
34 03	RCL 3	71	x	35 01	g NOP
02	2	81	÷	35 01	g NOP
71	x	32	f ⁻¹	35 01	g NOP
35	g	07	LN	35 01	g NOP
02	π	35 00	g LST X	35 01	g NOP
71	x	42	CHS		
33 03	STO 3	32	f ⁻¹		
34 04	RCL 4	07	LN		
01	1	51	—		

R₁	n	R₄	ϵ_{dB}, C_1	R₇	G _i
R₂	R	R₅	i	R₈	a _i
R₃	f_c, ω_c	R₆	γ	R₉	Used

CHEBYSHEV FILTER (CARD 2)

CODE	KEYS	CODE	KEYS	CODE	KEYS
23	LBL	33 05	STO 5	71	x
11	A	35 07	g x \rightarrow y	34 01	RCL 1
21	DSP	84	R/S	02	2
83	.	23	LBL	71	x
00	0	01	1	81	\div
34 01	RCL 1	32	f $^{-1}$	31	f
34 05	RCL 5	51	—	04	SIN
35 24	g x $>$ y	31	f	33 08	STO 8
00	0	71	SF 2	71	x
81	\div	34 04	RCL 4	34 05	RCL 5
84	R/S	01	1	01	1
23	LBL	22	GTO	51	—
12	B	02	2	35	g
31	f	23	LBL	02	π
61	TF 1	03	3	71	x
22	GTO	32	f $^{-1}$	34 01	RCL 1
01	1	71	SF 1	81	\div
31	f	15	E	31	f
81	TF 2	34 02	RCL 2	04	SIN
22	GTO	71	x	41	\uparrow
03	3	34 03	RCL 3	71	x
31	f	22	GTO	34 06	RCL 6
71	SF 2	02	2	41	\uparrow
15	E	23	LBL	71	x
34 03	RCL 3	15	E	61	+
34 02	RCL 2	34 08	RCL 8	34 07	RCL 7
71	x	04	4	71	x
23	LBL	71	x	81	\div
02	2	34 05	RCL 5	33 07	STO 7
21	DSP	02	2	24	RTN
03	3	71	x		
81	\div	01	1		
34 05	RCL 5	51	—		
01	1	35	g		
61	+	02	π		

R₁	n	R₄	C ₁	R₇	G _i
R₂	R	R₅	i	R₈	a _i
R₃	ω_C	R₆	γ	R₉	Used

CAPACITANCE OF PARALLEL PLATES

CODE	KEYS	CODE	KEYS	CODE	KEYS
02	2	00	0	84	R/S
83	.	35 07	g x \rightleftarrows y	34 04	RCL 4
05	5	35 24	g x>y	35	g
04	4	33 04	STO 4	02	π
42	CHS	84	R/S	02	2
33 06	STO 6	34 06	RCL 6	71	x
84	R/S	71	x	71	x
23	LBL	33 04	STO 4	34 02	RCL 2
11	A	84	R/S	81	\div
33 01	STO 1	23	LBL	31	f
84	R/S	15	E	07	LN
23	LBL	34 01	RCL 1	01	1
12	B	34 02	RCL 2	61	+
00	0	81	\div	34 02	RCL 2
35 07	g x \rightleftarrows y	34 03	RCL 3	34 04	RCL 4
35 24	g x>y	71	x	81	\div
33 02	STO 2	34 04	RCL 4	35	g
84	R/S	71	x	02	π
34 06	RCL 6	83	.	81	\div
71	x	00	0	71	x
33 02	STO 2	08	8	01	1
84	R/S	08	8	61	+
23	LBL	05	5	34 05	RCL 5
13	C	04	4	71	x
00	0	01	1	84	R/S
35 07	g x \rightleftarrows y	09	9	35 01	g NOP
35 24	g x>y	71	x	35 01	g NOP
33 03	STO 3	33 05	STO 5	35 01	g NOP
84	R/S	34 03	RCL 3	35 01	g NOP
34 06	RCL 6	34 04	RCL 4	35 01	g NOP
71	x	43	EEX	35 01	g NOP
33 03	STO 3	02	2		
84	R/S	71	x		
23	LBL	35 24	g x>y		
14	D	34 05	RCL 5		

R₁	ϵ_r	R₄	W	R₇
R₂	d	R₅	C with P = 0	R₈
R₃	L	R₆	-2.54	R₉ Used

SELF INDUCTANCE OF STRAIGHT ROUND WIRE

CODE	KEYS
02	2
83	.
05	5
04	4
43	CHS
33 04	STO 4
01	1
33 03	STO 3
44	CLX
84	R/S
23	LBL
11	A
00	0
35 07	$g x \leftrightarrow y$
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	$g x \leftrightarrow y$
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

