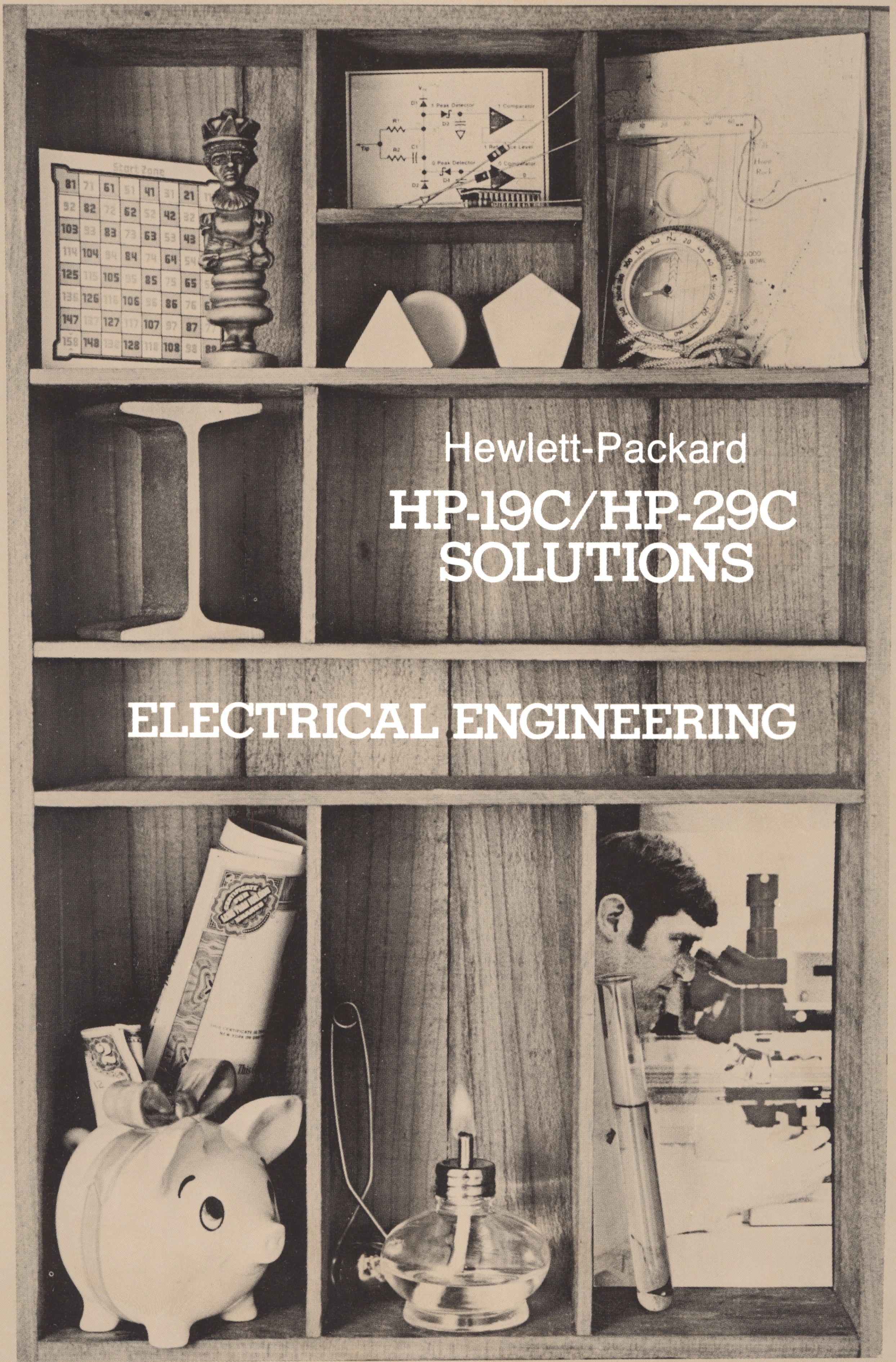


Hewlett-Packard

HP-19C/HP-29C SOLUTIONS

ELECTRICAL ENGINEERING

INTRODUCTION

This HP-19C/HP-29C Solutions book was written to help you get the most from your calculator. The programs were chosen to provide useful calculations for many of the common problems encountered.

They will provide you with immediate capabilities in your everyday calculations and you will find them useful as guides to programming techniques for writing your own customized software. The comments on each program listing describe the approach used to reach the solution and help you follow the programmer's logic as you become an expert on your HP calculator.

You will find general information on how to key in and run programs under "A Word about Program Usage" in the Applications book you received with your calculator.

We hope that this Solutions book will be a valuable tool in your work and would appreciate your comments about it.

TABLE OF CONTENTS

RESISTIVE/REACTIVE CIRCUIT CALCULATIONS

This program performs resonance calculations for R-L-C circuits, calculates the reactance of inductive and capacitive branches, the equivalent value of series capacitors or parallel resistors and inductors, and performs power calculations for resistive branches using straightforward manipulations of the following equations:

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

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

$$X_L = 2\pi fL$$

$$P = I^2R = E^2/R$$

$$\frac{A_1A_2}{A_1+A_2} = A_3$$

where

- f_r = resonant frequency in hertz
- L = inductance in henrys
- C = capacitance in farads
- X_C = capacitive reactance in Ω
- X_L = inductive reactance in Ω
- P = power in watts
- I = current in amps
- R = resistance in Ω
- E = voltage in volts
- A_1, A_2 = the values of two parallel resistors in ohms, two parallel inductors in henrys, or two series capacitors in farads
- A_3 = the resultant, equivalent resistance in ohms, inductance in henrys, or capacitance in farads

NOTE: Given a resistance or capacitance, A_1, the value of the circuit element required to produce a desired resultant resistance or capacitance may be calculated by entering A_1 as a negative value.

