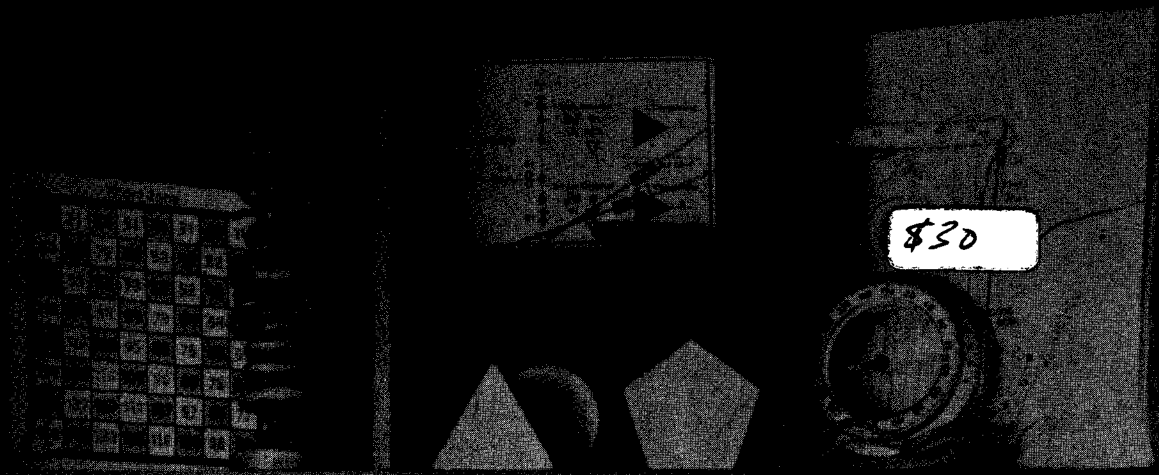
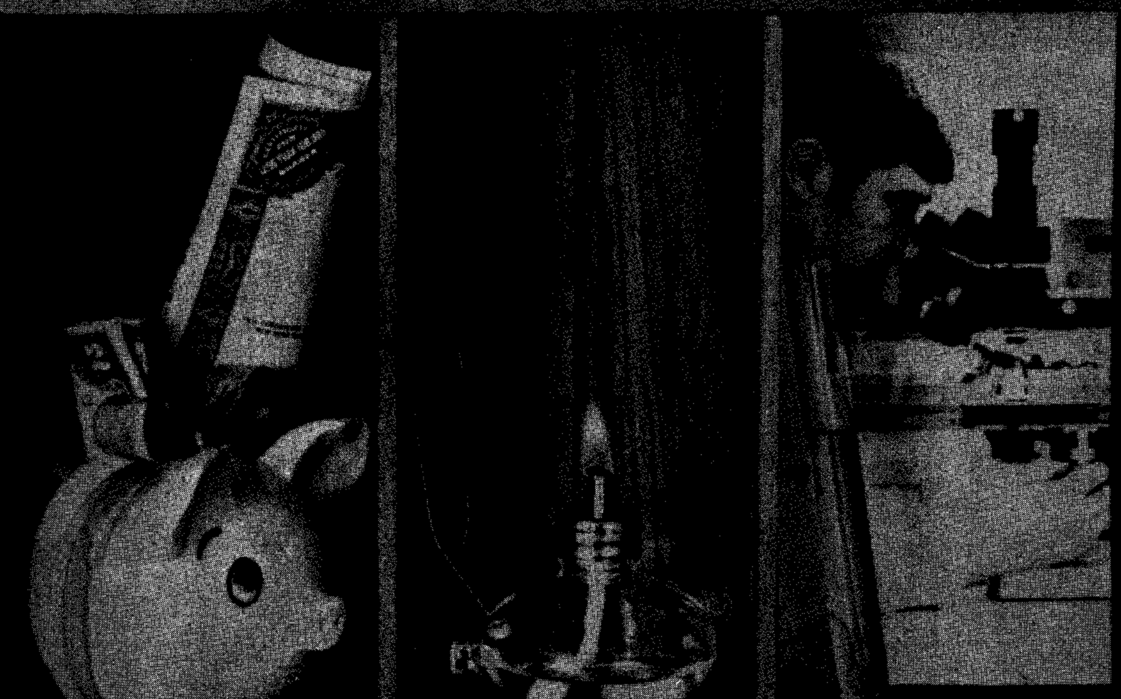


$30

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 = .01μF, L = 160μh.
   Calculate f_r
2. L = 2.5h, f_r = 60H_z
   Calculate C and X_L at f_r
3. E = 345v, R = 1.25MΩ
   Calculate P and I
4. R_1= 120Ω, R_2 = 240Ω
   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.