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	CODE	KEYS	CODE	KEYS
81	÷	00	0	71	x
71	x	34 03	RCL 3	09	9
31	f	22	GTO	34 01	RCL 1
09	\sqrt{x}	00	0	71	x
31	f	23	LBL	01	1
01	R→P	12	B	00	0
35 09	g R↑	35	g	34 02	RCL 2
61	+	83	DSZ	71	x
84	R/S	33 02	STO 2	34 03	RCL 3
23	LBL	84	R/S	71	x
15	E	34 03	RCL 3	61	+
34 02	RCL 2	34 01	RCL 1	81	÷
34 04	RCL 4	34 04	RCL 4	84	R/S
71	x	81	÷	23	LBL
33 06	STO 6	71	x	13	C
01	1	09	9	35	g
33 08	STO 8	34 03	RCL 3	83	DSZ
84	R/S	81	÷	33 03	STO 3
23	LBL	51	—	84	R/S
11	A	34 01	RCL 1	05	5
35	g	71	x	34 06	RCL 6
83	DSZ	01	1	71	x
33 01	STO 1	00	0	34 01	RCL 1
84	R/S	81	÷	41	↑
04	4	84	R/S	71	x
83	•	23	LBL	81	÷
05	5	14	D	34 04	RCL 4
34 03	RCL 3	35	g	09	9
41	↑	83	DSZ	34 01	RCL 1
71	x	33 04	STO 4	35 01	g NOP
81	÷	84	R/S		
34 04	RCL 4	34 03	RCL 3		
71	x	34 01	RCL 1		
34 06	RCL 6	71	x		
01	1	41	↑		

R₁	R	R₄	L	R₇	
R₂	D	R₅		R₈	DSZ
R₃	N	R₆	DL	R₉	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	\div
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	\div
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	+
02	2
05	5
83	.
05	5

CODE	KEYS
09	9
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	\div
34 01	RCL 1
81	\div
84	R/S

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

TRANSFORMER DESIGN

CODE	KEYS	CODE	KEYS	CODE	KEYS
84	R/S	03	3	14	D
01	1	34 04	RCL 4	35	g
33 08	STO 8	71	x	83	DSZ
03	3	23	LBL	33 04	STO 4
04	4	04	4	22	GTO
09	9	34 05	RCL 5	00	0
43	EEX	34 07	RCL 7	34 01	RCL 1
04	4	71	x	34 02	RCL 2
33 07	STO 7	35 07	g x↔y	71	x
84	R/S	81	÷	34 03	RCL 3
33 06	STO 6	22	GTO	71	x
34 02	RCL 2	00	0	22	GTO
81	÷	23	LBL	04	4
31	f	12	B	23	LBL
09	√x	35	g	15	E
83	•	83	DSZ	35	g
07	7	33 02	STO 2	83	DSZ
02	2	22	GTO	33 05	STO 5
33 08	STO 8	00	0	22	GTO
81	÷	34 01	RCL 1	00	0
22	GTO	22	GTO	34 01	RCL 1
00	0	02	2	34 02	RCL 2
23	LBL	23	LBL	71	x
11	A	13	C	34 03	RCL 3
35	g	35	g	71	x
83	DSZ	83	DSZ	34 04	RCL 4
33 01	STO 1	33 03	STO 3	71	x
22	GTO	22	GTO	34 07	RCL 7
00	0	00	0	81	÷
34 02	RCL 2	34 01	RCL 1	35 01	g NOP
23	LBL	34 02	RCL 2		
02	2	71	x		
34 03	RCL 3	22	GTO		
71	x	03	3		
23	LBL	23	LBL		

R₁	N _p	R₄	B _m	R₇	temporary
R₂	f	R₅	E _p	R₈	.72, DSZ
R₃	A _c	R₆	W _{out}	R₉	

REED RELAY DESIGN (CARD 1)

CODE	KEYS	CODE	KEYS	CODE	KEYS
02	2	81	÷	02	2
83	.	35	g	81	÷
05	5	06	ABS	33 07	STO 7
04	4	33 01	STO	34 06	RCL 6
33 07	STO 7	44	CLX	34 02	RCL 2
00	0	34 02	RCL 2	34 03	RCL 3
33 08	STO 8	35 24	g x>y	61	+
84	R/S	34 07	RCL 7	33 02	STO 2
23	LBL	81	÷	81	÷
11	A	35	g	02	2
35	g	06	ABS	83	.
83	DSZ	33 02	STO 2	06	6
33 01	STO 1	44	CLX	43	EEX
84	R/S	34 03	RCL 3	05	5
33 04	STO 4	35 24	g x>y	71	x
84	R/S	34 07	RCL 7	02	2
23	LBL	81	÷	83	.
12	B	35	g	03	3
35	g	06	ABS	05	5
83	DSZ	33 03	STO 3	06	6
33 02	STO 2	34 06	RCL 6	02	2
84	R/S	84	R/S	34 04	RCL 4
33 05	STO 5	23	LBL	71	x
84	R/S	15	E	81	÷
23	LBL	01	1	31	f
13	C	33 08	STO 8	07	LN
35	g	35 08	g R↓	04	4
83	DSZ	24	RTN	41	↑
33 03	STO 3	23	LBL	00	0
84	R/S	14	D	84	R/S
33 06	STO 6	34 02	RCL 2		
00	0	34 03	RCL 3		
34 01	RCL 1	51	—		
35 24	g x>y	34 01	RCL 1		
34 07	RCL 7	71	x		