EXAMPLES:

1. $C = .01\mu F$, $L = 160\mu h$.
   Calculate f_r
2. $L = 2.5h$, $f_r = 60H_z$
   Calculate C and X_L at f_r
3. $E = 345v$, $R = 1.25M\Omega$
   Calculate P and I
4. $R_1 = 120\Omega$, $R_2 = 240\Omega$
   a. Find the equivalent resistance of these two resistors in parallel, R_3.
   b. Parallel R_3 with 50Ω.
   c. Find the resistance required for a resultant resistance of 25Ω.

<u>SOLUTION:</u>

```
 160.-06 ENT↑
 0.01-06 GSB1
125.82+03  ***    fr

 60.0000 ENT↑
  2.5000 GSB2
2.8145-06  ***    C

 60.0000 ENT↑
  2.5000 GSB4
942.46+00  ***    XL

345.0000 ENT↑
 1.25+06 GSB5
95.220-03  ***    P

 1.25+06 GSB7
276.00-06  ***    I

120.0000 ENT↑
240.0000 GSB9
80.000+00  ***    R3

 50.0000 GSB9
30.769+00  ***    4b
             CHS
 25.0000 GSB9
133.33+00  ***    4c
```

User Instructions

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1.	Key in the program and choose an appropriate display format				
2.	Calculate f_r	L	ENT		
		C	GSB	1	f_r
3.	Calculate L or C	f_r	ENT		
		C or L	GSB	2	L or C
	REACTANCE CALCULATIONS				
4.	Calculate X_C	f	ENT		
		C	GSB	3	X_C
5.	Calculate X_L	f	ENT		
		L	GSB	4	X_L
	POWER CALCULATIONS				
6a	Given E: Calculate P	E	ENT		
		R	GSB	5	P
6b	Given I: Calculate P	I	ENT		
		R	GSB	6	P
	Given P,R:				
7a	Calculate I	P	ENT		
		R	GSB	7	I
7b	Calculate E	P	ENT		
		R	GSB	8	E
	PARALLEL RESISTANCE/SERIES CAPACITANCE				
8.	Given two circuit elements, calculate resultant	A_1	ENT		
		A_2	GSB	9	A_3
9.	Given one circuit element and the desired	A_1	CHS	ENT	
	resultant value, calculate the value of the circuit element required.	A_3	GSB	9	A_2

Program Listings

01 *LBL1	
02 ×	
03 √X	
04 GTO2	
05 *LBL2	
06 X⇄Y	
07 GSB0	
08 X²	
09 X⇄Y	
10 ÷	
11 R/S	L or C
12 *LBL3	
13 ×	
14 GTO6	
15 *LBL4	
16 ×	
17 GSB0	
18 1/X	
19 R/S	X_L
20 *LBL5	
21 1/X	
22 *LBL6	
23 X⇄Y	
24 X²	
25 ×	
26 R/S	P
27 *LBL7	
28 1/X	
29 *LBL8	
30 ×	
31 √X	
32 R/S	I or E
33 *LBL0	
34 2	
35 ×	
36 Pi	
37 ×	
38 1/X	
39 RTN	f_r or X_C
40 *LBL9	
41 ×	
42 ENT↑	
43 ENT↑	
44 LSTX	
45 ÷	
46 LSTX	
47 +	
48 ÷	
49 R/S	A_3 or A_2

*** "Printx" may be inserted or used to replace "R/S".

REGISTERS					
0	1	2	3	4	5
6	7	8	9	.0	.1
.2	.3	.4	.5	16	17
18	19	20	21	22	23
24	25	26	27	28	29

IMPEDANCE OF A LADDER NETWORK

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

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

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

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

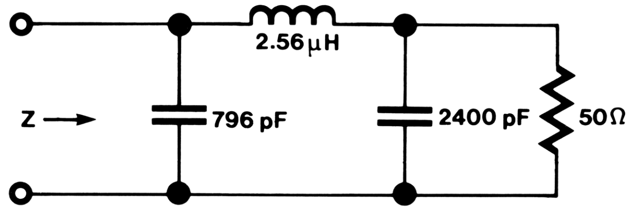
$$Y_{new} = \begin{cases} \left(\dfrac{1}{Y_{in}} + (R_s + j0)\right)^{-1} \\ \left(\dfrac{1}{Y_{in}} + (0 + j\,\omega\, L_s)\right)^{-1} \\ \left(\dfrac{1}{Y_{in}} + \left(0 - j\,\dfrac{1}{\omega C_s}\right)\right)^{-1} \end{cases}$$

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.

