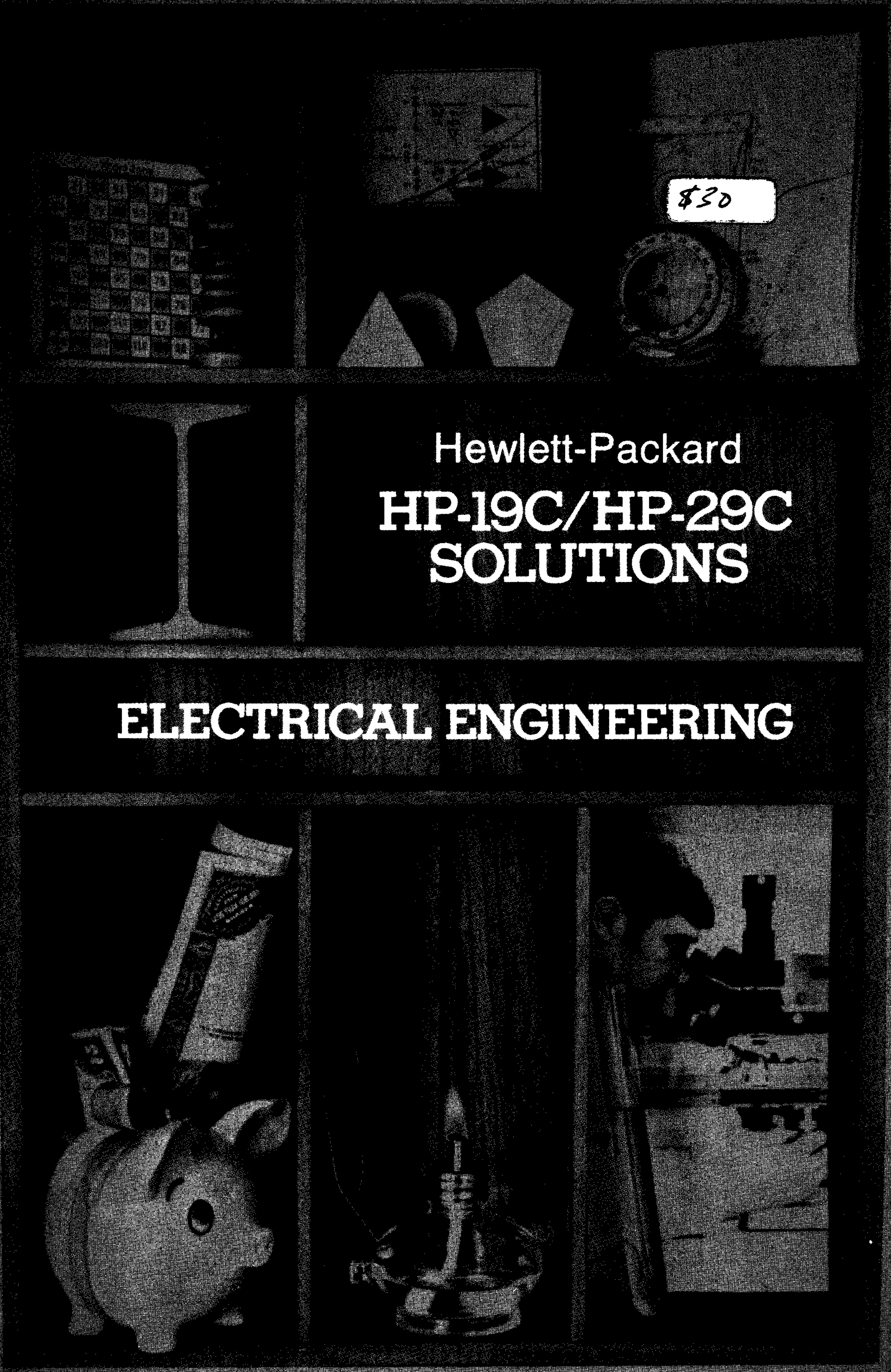

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Hewlett-Packard

# 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, $f_r$ = 60$H_z$
   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  ***   f_r