R₁	L, WS	R₄	S _{max}	R₇	A
R₂	OD, OD + ID	R₅	S _{min}	R₈	T, DSZ
R₃	ID	R₆	V	R₉	Used

REED RELAY DESIGN (CARD 2)

CODE	KEYS	CODE	KEYS	CODE	KEYS
35 08	g R↓	23	LBL	81	÷
71	x	14	D	01	1
83	.	83	.	43	EEX
05	5	02	2	03	3
61	+	03	3	71	x
31	f	01	1	84	R/S
83	INT	02	2	23	LBL
33 01	STO 1	34 01	RCL 1	15	E
00	0	71	x	21	DSP
84	R/S	32	f ⁻¹	83	•
23	LBL	07	LN	02	2
13	C	83	•	34 04	RCL 4
21	DSP	00	0	01	1
83	.	04	4	83	•
00	0	09	9	01	1
34 01	RCL 1	06	6	71	x
83	.	71	x	34 08	RCL 8
02	2	01	1	81	÷
02	2	02	2	34 03	RCL 3
09	9	43	EEX	71	x
71	x	03	3	84	R/S
32	f ⁻¹	81	÷	34 05	RCL 5
07	LN	34 08	RCL 8	83	•
08	8	71	x	03	3
83	.	35	g	71	x
05	5	02	π	34 08	RCL 8
07	7	71	x	81	÷
71	x	34 02	RCL 2	34 03	RCL 3
34 07	RCL 7	71	x	71	x
71	x	33 03	STO 3	84	R/S
33 08	STO 8	84	R/S		
34 01	RCL 1	34 06	RCL 6		
84	R/S	32	f ⁻¹		
34 08	RCL 8	09	√x		
84	R/S	34 03	RCL 3		

R₁	L, WS	R₄	S _{max}	R₇	A
R₂	OD + ID	R₅	S _{min}	R₈	T
R₃	ID, R _c	R₆	V	R₉	

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

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

**TRANSMISSION LINE
IMPEDANCE TRANSFORMATION**

CODE	KEYS	CODE	KEYS	CODE	KEYS
32	f ⁻¹	08	8	71	x
51	SF 1	03	3	34 02	RCL 2
84	R/S	43	EEX	35 00	g LST X
23	LBL	42	CHS	71	x
11	A	08	8	35 00	g LST X
32	f ⁻¹	71	x	35 09	g R↑
61	TF 1	34 04	RCL 4	71	x
33 02	STO 2	81	÷	35 07	g x↔y
84	R/S	33 05	STO 5	35 00	g LST X
33 01	STO 1	22	GTO	61	+
22	GTO	00	0	35 07	g x↔y
00	0	23	LBL	34 02	RCL 2
23	LBL	14	D	35 07	g x↔y
12	B	32	f ⁻¹	51	—
32	f ⁻¹	61	TF 1	35 07	g x↔y
61	TF 1	33 07	STO 7	34 08	RCL 8
33 04	STO 4	84	R/S	31	f
84	R/S	33 06	STO 6	01	R→P
33 03	STO 3	22	GTO	35 07	g x↔y
22	GTO	00	0	35 09	g R↑
00	0	23	LBL	35 09	g R↑
23	LBL	15	E	31	f
13	C	31	f	01	R→P
32	f ⁻¹	51	SF 1	35 08	g R↓
61	TF 1	84	R/S	51	—
33 05	STO 5	23	LBL	35 07	g x↔y
84	R/S	15	E	35 09	g R↑
34 01	RCL 1	34 06	RCL 6	81	÷
34 03	RCL 3	34 07	RCL 7	34 02	RCL 2
71	x	32	f ⁻¹	71	x
01	1	01	R→P		
83	.	33 08	STO 8		
02	2	34 05	RCL 5		
00	0	31	f		
00	0	06	TAN		