EXAMPLE:

f = 4 MHz



SOLUTION:

	FIX2	
4.+06	GSB1	
50.00	GSB3	$\|Z_{in}\|$
50.00	***	
	X⇄Y	
0.00	***	$\angle Z_{in}$
2400.-12	GSB5	
15.74	***	$\|Z_{in}\|$
	X⇄Y	
-71.66	***	$\angle Z_{in}$
2.56-06	GSB2	
	GSB5	
49.65	***	$\|Z_{in}\|$
	X⇄Y	
84.28	***	$\angle Z_{in}$
796.-12	GSB5	
497.69	***	$\|Z_{in}\|$
	X⇄Y	
8.98	***	$\angle Z_{in}$

User Instructions

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1.	Key in the program and choose an appropriate display format.				
2.	Initialize	f	GSB	1	W
3.	Input a parallel element:				
		R_p	GSB	3	$\|Z_{in}\|$
			x↔y		$\angle Z_{in}$
		C_p	GSB	5	$\|Z_{in}\|$
			x↔y		$\angle Z_{in}$
		L_p	GSB	4	$\|Z_{in}\|$
			x↔y		$\angle Z_{in}$
4a	For a series element:				
		R_s	GSB	2	
			GSB	3	$\|Z_{in}\|$
			x↔y		$\angle Z_{in}$
		C_s	GSB	2	
			GSB	4	$\|Z_{in}\|$
			x↔y		$\angle Z_{in}$
		L_s	GSB	2	
			GSB	5	$\|Z_{in}\|$
			x↔y		$\angle Z_{in}$
4b	For a parallel element: Go to step 3				
5.	Repeat step 4 until all elements are entered				

Program Listings

Step	Key	Comment
01	*LBL1	f
02	2	
03	×	
04	Pi	
05	×	Clear flag
06	CLRG	w
07	STO3	
08	R/S	
09	*LBL0	Z↔Y
10	R↓	
11	→P	
12	1/X	
13	X⇄Y	
14	CHS	
15	X⇄Y	
16	→R	
17	0	
18	RTN	R,C,L
19	*LBL2	Set flag (series)
20	STO0	
21	R/S	
22	*LBL3	
23	1/X	
24	RCL0	
25	X=0?	0,Y (parallel)
26	GTO8	
27	0	
28	GTO8	
29	*LBL4	0,Z (series)
30	RCL3	
31	×	
32	1/X	X_C or B_L
33	CHS	
34	0	
35	X⇄Y	
36	GTO8	
37	*LBL5	
38	RCL3	
39	×	X_L or B_C
40	0	
41	X⇄Y	
42	*LBL8	
43	STO7	
44	X⇄Y	
45	STO6	
46	RCL2	
47	RCL1	
48	RCL0	
49	X≠0?	

Step	Key	Comment
50	GSB0	Convert $Y_{in} \rightarrow Z_{in}$
51	R↓	
52	RCL6	
53	+	Add admittances or impedances
54	X⇄Y	
55	RCL7	
56	+	
57	X⇄Y	
58	RCL0	
59	X≠0?	
60	GSB0	
61	R↓	Convert $Z \rightarrow Y$
62	STO1	
63	X⇄Y	
64	STO2	
65	X⇄Y	
66	0	
67	GSB0	Convert $Y \rightarrow Z$
68	STO0	Clear flag
69	R↓	
70	→P	
71	R/S	*** $\lvert Z_{in} \rvert \angle Z_{in}$

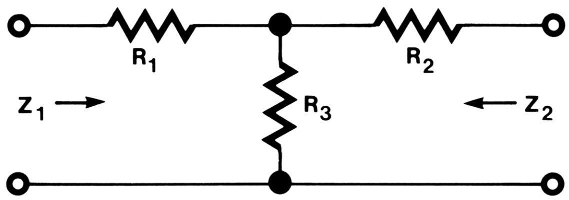
*** "Printx" may be inserted.

REGISTERS

0 flag	1 $Re[Y_{in}]$	2 $Im[Y_{in}]$	3 $\omega = 2\pi f$	4	5
6 used	7 used	8	9	.0	.1
.2	.3	.4	.5	16	17
18	19	20	21	22	23
24	25	26	27	28	29

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

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

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

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

<u>NOTE</u>: If the desired loss is less than the minimum loss R_2 will be negative.

<u>EXAMPLE</u>:

$Z_1 = 75\Omega$

$Z_2 = 50\Omega$

Loss = 6 dB

<u>SOLUTION</u>:

```
  75.0000 ENT↑
  50.0000 GSB1
   6.0000 GSB2
5.7195+00  ***    Min Loss
           R/S
43.344+00  ***    R1
           R/S
1.5715+00  ***    R2
           R/S
81.973+00  ***    R3
```

User Instructions

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1.	Key in the program				
2.	Enter impedances	Z_1, Ω	ENT		
		Z_2, Ω	GSB	1	
3.	Enter desired loss and run	Loss, dB	GSB	2	Min Loss,
	(If Min Loss > Desired Loss, enter a new Desired Loss)				db
4.	Outputs:		R/S		R_1, Ω
			R/S		R_2, Ω
			R/S		R_3, Ω

Program Listings

Step	Instruction	
01	*LBL1	
02	ENG4	
03	STO2	
04	X⇄Y	
05	STO1	
06	R/S	
07	*LBL2	
08	1	
09	0	
10	÷	
11	10ˣ	
12	STO7	N
13	×	
14	×	
15	√X	
16	2	
17	×	
18	RCL7	
19	1	
20	ST+7	
21	-	
22	STO8	
23	÷	
24	STO5	R_3
25	RCL1	
26	RCL7	
27	×	
28	RCL8	
29	÷	
30	RCL5	
31	-	
32	STO3	R_1
33	RCL2	
34	RCL7	
35	×	
36	RCL8	
37	÷	
38	RCL5	
39	-	
40	STO4	R_2
41	RCL1	
42	RCL2	
43	÷	
44	ENT↑	
45	√X	
46	X⇄Y	
47	1	
48	-	
49	√X	
50	+	
51	X²	
52	LOG	
53	1	
54	0	
55	×	
56	STO6	
57	R/S	*** Min Loss
58	RCL3	
59	R/S	*** R_1
60	RCL4	
61	R/S	*** R_2
62	RCL5	
63	R/S	*** R_3

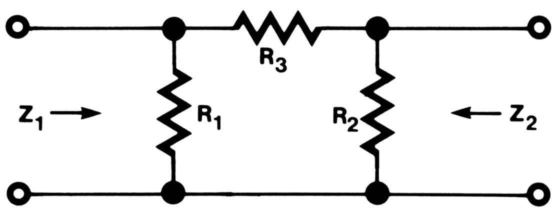
*** "Printx" may be inserted or used to replace "R/S".