SOLUTION:

```
  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
942.48+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 GSB3
80.000+00  ***    R3

  50.0000 GSB3
30.769+00  ***    4b
              CHS
  25.0000 GSB3
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	A_3	GSB	9	A_2
	circuit element required.				

Program Listings

01 *LBL1	
02 ×	
03 √X	
04 GTO0	
05 *LBL2	
06 X⇄Y	
07 GSB0	
08 X²	
09 X⇄Y	
10 ÷	
11 R/S	L or C
12 *LBL3	
13 ×	
14 GTO0	
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

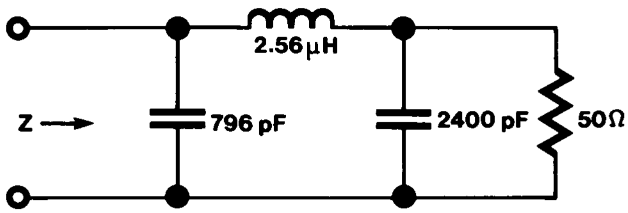
$$Y_{new} = \begin{cases} \left(\dfrac{1}{Y_{in}} + (R_s + j0)\right)^{-1} \\ \left(\dfrac{1}{Y_{in}} + (0 + j\,\omega L_s)\right)^{-1} \\ \left(\dfrac{1}{Y_{in}} + \left(0 - j\,\dfrac{1}{\omega C_s}\right)\right)^{-1} \end{cases}$$

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   |Zin|
  50.00    ***
           X⇄Y
   0.00    ***    ∠Zin
2400.-12   GSB5
  15.74    ***    |Zin|
           X⇄Y
 -71.66    ***    ∠Zin
 2.56-06   GSB2
           GSB5
  49.65    ***    |Zin|
           X⇄Y
  84.28    ***    ∠Zin
 796.-12   GSB5
 497.69    ***    |Zin|
           X⇄Y
   8.98    ***    ∠Zin
```

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	Comment	Step	Comment
01 *LBL1	f	50 GSB0	Convert $Y_{in} \to Z_{in}$
02 2		51 R↓	
03 x		52 RCL6	Add admittances
04 Pi		53 +	or impedances
05 x	Clear flag	54 X⇄Y	
06 CLRG	w	55 RCL7	
07 STO3		56 +	
08 R/S		57 X⇄Y	
09 *LBL0	Z↔Y	58 RCL0	
10 R↓		59 X≠0?	
11 →P		60 GSB0	
12 1/X		61 R↓	Convert Z→Y
13 X⇄Y		62 STO1	
14 CHS		63 X⇄Y	
15 X⇄Y		64 STO2	
16 →R		65 X⇄Y	
17 0		66 0	
18 RTN	R,C,L	67 GSB0	Convert Y→Z
19 *LBL2	Set flag (series)	68 STO0	Clear flag
20 STO0		69 R↓	
21 R/S		70 →P	
22 *LBL3		71 R/S	*** $\lvert Z_{in}\rvert \angle Z_{in}$
23 1/X			
24 RCL0			
25 X=0?			
26 GTO8	0,Y (parallel)		
27 0			
28 GTO8			
29 *LBL4	0,Z (series)		
30 RCL3			
31 x			
32 1/X	X_C or B_L		
33 CHS			
34 0			
35 X⇄Y			
36 GTO8			
37 *LBL5			
38 RCL3			
39 x	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?			

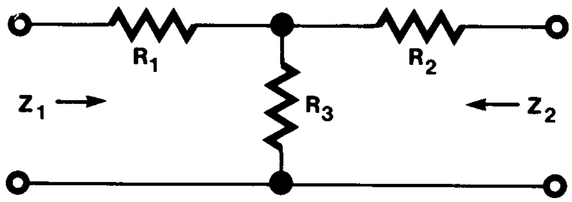
*** "Printx" may be inserted.