R₁	f	R₄	v	R₇	MAG[Z]
R₂	Z ₀	R₅	θ	R₈	Used
R₃	l	R₆	ANG[Z]	R₉	Used

MICROSTRIP TRANSMISSION LINE

CODE	KEYS	CODE	KEYS	CODE	KEYS
00	0	07	LN	83	DSZ
33 08	STO 8	08	8	24	RTN
84	R/S	07	7	35 01	g NOP
23	LBL	71	x	83	.
11	A	34 04	RCL 4	03	3
35	g	01	1	00	0
83	DSZ	83	.	04	4
33 02	STO 2	04	4	08	8
24	RTN	01	1	81	÷
33 01	STO 1	61	+	24	RTN
24	RTN	31	f	23	LBL
23	LBL	09	\sqrt{x}	15	E
12	B	81	÷	01	1
35	g	24	RTN	33 08	STO 8
83	DSZ	23	LBL	35 08	g R↓
33 04	STO 4	14	D	24	RTN
24	RTN	83	.	35 01	g NOP
33 03	STO 3	04	4	35 01	g NOP
24	RTN	07	7	35 01	g NOP
23	LBL	05	5	35 01	g NOP
13	C	34 04	RCL 4	35 01	g NOP
05	5	71	x	35 01	g NOP
83	.	83	.	35 01	g NOP
09	9	06	6	35 01	g NOP
08	8	07	7	35 01	g NOP
34 03	RCL 3	61	+	35 01	g NOP
71	x	31	f	35 01	g NOP
34 01	RCL 1	09	\sqrt{x}	35 01	g NOP
83	.	01	1	35 01	g NOP
08	8	83	.	35 01	g NOP
71	x	00	0	35 01	g NOP
34 02	RCL 2	01	1		
61	+	07	7		
81	÷	71	x		
31	f	35	g		

R₁	w	R₄	ϵ_r	R₇	
R₂	t	R₅		R₈	DSZ
R₃	h	R₆		R₉	

S \rightleftarrows Y PARAMETER CONVERSION (CARD 1)

CODE	KEYS	CODE	KEYS	CODE	KEYS
34 02	RCL 2	23	LBL	51	—
33 01	STO 1	15	E	34 06	RCL 6
34 03	RCL 3	34 05	RCL 5	34 07	RCL 7
33 02	STO 2	34 04	RCL 4	71	x
34 04	RCL 4	01	1	61	+
33 03	STO 3	61	+	31	f
35 09	g R \uparrow	71	x	01	R \rightarrow P
33 04	STO 4	34 08	RCL 8	35 07	g x \rightleftarrows y
84	R/S	34 01	RCL 1	24	RTN
23	LBL	01	1	23	LBL
12	B	61	+	14	D
34 06	RCL 6	71	x	31	f
33 05	STO 5	61	+	01	R \rightarrow P
34 07	RCL 7	34 02	RCL 2	35 09	g R \uparrow
33 06	STO 6	34 07	RCL 7	81	\div
34 08	RCL 8	71	x	02	2
33 07	STO 7	51	—	71	x
35 09	g R \uparrow	34 06	RCL 6	84	R/S
34 04	RCL 4	34 03	RCL 3	35 08	g R \downarrow
32	f $^{-1}$	71	x	35 07	g x \rightleftarrows y
01	R \rightarrow P	51	—	51	—
33 04	STO 4	34 01	RCL 1	01	1
35 08	g R \downarrow	01	1	42	CHS
33 08	STO 8	61	+	32	f $^{-1}$
84	R/S	34 04	RCL 4	01	R \rightarrow P
23	LBL	01	1	31	f
13	C	61	+	01	R \rightarrow P
15	E	71	x	35 08	g R \downarrow
34 06	RCL 6	34 05	RCL 5	84	R/S
34 02	RCL 2	34 08	RCL 8	24	RTN
14	D	71	x		
15	E	51	—		
34 07	RCL 7	34 02	RCL 2		
34 03	RCL 3	34 03	RCL 3		
14	D	71	x		

R₁ Re [s ₁₁]	R₄ Re [s ₂₂]	R₇ temporary
R₂ temporary	R₅ Im [s ₁₁]	R₈ Im [s ₂₂]
R₃ temporary	R₆ temporary	R₉ temporary, ± 1

S \rightleftarrows Y PARAMETER CONVERSION (CARD 2)

CODE	KEYS	CODE	KEYS	CODE	KEYS
33	STO	15	E	81	\div
09	9	34 05	RCL 5	84	R/S
35 07	g x \rightleftarrows y	34	RCL	35 07	g x \rightleftarrows y
34 02	RCL 2	09	9	34 02	RCL 2
34 03	RCL 3	42	CHS	51	-
71	x	34 04	RCL 4	01	1
34 06	RCL 6	51	-	32	f $^{-1}$
34 07	RCL 7	71	x	01	R \rightarrow P
71	x	34 08	RCL 8	31	f
51	-	34	RCL	01	R \rightarrow P
34 02	RCL 2	09	9	35 08	g R \downarrow
34 07	RCL 7	34 01	RCL 1	84	R/S
71	x	51	-	24	RTN
34 03	RCL 3	71	x	35 01	g NOP
35 09	g R \uparrow	61	+	35 01	g NOP
33 03	STO 3	34 07	RCL 7	35 01	g NOP
35 08	g R \downarrow	61	+	35 01	g NOP
34 06	RCL 6	34	RCL	35 01	g NOP
71	x	09	9	35 01	g NOP
61	+	34 01	RCL 1	35 01	g NOP
33 07	STO 7	51	-	35 01	g NOP
35 07	g x \rightleftarrows y	34	RCL	35 01	g NOP
33 06	STO 6	09	9	35 01	g NOP
34	RCL	34 04	RCL 4	35 01	g NOP
09	9	61	+	35 01	g NOP
33 02	STO 2	71	x	35 01	g NOP
01	1	34 05	RCL 5	35 01	g NOP
33	STO	34 08	RCL 8	35 01	g NOP
09	9	71	x	35 01	g NOP
15	E	61	+	35 01	g NOP
01	1	34 06	RCL 6	35 01	g NOP
42	CHS	61	+		
33	STO	31	f		
09	9	01	R \rightarrow P		
23	LBL	34 03	RCL 3		