REGISTERS

0	1 Z_1	2 Z_2	3 R_1	4 R_2	5 R_3
6 Min Loss	7 N, N+1	8 N-1	9	.0	1
.2	.3	.4	.5	16	17
18	19	20	21	22	23
24	25	26	27	28	29

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

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

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

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

EXAMPLE:

$Z_1 = 75\Omega$

$Z_2 = 50\Omega$

Loss = 6dB

SOLUTION:

```
  75.0000 ENT↑
  50.0000 GSB1
   6.0000 GSB2
5.7195+00  ***   Min Loss
           R/S
2.3862+03  ***   R1
           R/S
86.517+00  ***   R2
           R/S
45.747+00  ***   R3
```

User Instructions

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1.	Key in the program				
2.	Enter impedances	Z_1,	ENT		
		Z_2,	GSB	1	
3.	Enter Desired Loss and run	Loss, dB	GSB	2	Min Loss,
	(If Min Loss>Desired Loss, enter a new				dB
	Desired Loss)				
4.	Outputs:		R/S		R_1, Ω
			R/S		R_2, Ω
			R/S		R_3, Ω

Program Listings


```
01 *LBL1
02  ENG4
03  STO2
04   X<>Y
05  STO1
06   R/S
07 *LBL2
08    1
09    0
10    ÷
11   10^X
12  STO7          N
13    ÷
14    x
15   √X
16  RCL7
17    1
18  ST+7
19    -
20  ST÷7
21    2
22    ÷
23    x
24  STO5          R3
25   1/X
26  STO8
27  RCL7
28  RCL1
29    ÷
30  RCL8
31    -
32   1/X
33  STO3          R1
34  RCL7
35  RCL2
36    ÷
37  RCL8
38    -
39   1/X
40  STO4          R2
41  RCL1
42  RCL2
43    ÷
44   √X
45  LSTX
46    1
47    -
48   √X
49    +
50   X²
51   LOG
52    1
53    0
54    x
55  STO6
56   R/S          *** Min Loss
57  RCL3
58   R/S          *** R1
59  RCL4
60   R/S          *** R2
61  RCL5
62   R/S          *** R3
```

REGISTERS

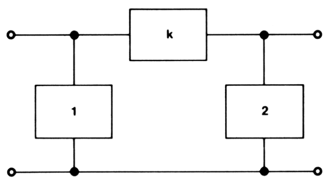
0	1 Z_1	2 Z_2	3 R_1	4 R_2	5 R_3
6 Min Loss	7 N, $\frac{N+1}{N-1}$	8 $1/R_3$	9	.0	.1
.2	.3	.4	.5	16	17
18	19	20	21	22	23
24	25	26	27	28	29

WYE-DELTA OR DELTA-WYE TRANSFORMATION

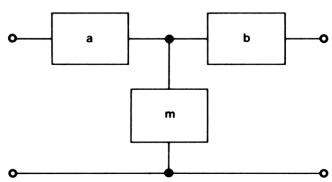
This program performs the Y-Δ transform for circuits consisting of resistors, inductors, or capacitors*.

The Y-Δ transforms for one-of-a-kind elements are summarized below.

"Δ" Topology



"Y" Topology



For Capacitors:

Y→Δ
$$C_1 = \frac{Ca\ Cm}{\Sigma C}$$
$$C_2 = \frac{Cb\ Cm}{\Sigma C}$$
$$C_k = \frac{Ca\ Cb}{\Sigma C}$$
$$\Sigma C = Ca+Cb+Cm$$

Δ→Y
$$Ca = \frac{\Sigma CC}{C_2}$$
$$Cb = \frac{\Sigma CC}{C_1}$$
$$Cm = \frac{\Sigma CC}{C_k}$$
$$\Sigma CC = C_1C_2+C_2C_k+C_1C_k$$

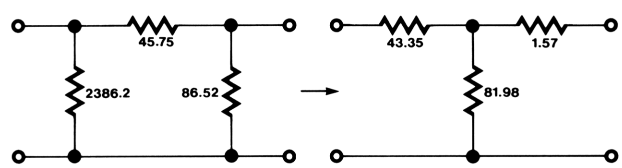
* Adapted from HP-67/97 Users' Library program #00404D by Bruce Murdock.