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, db
	(If Min Loss > Desired Loss, enter a new 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     ×
15    √X
16     2
17     ×
18  RCL7
19     1
20  ST+7
21     -
22  STO8
23     ÷
24  STO5          R3
25  RCL1
26  RCL7
27     ×
28  RCL8
29     ÷
30  RCL5
31     -
32  STO3          R1
33  RCL2
34  RCL7
35     ×
36  RCL8
37     ÷
38  RCL5
39     -
40  STO4          R2
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          *** R1
60  RCL4
61   R/S          *** R2
62  RCL5
63   R/S          *** R3
```

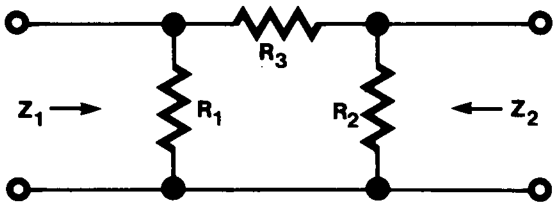
*** "Printx" may be inserted or used to replace "R/S".

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

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

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

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

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

Step	Key	Comment
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	R_3
25	1/X	
26	STO8	
27	RCL7	
28	RCL1	
29	÷	
30	RCL8	
31	-	
32	1/X	
33	STO3	R_1
34	RCL7	
35	RCL2	
36	÷	
37	RCL8	
38	-	
39	1/X	
40	STO4	R_2
41	RCL1	
42	RCL2	
43	÷	
44	√X	
45	LSTX	
46	1	
47	-	
48	√X	
49	+	
50	X^2	
51	LOG	
52	1	
53	0	
54	x	
55	STO6	
56	R/S	*** Min Loss
57	RCL3	
58	R/S	*** R_1
59	RCL4	
60	R/S	*** R_2
61	RCL5	
62	R/S	*** R_3

REGISTERS

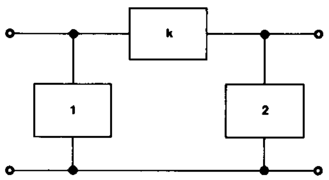
0	1 Z_1	2 Z_2	3 R_1	4 R_2	5 R_3
6 Min Loss	7 N, $\frac{N+1}{N-1}$	8 $1/R_3$	9	.0	.1
.2	.3	.4	.5	16	17
18	19	20	21	22	23
24	25	26	27	28	29

WYE-DELTA OR DELTA-WYE TRANSFORMATION

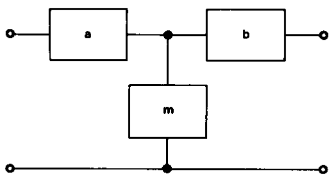
This program performs the Y-Δ transform for circuits consisting of resistors, inductors, or capacitors*.

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

"Δ" Topology



"Y" Topology



<u>For Capacitors</u>:

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.

<u>For Inductors</u>: (and Resistors,replace L's by R's)

Y→Δ $$L_1 = \frac{\Sigma LL}{Lb}$$

$$L_2 = \frac{\Sigma LL}{La}$$

$$L_k = \frac{\Sigma LL}{Lm}$$

$$\Sigma LL = La\ Lb+Lb\ Lm+La\ Lm$$

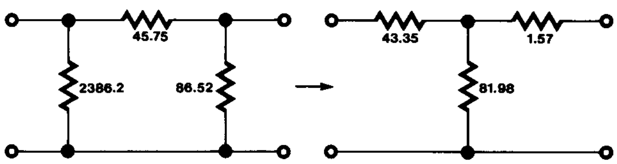
Δ→Y $$La = \frac{L_1L_k}{\Sigma L}$$

$$Lb = \frac{L_2L_k}{\Sigma L}$$

$$Lm = \frac{L_1L_2}{\Sigma L}$$

$$\Sigma L = L_1+L_2+L_k$$

<u>EXAMPLE</u>:



<u>SOLUTION</u>:

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

Step	Key	Comment
01	*LBL1	
02	STO3	
03	R↓	
04	STO2	
05	R↓	
06	STO1	
07	0	Clear flag to
08	STO0	indicate capacitors
09	R/S	
10	*LBL2	
11	1	
12	STO0	Set flag to indi- cate inductors or
13	R/S	resistors
14	*LBL3	Y→Δ for capacitors
15	RCL0	or
16	X>0?	Δ→Y for resistors
17	GTO0	and inductors
18	*LBL9	
19	RCL1	
20	RCL2	
21	+	
22	RCL3	
23	+	
24	STO4	Σ
25	RCL1	
26	RCL2	
27	x	
28	RCL4	
29	÷	
30	STO5	
31	RCL1	
32	RCL3	
33	x	
34	RCL4	
35	÷	
36	STO6	
37	RCL2	
38	RCL3	
39	x	
40	RCL4	
41	÷	
42	STO7	
43	GTO8	
44	*LBL4	Δ→Y for capacitors
45	RCL0	or
46	X>0?	Y→Δ for resistors
47	GTO9	and inductors
48	*LBL0	
49	RCL1	
50	RCL2	
51	x	
52	RCL2	
53	RCL3	
54	x	
55	+	
56	RCL1	
57	RCL3	
58	x	
59	+	
60	STO4	ΣΣ
61	RCL3	
62	÷	
63	STO5	
64	RCL4	
65	RCL2	
66	÷	
67	STO6	
68	RCL4	
69	RCL1	
70	÷	
71	STO7	
72	*LBL8	Output
73	RCL5	*** l or a
74	R/S	
75	RCL6	
76	R/S	*** k or m
77	RCL7	
78	R/S	*** 2 or b

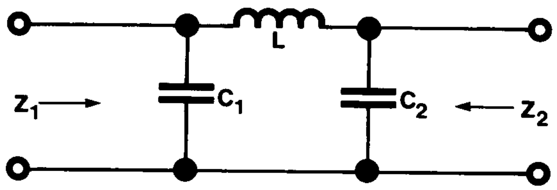
*** "Printx" may replace "R/S".

REGISTERS

0 flag	1 l or a	2 k or m	3 2 or b	4 Σ or ΣΣ	5 l 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:

$Z_1 = 500\Omega$

$Z_2 = 50\Omega$

$f = 4\text{MHz}$

$Q = 10$

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