R₁	Re [s ₁₁]	R₄	Re [s ₂₂]	R₇	temporary
R₂	temporary	R₅	Im [s ₁₁]	R₈	Im [s ₂₂]
R₃	temporary	R₆	temporary	R₉	temporary, ± 1

POWER SUPPLY RECTIFIER CIRCUITS

CODE	KEYS	CODE	KEYS	CODE	KEYS
31	f	01	1	23	LBL
43	REG	33 08	STO 8	01	1
84	R/S	35 08	g R↓	34 06	RCL 6
23	LBL	84	R/S	02	2
11	A	23	LBL	71	x
35	g	14	D	35	g
83	DSZ	34 01	RCL 1	02	π
33 02	STO 2	02	2	81	\div
84	R/S	31	f	35 00	g LST X
33 01	STO 1	09	\sqrt{x}	34 03	RCL 3
84	R/S	71	x	71	x
23	LBL	33 06	STO 6	41	\uparrow
12	B	34 06	RCL 6	71	x
35	g	34 05	RCL 5	01	1
83	DSZ	03	3	02	2
33 04	STO 4	35 23	g x=y	34 02	RCL 2
84	R/S	22	GTO	71	x
33 03	STO 3	01	1	71	x
84	R/S	35 08	g R↓	34 07	RCL 7
23	LBL	81	\div	71	x
13	C	34 02	RCL 2	81	\div
33 05	STO 5	34 03	RCL 3	23	LBL
34 04	RCL 4	81	\div	02	2
06	6	34 04	RCL 4	35	g
81	\div	81	\div	83	DSZ
35	g	33	STO	35 01	g NOP
02	π	09	9	84	R/S
81	\div	02	2	35 07	g $x \rightarrow y$
34 03	RCL 3	81	\div	84	R/S
81	\div	51	—	35 01	g NOP
33 07	STO 7	34	RCL		
34 05	RCL 5	09	9		
84	R/S	22	GTO		
23	LBL	02	2		
15	E				

R₁	V _i	R₄	R	R₇	L _{MIN} or L
R₂	C	R₅	Type	R₈	DSZ
R₃	f	R₆	$\sqrt{2} V_i$	R₉	Temporary

CONTROLLED RECTIFIER CIRCUITS

CODE	KEYS	CODE	KEYS	CODE	KEYS
35	g	83	DSZ	35 00	g LST X
41	DEG	33 03	STO 3	51	-
31	f	24	RTN	35	g
43	REG	34 01	RCL 1	02	π
84	R/S	14	D	33 08	STO 8
23	LBL	71	x	02	2
11	A	24	RTN	71	x
35	g	23	LBL	61	+
83	DSZ	14	D	35 00	g LST X
33 01	STO 1	01	1	02	2
24	RTN	34 02	RCL 2	71	x
34 03	RCL 3	31	f	35 07	g \leftrightarrow y
14	D	05	COS	81	\div
81	\div	61	+	31	f
24	RTN	35	g	09	\sqrt{x}
23	LBL	02	π	81	\div
12	B	81	\div	35	g
35	g	24	RTN	41	DEG
83	DSZ	23	LBL	84	R/S
33 02	STO 2	15	E	09	9
24	RTN	01	1	00	0
34 03	RCL 3	33 08	STO 8	34 02	RCL 2
34 01	RCL 1	84	R/S	35 22	g \leqslant y
81	\div	34 01	RCL 1	35 01	g NOP
35	g	34 02	RCL 2	35 07	g \leftrightarrow y
02	π	35	g	31	f
71	x	02	π	04	SIN
01	1	71	x	34 01	RCL 1
51	-	09	9	71	x
32	f^{-1}	00	0	84	R/S
05	COS	81	\div		
24	RTN	35	g		
23	LBL	42	RAD		
13	C	31	f		
35	g	04	SIN		