For Inductors: (and Resistors, replace L's by R's)

Y→Δ
$$L_1 = \frac{\Sigma LL}{Lb}$$
$$L_2 = \frac{\Sigma LL}{La}$$
$$L_k = \frac{\Sigma LL}{Lm}$$
$$\Sigma LL = La\ Lb+Lb\ Lm+La\ Lm$$

Δ→Y
$$La = \frac{L_1L_k}{\Sigma L}$$
$$Lb = \frac{L_2L_k}{\Sigma L}$$
$$Lm = \frac{L_1L_2}{\Sigma L}$$
$$\Sigma L = L_1+L_2+L_k$$

EXAMPLE:



SOLUTION:

2386.20	ENT↑	1
45.75	ENT↑	k
86.52	GSB1	2
	GSB2	
	GSB4	a
43.35	***	
	R/S	m
81.98	***	
	R/S	b
1.57	***	

User Instructions

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1.	Key in the program and choose an appropriate display format				
2.	Enter elements for Y or Δ	a or 1	ENT		
		m or k	ENT		
		b or 2	GSB	1	0
3a	For inductors or resistors		GSB	2	1
3b	For capacitors, go to step 4				
4a	For Y→Δ		GSB	3	element 1
					element k
					element 2
4b	For Δ→Y		GSB	4	element a
					element m
					element b

Program Listings

```
*LBL1
STO3
R↓
STO2
R↓
STO1          Clear flag to
0             indicate capacitors
STO0
R/S
*LBL2
1             Set flag to indi-
STO0          cate inductors or
R/S           resistors
*LBL3         Y→Δ for capacitors
RCL0            or
X>0?          Δ→Y for resistors
GTO0          and inductors
*LBL9
RCL1
RCL2
+
RCL3
+
STO4          Σ
RCL1
RCL2
x
RCL4
÷
STO5
RCL1
RCL3
x
RCL4
÷
STO6
RCL2
RCL3
x
RCL4
÷
STO7
GTO8
*LBL4         Δ→Y for capacitors
RCL0            or
X>0?          Y→Δ for resistors
GTO9          and inductors
*LBL0
RCL1
RCL2
x
RCL2
RCL3
x
+
RCL1
RCL3
x
+
STO4          ΣΣ
RCL3
÷
STO5
RCL4
RCL2
÷
STO6
RCL4
RCL1
÷
STO7
*LBL8         Output
RCL5          *** 1 or a
R/S
RCL6
R/S           *** k or m
RCL7
R/S           *** 2 or b
```

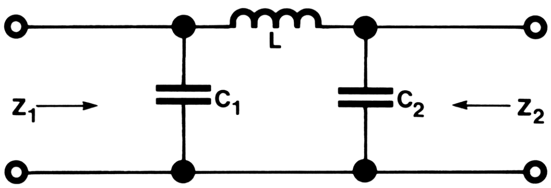
*** "Printx" may replace "R/S".

REGISTERS

0 flag	1 1 or a	2 k or m	3 2 or b	4 Σ or ΣΣ	5 1 or a
6 k or m	7 2 or b	8	9	.0	.1
.2	.3	.4	.5	16	17
18	19	20	21	22	23
24	25	26	27	28	29

PI NETWORK IMPEDANCE MATCHING

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



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

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

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

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

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

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

EXAMPLE:

$Z_1 = 500\Omega$

$Z_2 = 50\Omega$

$f = 4MHz$

$Q = 10$

SOLUTION:

```
500.0000 ENT↑
 50.0000 ENT↑
   4.+06 ENT↑
 10.0000 GSB1
795.77-12  ***  C1
           R/S
2.4006-09  ***  C2
           R/S
2.5639-06  ***  L
```

User Instructions

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1.	Key in the program				
2.	Enter variables and run				
		Z_1,Ω	ENT		
		Z_2,Ω	ENT		
		f,Hz	ENT		
		Q	GSB	1	C_1,F
			R/S		C_2,F
			R/S		L,H

Program Listings


```
01 *LBL1
02  STO4
03    R↓
04  STO3
05    R↓
06  STO2
07    R↓
08  STO1
09  ENG4
10  RCL4
11  RCL1
12    ÷
13  GSB0
14  RCL2
15  RCL1
16    ÷
17  RCL4
18    X²
19    1
20    +
21  STO5
22    x
23    1
24    -
25   √X
26  RCL2
27    ÷          1/XC2
28  STO6
29  GSB0
30  RCL2
31  RCL6
32    x
33  RCL4
34    ÷
35    1
36    +
37  RCL4
38  RCL1
39    x
40  RCL5
41    ÷
42    x
43 *LBL0
44    Pi
45    2
46    x
47  RCL3
48    x
49    ÷
50   R/S
51   RTN
52   R/S
```

***C_1,C_2,L

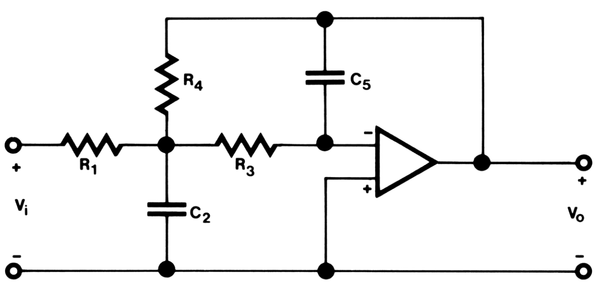
REGISTERS

0	1 Z_1	2 Z_2	3 f	4 Q	5 Q^2+1
6 $1/X_{C2}$	7	8	9	.0	.1
.2	.3	.4	.5	16	17
18	19	20	21	22	23
24	25	26	27	28	29

ACTIVE FILTER DESIGN

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

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



Given

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

f_c, the cutoff frequency in hertz

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

$C = C_5$, farads

the program computes values for R_1, C_2, R_3 and R_4 according to the following equations:

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

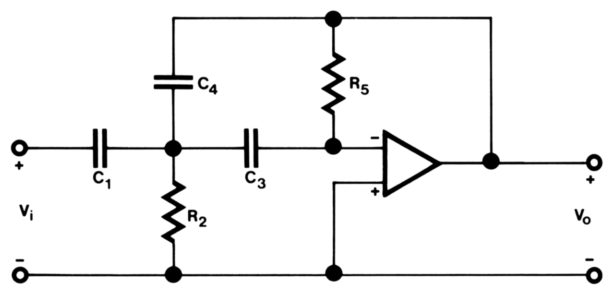
$$R_1 = \frac{R_4}{G}$$

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

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

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

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



Given

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

f_c

α

$C = C_1 = C_3$, farads

this program solves the following equations for the values of R_2, R_5, and C_4.[2]

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

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

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

NOTES: 1. If α is not specified, $\alpha=\sqrt{2}$ is used, giving component values for a Butterworth filter.