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

  60.0000 ENT↑
   2.5000 GSB4
942.48+00  ***   X_L

 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  ***   R_3

  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. | | | | |
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# Program Listings

| | |
|---|---|
| 01 *LBL1 | |
| 02 x | |
| 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 x | |
| 14 GTO0 | |
| 15 *LBL4 | |
| 16 x | |
| 17 GSB0 | |
| 18 1/X | |
| 19 R/S | $X_L$ |
| 20 *LBL5 | |
| 21 1/X | |
| 22 *LBL6 | |
| 23 X⇄Y | |
| 24 X² | |
| 25 x | |
| 26 R/S | P |
| 27 *LBL7 | |
| 28 1/X | |
| 29 *LBL8 | |
| 30 x | |
| 31 √X | |
| 32 R/S | I or E |
| 33 *LBL0 | |
| 34 2 | |
| 35 x | |
| 36 Pi | |
| 37 x | |
| 38 1/X | |
| 39 RTN | $f_r$ or $X_C$ |
| 40 *LBL9 | |
| 41 x | |
| 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

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

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

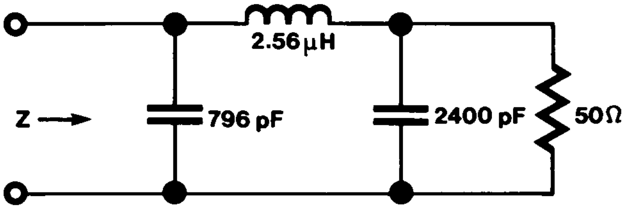
$$Y_{new} = \begin{cases} \left(\frac{1}{Y_{in}} + (R_s + j0)\right)^{-1} \\ \left(\frac{1}{Y_{in}} + (0 + j\,\omega\,L_s)\right)^{-1} \\ \left(\frac{1}{Y_{in}} + \left(0 - j\,\frac{1}{\omega\,C_s}\right)\right)^{-1} \end{cases}$$

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.

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
    0.98      ***    ∠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:<br>Go to step 3 | | | | |
| 5. | Repeat step 4 until all elements are entered | | | | |

# Program Listings

| | | | | | |
|---|---|---|---|---|---|
| 01 | *LBL1 | f | 50 | GSB0 | Convert $Y_{in} \rightarrow Z_{in}$ |
| 02 | 2 | | 51 | R↓ | |
| 03 | x | | 52 | RCL6 | |
| 04 | Pi | | 53 | + | Add admittances or impedances |
| 05 | x | Clear flag | 54 | X⇄Y | |
| 06 | CLRG | W | 55 | RCL7 | |
| 07 | ST03 | | 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 | ST01 | |
| 14 | CHS | | 63 | X⇄Y | |
| 15 | X⇄Y | | 64 | ST02 | |
| 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 | ST00 | Clear flag |
| 20 | ST00 | | 69 | R↓ | |
| 21 | R/S | | 70 | →P | |
| 22 | *LBL3 | | 71 | R/S | |
| 23 | 1/X | | | | *** $\lvert Z_{in} \rvert \angle Z_{in}$ |
| 24 | RCL0 | | | | |
| 25 | X=0? | | | | |
| 26 | GT08 | O,Y (parallel) | | | |
| 27 | 0 | | | | |
| 28 | GT08 | | | | |
| 29 | *LBL4 | O,Z (series) | | | |
| 30 | RCL3 | | | | |
| 31 | x | | | | |
| 32 | 1/X | $X_C$ or $B_L$ | | | |
| 33 | CHS | | | | |
| 34 | 0 | | | | |
| 35 | X⇄Y | | | | |
| 36 | GT08 | | | | |
| 37 | *LBL5 | | | | |
| 38 | RCL3 | | | | |
| 39 | x | $X_L$ or $B_C$ | | | |
| 40 | 0 | | | | |
| 41 | X⇄Y | | | | |
| 42 | *LBL8 | | | | |
| 43 | ST07 | | | | |
| 44 | X⇄Y | | | | |
| 45 | ST06 | | | | |
| 46 | RCL2 | | | | |
| 47 | RCL1 | | | | |
| 48 | RCL0 | | | | |
| 49 | X≠0? | | | | |

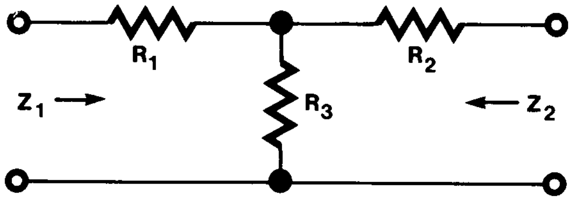
*** "Printx" may be inserted.