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	CODE	KEYS	CODE	KEYS
31	f	07	7	35 01	g NOP
42	STK	03	3	35 01	g NOP
31	f	61	+	35 01	g NOP
43	REG	71	x	35 01	g NOP
84	R/S	34 02	RCL 2	35 01	g NOP
23	LBL	81	÷	35 01	g NOP
11	A	08	8	35 01	g NOP
33 01	STO 1	83	•	35 01	g NOP
84	R/S	06	6	35 01	g NOP
23	LBL	02	2	35 01	g NOP
12	B	05	5	35 01	g NOP
33 02	STO 2	43	EEX	35 01	g NOP
84	R/S	42	CHS	35 01	g NOP
23	LBL	05	5	35 01	g NOP
13	C	71	x	35 01	g NOP
33 03	STO 3	84	R/S	35 01	g NOP
84	R/S	35 01	g NOP	35 01	g NOP
23	LBL	35 01	g NOP	35 01	g NOP
14	D	35 01	g NOP	35 01	g NOP
33 04	STO 4	35 01	g NOP	35 01	g NOP
84	R/S	35 01	g NOP	35 01	g NOP
23	LBL	35 01	g NOP	35 01	g NOP
15	E	35 01	g NOP	35 01	g NOP
34 04	RCL 4	35 01	g NOP	35 01	g NOP
83	•	35 01	g NOP	35 01	g NOP
06	6	35 01	g NOP	35 01	g NOP
51	—	35 01	g NOP	35 01	g NOP
34 03	RCL 3	35 01	g NOP	35 01	g NOP
81	÷	35 01	g NOP	35 01	g NOP
34 02	RCL 2	35 01	g NOP	35 01	g NOP
81	÷	35 01	g NOP	35 01	g NOP
31	f	35 01	g NOP	35 01	g NOP
07	LN	35 01	g NOP	35 01	g NOP
34 01	RCL 1	35 01	g NOP	35 01	g NOP
02	2	35 01	g NOP		

R₁	T	R₄	V _C	R₇
R₂	I	R₅		R₈
R₃	R ₁	R₆		R₉

TRANSISTOR BIAS

CODE	KEYS	CODE	KEYS	CODE	KEYS
21	DSP	22	GTO	34 06	RCL 6
02	2	00	0	61	+
31	f	34 06	RCL 6	71	x
42	STK	34 01	RCL 1	22	GTO
23	LBL	81	÷	02	2
00	0	34 04	RCL 4	23	LBL
32	f^{-1}	71	x	15	E
51	SF 1	83	•	31	f
24	RTN	06	6	51	SF 1
84	R/S	51	–	84	R/S
23	LBL	34 05	RCL 5	23	LBL
11	A	71	x	01	1
32	f^{-1}	23	LBL	33 07	STO 7
61	TF 1	02	2	34 01	RCL 1
33 02	STO 2	34 05	RCL 5	34 02	RCL 2
22	GTO	01	1	71	x
01	1	61	+	34 01	RCL 1
35 07	$g \times \leftrightarrow y$	34 03	RCL 3	34 02	RCL 2
33 01	STO 1	71	x	61	+
22	GTO	34 06	RCL 6	00	0
01	1	61	+	35 23	$g \times = y$
23	LBL	81	÷	34 07	RCL 7
12	B	22	GTO	22	GTO
32	f^{-1}	00	0	00	0
61	TF 1	23	LBL	61	+
33 04	STO 4	14	D	61	+
84	R/S	34 05	RCL 5	81	÷
33 03	STO 3	31	f	33 06	STO 6
22	GTO	61	TF 1	34 07	RCL 7
01	1	22	GTO	35 01	g NOP
23	LBL	02	2		
13	C	13	C		
31	f	34 05	RCL 5		
61	TF 1	81	÷		
33 05	STO 5	34 03	RCL 3		

R₁	R_1	R₄	V_C	R₇	Used
R₂	R_2	R₅	β	R₈	
R₃	R_3	R₆	R_B	R₉	Used

JFET BIAS AND TRANSCONDUCTANCE

CODE	KEYS	CODE	KEYS	CODE	KEYS
21	DSP	21	DSP	23	LBL
02	2	03	3	02	2
44	CLX	24	RTN	15	E
84	R/S	23	LBL	13	C
23	LBL	01	1	34 01	RCL 1
11	A	15	E	81	÷
35	g	13	C	01	1
83	DSZ	34 01	RCL 1	51	—
33 02	STO 2	81	÷	02	2
84	R/S	01	1	71	x
33 01	STO 1	51	—	34 02	RCL 2
84	R/S	02	2	71	x
23	LBL	71	x	34 01	RCL 1
12	B	34 02	RCL 2	81	÷
35	g	71	x	34 04	RCL 4
83	DSZ	34 01	RCL 1	35 07	g x↔y
33 04	STO 4	81	÷	81	÷
84	R/S	21	DSP	35	g
33 03	STO 3	03	3	06	ABS
84	R/S	84	R/S	21	DSP
23	LBL	23	LBL	83	•
13	C	14	D	00	0
35	g	35	g	84	R/S
83	DSZ	83	DSZ	23	LBL
22	GTO	22	GTO	15	E
01	1	02	2	01	1
01	1	15	E	33 08	STO 8
34 03	RCL 3	13	C	35 08	g R↓
34 02	RCL 2	34 03	RCL 3	24	RTN
81	÷	81	÷	35 01	g NOP
31	f	42	CHS		
09	√x	21	DSP		
51	—	83	•		
34 01	RCL 1	00	0		
71	x	84	R/S		