2. These equations derive from the fact that both transfer functions have the form

$$H(s)=\frac{-G\,\omega_c^2}{s^2+2\omega_c s+\omega_c^2},$$

EXAMPLES:

1. Compute R_4, R_1, R_3, and C_2 for a low-pass filter with

   f_c = 100 Hz

   C = .1μF

   G = 10

   $\alpha = \sqrt{2}$

2. Compute R_2, C_4, and R_5 for a high-pass filter with

   f_c = .1 Hz

   C = 10μF

   G = 1

   $\alpha = \sqrt{2}$

SOLUTIONS:

	FIX2	
100.00	ENT↑	
0.1-06	ENT↑	
10.00	ENT↑	
2.00	√X	
	GSB1	
11253.95	***	R_4
	R/S	
1125.40	***	R_1
	R/S	
1023.09	***	R_3
	R/S	
2.20-06	***	C_2

0.10	ENT↑	
10.-06	ENT↑	
1.00	ENT↑	
2.00	√X	
	GSB2	
75026.36	***	R_2
	R/S	
1.00-05	***	C_4
	R/S	
337618.62	***	R_5

User Instructions

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1.	Key in the program and choose an appropriate display format				
2.	Enter design parameters	f_c, Hz	ENT		
		C, F	ENT		
		G	ENT		
		α			
3a	For a low-pass filter		GSB	1	R_4, Ω
			R/S		R_1, Ω
	or		R/S		R_3, Ω
			R/S		C_2, F
3b	For high-pass filter		GSB	2	R_2, Ω
			R/S		C_4, F
			R/s		R_5, Ω

Program Listings

```
01 *LBL1
02  STO7
03    R↓
04    R↓
05  STO6
06    x
07    Pi
08    x
09    4
10    x
11    ÷
12   R/S        *** R4
13  STO4
14   X⇄Y
15    ÷
16   R/S        *** R1
17  RCL4
18  LSTX
19    1
20    +
21    ÷
22   R/S        *** R3
23  LSTX
24  RCL6
25    x
26    4
27    x
28  RCL7
29    X²
30    ÷
31   R/S        *** C2
32 *LBL2
33  STO7
34    R↓
35  STO5
36    R↓
37  STO6
38    x
39    2
40    x
41    Pi
42    x
43  STx7
44  RCL5
45   1/X
46    2         (2 G+1)/G
47    +
48  ST÷7
49    x
50    ÷
51   R/S        *** R2
52  RCL6
53  RCL5
54  ST÷7
55    ÷
56   R/S        *** C4
57  RCL7
58   1/X
59   R/S        *** R5
```

REGISTERS

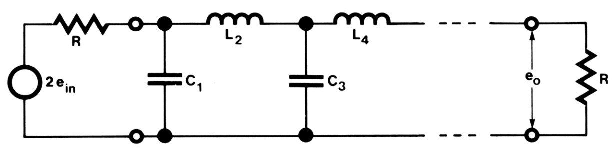
0	1	2	3	4 R4	5 G
6 C	7 α	8 2 G+1	9	.0	.1
.2	.3	.4	.5	16	17
18	19	20	21	22	23
24	25	26	27	28	29

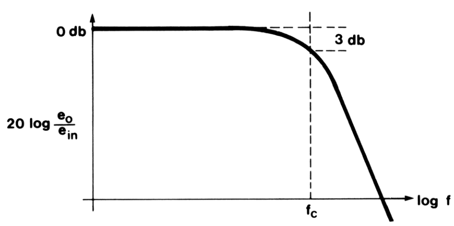
BUTTERWORTH FILTER DESIGN

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

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

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





NOTE: $n \le 10$

EXAMPLE:

$n = 6$

$R = 50\Omega$

$f_c = 10$ MHz

SOLUTION:

6.0000	ENT↑	
50.0000	ENT↑	
10.+06	GSB1	
1.0000+00	***	i
	R/S	
164.77-12	***	C_1
	R/S	
2.0000+00	***	
	R/S	
1.1254-06	***	L_2
	R/S	
3.0000+00	***	
	R/S	
614.93-12	***	C_3
	R/S	
4.0000+00	***	
	R/S	
1.5373-06	***	L_4
	R/S	
5.0000+00	***	
	R/S	
450.16-12	***	C_5
	R/S	
6.0000+00	***	
	R/S	
411.92-09	***	L_6

User Instructions

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1.	Key in the program				
2.	Enter filter parameters	n	ENT		
		R,Ω	ENT		
		f_c,Hz			
3.	Run		GSB	1	i=1
			R/S		Ci,F
			R/S		i=2
			R/S		Li,H
			•		
			•		
			•		
			R/S		i=n
			R/S		L_n or C_n
			R/S		0