```
*LBL1
STO4
R↓
STO3
R↓
STO2
R↓
STO1
ENG4
RCL4
RCL1
÷
GSB0
RCL2
RCL1
÷
RCL4
X²
1
+
STO5
x
1
-
√X
RCL2
÷
STO6
GSB0
RCL2
RCL6
x
RCL4
÷
1
+
RCL4
RCL1
x
RCL5
÷
x
*LBL0
Pi
2
x
RCL3
x
÷
R/S
RTN
R/S
```

$1/X_{C2}$

$***C_1, C_2, L$

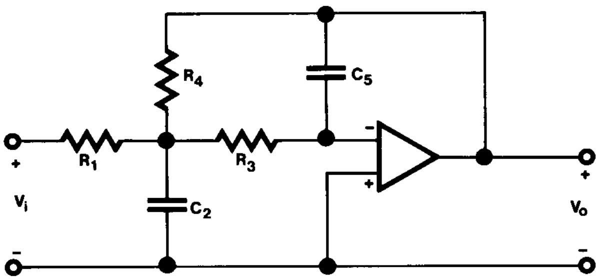
REGISTERS

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

$$\frac{V_o}{V_i}(s) = \frac{-\dfrac{1}{R_1R_3C_2C_5}}{s^2 + \dfrac{s}{C_2}\left(\dfrac{1}{R_1}+\dfrac{1}{R_3}+\dfrac{1}{R_4}\right) + \dfrac{1}{R_3R_4C_2C_5}}$$



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:

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

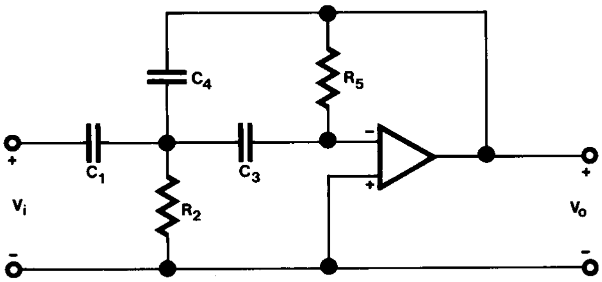
$$R_1 = \frac{R_4}{G}$$

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

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

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

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



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  ***   R4
           R/S
  1125.40  ***   R1
           R/S
  1023.09  ***   R3
           R/S
  2.20-06  ***   C2
```

```
     0.10 ENT↑
   10.-06 ENT↑
     1.00 ENT↑
     2.00   √X
          GSB2
 75026.36  ***   R2
           R/S
  1.00-05  ***   C4
           R/S
337618.62  ***   R5
```