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

PHASE-LOCKED LOOP

CODE	KEYS	CODE	KEYS	CODE	KEYS
00	0	71	x	24	RTN
33 08	STO 8	34 01	RCL 1	23	LBL
84	R/S	35	g	15	E
23	LBL	04	\sqrt{x}	35	g
11	A	61	+	83	DSZ
35	g	71	x	22	GTO
83	DSZ	33 06	STO 6	01	1
33 02	STO 2	35	g	34 05	RCL 5
84	R/S	83	DSZ	34 06	RCL 6
33 01	STO 1	24	RTN	41	\uparrow
84	R/S	35 01	g NOP	41	\uparrow
23	LBL	34 05	RCL 5	04	4
12	B	24	RTN	71	x
35	g	23	LBL	35	g
83	DSZ	14	D	04	\sqrt{x}
33 04	STO 4	34 01	RCL 1	61	+
84	R/S	34 02	RCL 2	71	x
33 03	STO 3	34 04	RCL 4	02	2
84	R/S	71	x	81	\div
23	LBL	81	\div	84	R/S
13	C	31	f	23	LBL
34 01	RCL 1	09	\sqrt{x}	01	1
34 02	RCL 2	33 05	STO 5	01	1
34 03	RCL 3	02	2	33 08	STO 8
61	+	81	\div	35 08	g R↓
34 04	RCL 4	34 04	RCL 4	84	R/S
71	x	34 03	RCL 3	35 01	g NOP
81	\div	71	x	35 01	g NOP
31	f	71	x	35 01	g NOP
09	\sqrt{x}	33 06	STO 6	35 01	g NOP
33 05	STO 5	35	g		
02	2	83	DSZ		
81	\div	24	RTN		
34 03	RCL 3	35 01	g NOP		
34 04	RCL 4	34 05	RCL 5		

R₁	G	R₄	C	R₇	
R₂	R ₁	R₅	ω_n	R₈	DSZ
R₃	R ₂	R₆	ξ	R₉	

FOURIER SERIES

CODE	KEYS	CODE	KEYS	CODE	KEYS
35	g	02	2	24	RTN
42	RAD	15	E	23	LBL
31	f	33	STO	15	E
43	REG	61	+	44	CLX
33	STO	02	2	34 08	RCL 8
09	9	15	E	42	CHS
24	RTN	33	STO	35	g
23	LBL	61	+	83	DSZ
12	B	03	3	35 07	g $x \leftrightarrow y$
42	CHS	15	E	71	x
33 08	STO 8	33	STO	35 00	g LST X
01	1	61	+	35 07	g $x \leftrightarrow y$
33 07	STO 7	04	4	34	RCL
24	RTN	15	E	09	9
23	LBL	33	STO	35 08	g R↓
13	C	61	+	23	LBL
34	RCL	05	5	01	1
09	9	15	E	31	f
81	÷	33	STO	05	COS
35 07	g $x \leftrightarrow y$	61	+	35 09	g R↑
35 00	g LST X	06	6	33	STO
81	÷	23	LBL	09	9
02	2	02	2	44	CLX
71	x	06	6	61	+
35	g	31	f	35 09	g R↑
02	π	61	TF 1	71	x
71	x	44	CLX	02	2
41	↑	01	1	71	x
15	E	33	STO	24	RTN
33	STO	61	+	35 01	g NOP
61	+	08	8		
01	1	34 07	RCL 7		
31	f	01	1		
61	TF 1	61	+		
22	GTO	33 07	STO 7		

R₁	C ₁	R₄	C ₄	R₇	k
R₂	C ₂	R₅	C ₅	R₈	J, j
R₃	C ₃	R₆	C ₆	R₉	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