Program Listings

Step	Key	Comment
01	*LBL1	
02	RAD	
03	ENG4	
04	ST.3	
05	R↓	
06	ST.2	
07	R↓	
08	ST.1	
09	STO0	
10	*LBL0	
11	RCL0	
12	2	
13	x	
14	1	
15	-	
16	Pi	
17	x	
18	RC.1	
19	2	
20	x	
21	÷	Sine argument
22	STOi	
23	DSZ	
24	GTO0	
25	Pi	
26	RC.3	
27	RC.2	
28	x	
29	x	
30	1/X	$1/\pi f_c R$
31	ST.5	
32	2	
33	CHS	
34	ST.4	
35	1	
36	STO0	
37	*LBL9	
38	RC.1	
39	RCL0	
40	X>Y?	i>n?
41	GTO8	end
42	R/S	*** i
43	RCLi	
44	SIN	
45	RC.5	
46	x	
47	R/S	*** C_i or L_i
48	RC.2	R
49	RC.4	± 2
50	CHS	
51	ST.4	
52	Y^x	
53	Sx.5	
54	ISZ	
55	GTO9	
56	*LBL8	
57	0	
58	R/S	

*** "Printx" may replace "R/S".

REGISTERS

0 i	1	2	3	4	5
6	7	8	9	.0	.1 n
.2 R	.3 f_c	.4 ±2	.5 $1/\pi f_c R$ or $R/\pi f_c$	16	17
18	19	20	21	22	23
24	25	26	27	28	29

STANDARD RESISTANCE VALUES*

For a given tolerance, a "step size" is computed which is used to determine two values, one below and one above the non-standard resistance. These are converted by a subroutine to standard values, and the geometric mean of the latter is calculated. If the given non-standard value is below the mean then the lower standard value is selected; otherwise the larger value is selected.

<u>NOTE</u>: Incorrect results will be obtained for tolerances other than 5%, 10%, or 20%.

<u>REFERENCE</u>: International Telephone and Telegraph Corp. <u>Reference Data for Radio Engineers</u>, fourth edition, p. 78.

<u>EXAMPLES</u>: Find the closest standard values for the following:

R_1 = 432Ω

R_2 = 114 KΩ

R_3 = 3.5 MΩ

<u>SOLUTION</u>:

ENG 4	
5.0000 GSB1	5%
432.0000 GSB2	
430.00+00 ***	R'_1
114.+03 GSB2	
110.00+03 ***	R'_2
3.5+06 GSB2	
3.6000+06 ***	R'_3
10.0000 GSB1	10%
432.0000 GSB2	
470.00+00 ***	R'_1
114.+03 GSB2	
120.00+03 ***	R'_2
3.5+06 GSB2	
3.3000+06 ***	R'_3
20.0000 GSB1	20%
432.0000 GSB2	
470.00+00 ***	R'_1
114.+03 GSB2	
100.00+03 ***	R'_2
3.5+06 GSB2	
3.3000+06 ***	R'_3

* Adapted from HP-65 Users' Library program #00915A by Jacob Jacobs.

User Instructions

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1.	Key in the program and choose an appropriate display format				
2.	Enter tolerance (5,10, or 20)	T%	GSB	1	
3.	Enter non-standard resistor size and compute nearest standard value	R,Ω	GSB	2	R¦Ω
4.	Change tolerance at any time by going to step 2				

Program Listings

Step	Comment
01 *LBL1	
02 1	
03 2	
04 0	
05 ÷	
06 10ˣ	
07 STO2	$10^{tol/120}$
08 R/S	
09 *LBL2	
10 LOG	
11 ENT↑	
12 INT	
13 STO4	
14 -	
15 1	
16 +	
17 10ˣ	
18 STO3	
19 1	
20 ST-4	
21 1	
22 0	
23 STO5	
24 *LBL0	
25 RCL3	
26 RCL5	
27 X>Y?	This step > Normal R?
28 GTO9	
29 RCL2	
30 ×	
31 STO5	
32 GTO0	
33 *LBL9	
34 GSB8	
35 STO7	This step
36 RCL5	
37 RCL2	
38 ÷	
39 GSB8	
40 STO6	Last step
41 RCL7	
42 ×	
43 √X	√(This step)*(Last step)
44 RCL3	
45 X≤Y?	
46 GSB7	
47 RCL7	
48 RCL4	
49 10ˣ	
50 ×	10 EXP R_7
51 R/S	*** R
52 *LBL8	Finds standard R value from multiple of step size
53 .	
54 5	
55 +	
56 INT	Round up
57 STO6	
58 2	
59 6	
60 X>Y?	
61 GTO6	
62 4	
63 7	
64 RCL6	
65 X>Y?	
66 GTO3	26<R<47 then add 1
67 1	
68 +	
69 RTN	
70 *LBL3	
71 8	
72 3	
73 RCL6	
74 X≠Y?	
75 RTN	
76 9	
77 2	
78 RTN	
79 *LBL7	
80 RCL6	
81 STO7	
82 RTN	
83 *LBL6	
84 RCL6	
85 RTN	
86 R/S	

*** "Printx" may be inserted.

REGISTERS

0	1	2 Step size	3 Normal R	4 Exp of R	5 This step
6 Temp	7 Temp	8	9	.0	.1
.2	.3	.4	.5	16	17
18	19	20	21	22	23
24	25	26	27	28	29

SMITH CHART CONVERSIONS

This program allows conversion among standing wave ratio, reflection coefficient, and return.