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
13  STO4        *** R4
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
47     +        (2 G+1)/G
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

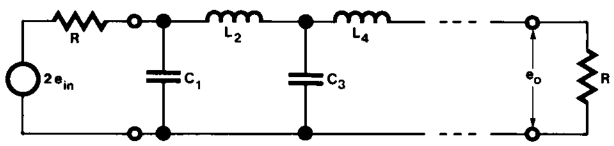
0	1	2	3	4 R4	5 G
6 C	7 α	8 2 G+1	9	.0	.1
.2	.3	.4	.5	16	17
18	19	20	21	22	23
24	25	26	27	28	29

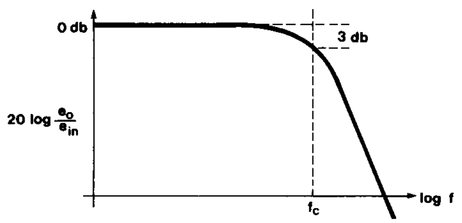
BUTTERWORTH FILTER DESIGN

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

```
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/πfcR
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      *** Ci or Li
48  RC.2      R
49  RC.4      ± 2
50   CHS
51  ST.4
52    Y^X
53  S×.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:

$R_1 = 432\Omega$

$R_2 = 114\ K\Omega$

$R_3 = 3.5\ M\Omega$

<u>SOLUTION</u>:

```
               ENG4
     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      R'2
   120.00+03  ***

    3.5+06  GSB2       R'3
  3.7000+06  ***

    20.0000  GSB1      20%
   432.0000  GSB2      R'1
   470.00+00  ***

    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	Key	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	$\sqrt{(\text{This step})*(\text{Last step})}$
44	RCL3	
45	X≤Y?	
46	GSB7	
47	RCL7	
48	RCL4	
49	10ˣ	
50	×	10 EXP R_7
51	R/S	
52	*LBL8	*** R
53	.	Finds standard R value from multiple of step size
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	
67	1	26<R<47 then add 1
68	+	
69	RTN	
70	*LBL3	
71	8	
72	3	
73	RCL6	
74	X≠Y?	
75	RTN	
76	8	
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

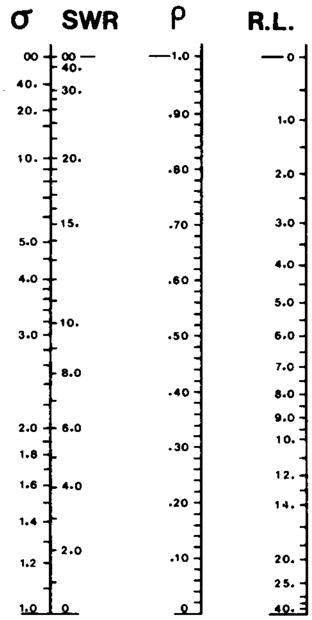
R.L. = return loss

are related as follows:

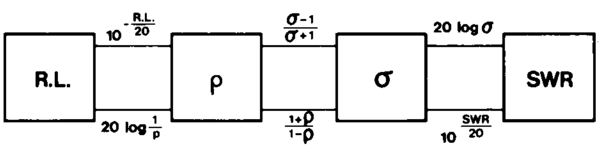
$$SWR = 20 \log \sigma$$

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

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



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

EXAMPLES:

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_0	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	Reverse ∠
37	→R	
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	*** ρ
49	X⇄Y	
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 form
59	+	
60	→P	|1| ∠ 1
61	STO2	
62	R↓	
63	RCL3	
64	RCL4	
65	→P	|2| ∠ 2
66	ST÷2	Divide in polar form
67	R↓	
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

In the Hewlett-Packard tradition of supporting HP programmable calculators with quality software, the following titles have been carefully selected to offer useful solutions to many of the most often encountered problems in your field of interest. These ready-made programs are provided with convenient instructions that will allow flexibility of use and efficient operation. We hope that these Solutions books will save your valuable time. They provide you with a tool that will multiply the power of your HP-19C or HP-29C many times over in the months or years ahead.

Mathematics Solutions
Statistics Solutions
Financial Solutions
Electrical Engineering Solutions
Surveying Solutions
Games
Navigational Solutions
Civil Engineering Solutions
Mechanical Engineering Solutions
Student Engineering Solutions