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	CODE	KEYS	CODE	KEYS
23	LBL	34 01	RCL 1	35 01	g NOP
11	A	71	x	35 01	g NOP
35	g	31	f	35 01	g NOP
83	DSZ	09	\sqrt{x}	35 01	g NOP
33 01	STO 1	84	R/S	35 01	g NOP
84	R/S	23	LBL	35 01	g NOP
03	3	13	C	35 01	g NOP
00	0	35	g	35 01	g NOP
34 03	RCL 3	83	DSZ	35 01	g NOP
51	-	33 03	STO 3	35 01	g NOP
01	1	84	R/S	35 01	g NOP
00	0	34 02	RCL 2	35 01	g NOP
81	\div	41	\uparrow	35 01	g NOP
32	f^{-1}	71	x	35 01	g NOP
08	LOG	34 01	RCL 1	35 01	g NOP
34 02	RCL 2	81	\div	35 01	g NOP
41	\uparrow	31	f	35 01	g NOP
71	x	08	LOG	35 01	g NOP
71	x	03	3	35 01	g NOP
84	R/S	61	+	35 01	g NOP
23	LBL	01	1	35 01	g NOP
12	B	00	0	35 01	g NOP
35	g	71	x	35 01	g NOP
83	DSZ	84	R/S	35 01	g NOP
33 02	STO 2	23	LBL	35 01	g NOP
84	R/S	15	E	35 01	g NOP
34 03	RCL 3	01	1	35 01	g NOP
03	3	33 08	STO 8	35 01	g NOP
00	0	84	R/S	35 01	g NOP
51	-	35 01	g NOP	35 01	g NOP
01	1	35 01	g NOP	35 01	g NOP
00	0	35 01	g NOP	35 01	g NOP
81	\div	35 01	g NOP	35 01	g NOP
32	f^{-1}	35 01	g NOP	35 01	g NOP
08	LOG	35 01	g NOP		

R₁	Z	R₄	R₇
R₂	V	R₅	R₈ DSZ
R₃	dBm	R₆	R₉

WIRE TABLES AI AND ANNEALED Cu

CODE	KEYS	CODE	KEYS	CODE	KEYS
23	LBL	83	.	03	3
11	A	00	0	71	x
21	DSP	00	0	24	RTN
83	.	00	0	23	LBL
00	0	09	9	14	D
33 01	STO 1	02	2	13	C
01	1	00	0	34 02	RCL 2
00	0	03	3	35 07	$g \times \overrightarrow{y}$
03	3	33 03	STO 3	41	\uparrow
07	7	34 01	RCL 1	71	x
01	1	24	RTN	81	\div
33 02	STO 2	23	LBL	24	RTN
83	.	13	C	23	LBL
00	0	21	DSP	15	E
00	0	03	3	13	C
03	3	83	.	41	\uparrow
00	0	04	4	71	x
02	2	06	6	34 03	RCL 3
06	6	41	\uparrow	71	x
09	9	41	\uparrow	24	RTN
33 03	STO 3	83	.	35 01	$g \text{ NOP}$
34 01	RCL 1	00	0	35 01	$g \text{ NOP}$
24	RTN	00	0	35 01	$g \text{ NOP}$
23	LBL	05	5	35 01	$g \text{ NOP}$
12	B	81	\div	35 01	$g \text{ NOP}$
21	DSP	34 01	RCL 1	35 01	$g \text{ NOP}$
83	.	03	3	35 01	$g \text{ NOP}$
00	0	61	+	35 01	$g \text{ NOP}$
33 01	STO 1	03	3	35 01	$g \text{ NOP}$
01	1	09	9	35 01	$g \text{ NOP}$
07	7	81	\div		
00	0	35	g		
00	0	05	y^x		
02	2	81	\div		
33 02	STO 2	43	EEX		

R₁	AWG	R₄	R₇
R₂	Resistivity	R₅	R₈
R₃	Density	R₆	R₉

HEAT SINKS

CODE	KEYS	CODE	KEYS	CODE	KEYS
21	DSP	00	0	83	.
04	4	35	g	08	8
31	f	83	DSZ	71	x
43	REG	22	GTO	03	3
84	R/S	01	1	02	2
23	LBL	33 05	STO 5	61	+
11	A	84	R/S	84	R/S
35	g	23	LBL	23	LBL
83	DSZ	01	1	02	2
33 02	STO 2	33 06	STO 6	34	RCL
84	R/S	34 05	RCL 5	09	9
33 01	STO 1	71	x	34 01	RCL 1
84	R/S	83	.	61	+
23	LBL	04	4	34 02	RCL 2
12	B	07	7	61	+
35	g	02	2	34 03	RCL 3
83	DSZ	42	CHS	71	x
33 04	STO 4	35	g	34 04	RCL 4
84	R/S	05	y ^x	61	+
33 03	STO 3	07	7	33 07	STO 7
84	R/S	08	8	84	R/S
23	LBL	83	.	23	LBL
13	C	05	5	15	E
00	0	09	9	01	1
35 07	g x↔y	71	x	33 08	STO 8
35 24	g x>y	33	STO	35 08	g R↓
22	GTO	09	9	84	R/S
00	0	84	R/S	35 01	g NOP
02	2	23	LBL	35 01	g NOP
83	.	14	D	35 01	g NOP
05	5	35	g		
04	4	83	DSZ		
42	CHS	22	GTO		
71	x	02	2		
23	LBL	01	1		

R₁	θ_{JC}	R₄	T _A	R₇	T _J
R₂	θ_{CS}	R₅	<i>l</i>	R₈	DSZ
R₃	P _d	R₆	h	R₉	θ_{SA}



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