The parameters

σ = voltage standing wave ration

SWR = standing wave ratio expressed in decibels

ρ = reflection coefficient

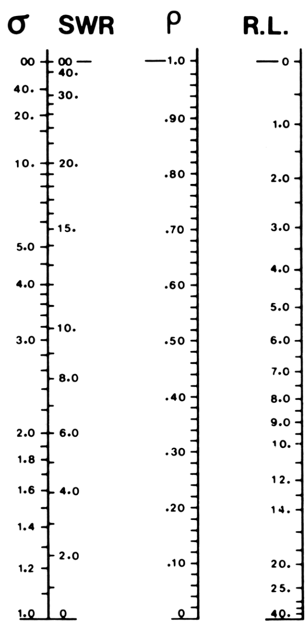
R.L. = return loss

are related as follows:

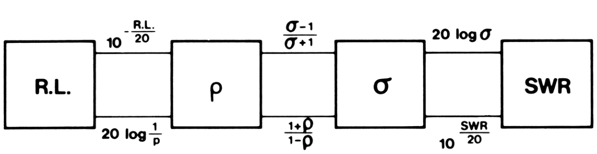
$$SWR = 20 \log \sigma$$

$$R.L. = 20 \log \frac{1}{\rho}$$

$$\sigma = \frac{1 + \rho}{1 - \rho}$$



These relationships are perhaps more clearly seen in this sketch:



The program also converts between impedance and reflection coefficient using the following relationships:

$$\Gamma = \rho \angle \phi = \frac{\frac{\mathbf{Z}}{Z_0} - 1}{\frac{\mathbf{Z}}{Z_0} + 1}$$

and

$$\mathbf{Z} = Z \angle \theta = Z_0 \frac{1 + \Gamma}{1 - \Gamma}$$

where

$\mathbf{\Gamma}$ = complex reflection coefficient

$\rho = |\mathbf{\Gamma}|$

$\phi = \angle\mathbf{\Gamma}$

$\mathbf{Z}$ = impedance

$Z = |\mathbf{Z}|$

$\theta = \angle\mathbf{Z}$

Z_0= characteristic impedance

<u>EXAMPLES</u>:

1. Convert a 6 dB SWR to σ.
2. Convert a 7 dB return loss to SWR
3. A 50Ω system is terminated with an impedance of 62∠37°. What is the reflection coefficient?
4. A reflection coefficient of .5∠7°is observed in a 72Ω system. What is the impedance?

SOLUTIONS:

```
 6.00 GSB4
 2.00  ***   σ
 7.00 GSB3
      GSB6
      GSB2
 8.35  ***   SWR

50.00 STO1
37.00 ENT↑
62.00 GSB8
 0.35  ***   ρ
```

```
         R/S
 70.19   ***   ϕ

 72.00 STO1
  7.00 ENT↑
  0.50 GSB7
212.50   ***   Z
         R/S
  9.23   ***   θ
```

User Instructions

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1.	Key in the program and choose an appropriate display format				
2.	Convert among σ, SWR, ρ, and R.L. as desired.				
	σ→SWR	σ	GSB	2	SWR
	SWR→σ	SWR	GSB	4	σ
	σ→ρ	σ	GSB	5	ρ
	ρ→σ	ρ	GSB	6	σ
	ρ→R.L.	ρ	GSB	1	R.L.
	R.L.→ρ	R.L.	GSB	3	ρ
3.	Store characteristic impedance	Z_o	STO	1	
4.	Convert between Z and Γ as desired.				
	Z→Γ	θ	ENT		
		Z	GSB	8	ρ
			R/S		ϕ
		ϕ	ENT		
	Γ→Z	ρ	GSB	7	Z
			R/S		θ

Program Listings

Step	Key	Comment
01	*LBL1	ρ→R.L.
02	1/X	
03	*LBL2	σ→SWR
04	LOG	
05	2	
06	0	
07	x	
08	R/S	*** R.L. or SWR
09	*LBL3	R.L.→ρ
10	CHS	
11	*LBL4	SWR →σ
12	2	
13	0	
14	÷	
15	10^x	
16	R/S	*** ρ or σ
17	*LBL5	σ → ρ
18	1/X	
19	CHS	
20	*LBL6	
21	1	
22	X⇄Y	
23	+	
24	1	
25	LSTX	
26	-	
27	÷	
28	R/S	*** ρ or σ
29	*LBL7	Γ → Z
30	1	
31	STO5	
32	R↓	
33	GSB0	
34	RCL1	
35	CHS	
36	x	
37	→R	Reverse ∠
38	→P	
39	R/S	*** Z
40	X⇄Y	
41	R/S	*** θ
42	*LBL8	Z → Γ
43	RCL1	
44	CHS	
45	STO5	
46	R↓	
47	GSB0	
48	R/S	
49	X⇄Y	*** ρ
50	R/S	*** φ
51	*LBL0	||∠
52	→R	R_e Im
53	STO4	
54	X⇄Y	
55	STO3	
56	X⇄Y	
57	RCL5	
58	ST-4	Add in rectangular
59	+	form
60	→P	|1| ∠ 1
61	STO2	
62	R↓	
63	RCL3	
64	RCL4	
65	→P	|2| ∠ 2
66	ST÷2	Divide in polar
67	R↓	form
68	-	∠ '
69	RCL2	|| '
70	RTN	

REGISTERS

0	1 Z_0	2 |1|, ||'	3 Im	4 Re,Re-k	5 k
6	7	8	9	.0	.1
.2	.3	.4	.5	16	17
18	19	20	21	22	23
24	25	26	27	28	29

NOTES

NOTES

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