**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   10ˣ
12  STO7          N
13     x
14     x
15    √X
16     2
17     x
18  RCL7
19     1
20  ST+7
21     -
22  STO8
23     ÷
24  STO5          R3
25  RCL1
26  RCL7
27     x
28  RCL8
29     ÷
30  RCL5
31     -
32  STO3          R1
33  RCL2
34  RCL7
35     x
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     x
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
```

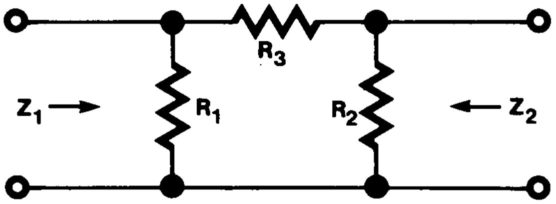
*** "Printx" may be inserted or used to replace "R/S".

**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 |
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# 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   X^2
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
```

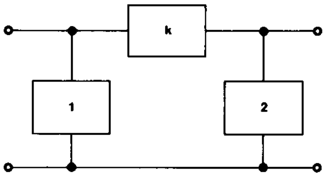
| REGISTERS | | | | | |
|---|---|---|---|---|---|
| 0 | 1 $Z_1$ | 2 $Z_2$ | 3 $R_1$ | 4 $R_2$ | 5 $R_3$ |
| 6 Min Loss | 7 N, $\frac{N+1}{N-1}$ | 8 $1/R_3$ | 9 | .0 | .1 |
| .2 | .3 | .4 | .5 | 16 | 17 |
| 18 | 19 | 20 | 21 | 22 | 23 |
| 24 | 25 | 26 | 27 | 28 | 29 |

# WYE-DELTA OR DELTA-WYE TRANSFORMATION

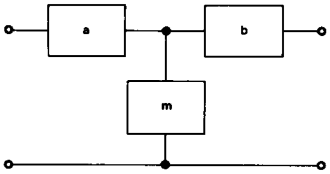
This program performs the Y-Δ transform for circuits consisting of resistors, inductors, or capacitors*.

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 $Ca = \frac{\Sigma CC}{C_2}$

$Cb = \frac{\Sigma CC}{C_1}$

$Cm = \frac{\Sigma CC}{C_k}$

$\Sigma CC = C_1C_2+C_2C_k+C_1C_k$

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

Y→Δ $L_1 = \frac{\Sigma LL}{Lb}$

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

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

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

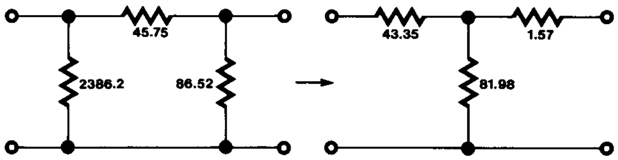
Δ→Y $La = \frac{L_1L_k}{\Sigma L}$

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

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

$\Sigma L = L_1+L_2+L_k$

**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  ***
```

---

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

# 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

```
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-
13   R/S       cate inductors or
14 *LBL3       resistors
15  RCL0       Y→Δ for capacitors
16  X>0?         or
17  GTO0       Δ→Y for resistors
18 *LBL9       and inductors
19  RCL1
20  RCL2
21     +
22  RCL3
23     +
24  STO4       Σ
25  RCL1
26  RCL2
27     ×
28  RCL4
29     ÷
30  STO5
31  RCL1
32  RCL3
33     ×
34  RCL4
35     ÷
36  STO6
37  RCL2
38  RCL3
39     ×
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     ×
52  RCL2
53  RCL3
54     ×
55     +
56  RCL1
57  RCL3
58     ×
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       *** 1 or a
74   R/S
75  RCL6
76   R/S       *** k or m
77  RCL7
78   R/S       *** 2 or b
```

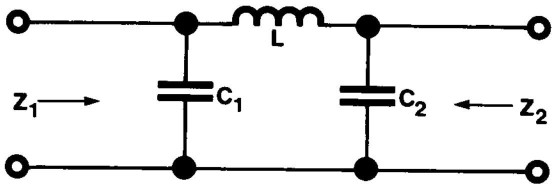
*** "Printx" may replace "R/S".

**REGISTERS**

| | | | | | |
|---|---|---|---|---|---|
| 0 flag | 1 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:

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

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

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

<u>NOTE</u>: $Z_1$, $Z_2$, 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

```
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/XC 2
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
```

***C1,C2,L

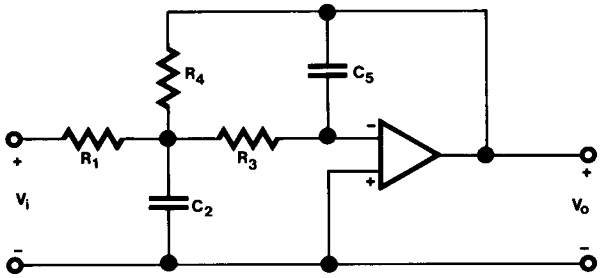
**REGISTERS**

| | | | | | |
|---|---|---|---|---|---|
| 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

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



Given

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

$f_c$, the cutoff frequency in hertz

$\alpha$, the desired "alpha peaking factor" ($\alpha = 2\zeta$, where $\zeta$ 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:

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

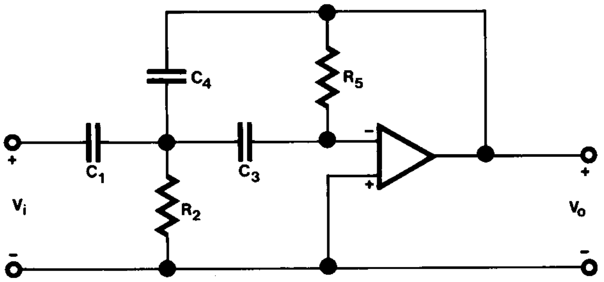
$$R_1 = \frac{R_4}{G}$$

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

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

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

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



Given

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

$f_c$

$\alpha$

$C = C_1 = C_3$, farads

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

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

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

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

NOTES: 1. If $\alpha$ 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
   $C = .1\mu F$
   $G = 10$
   $\alpha = \sqrt{2}$

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

   $f_c = .1$ Hz
   $C = 10\mu F$
   $G = 1$
   $\alpha = \sqrt{2}$

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 | | |
| | | $\alpha$ | | | |
| 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  ST×7
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**

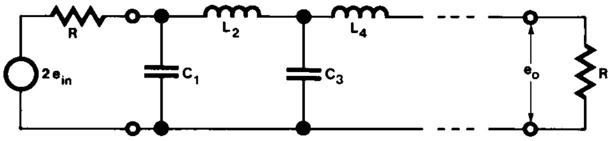
| | | | | | |
|---|---|---|---|---|---|
| 0 | 1 | 2 | 3 | 4 R4 | 5 G |
| 6 C | 7 α | 8 2 G+1 | 9 | .0 | .1 |
| .2 | .3 | .4 | .5 | 16 | 17 |
| 18 | 19 | 20 | 21 | 22 | 23 |
| 24 | 25 | 26 | 27 | 28 | 29 |

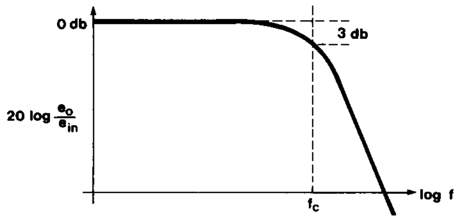
# BUTTERWORTH FILTER DESIGN

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: $n \leq 10$

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  ***     C1
              R/S
   2.0000+00  ***
              R/S
   1.1254-06  ***     L2
              R/S
   3.0000+00  ***
              R/S
   614.93-12  ***     C3
              R/S
   4.0000+00  ***
              R/S
   1.5373-06  ***     L4
              R/S
   5.0000+00  ***
              R/S
   450.16-12  ***     C5
              R/S
   6.0000+00  ***
              R/S
   411.92-09  ***     L6
```

# 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    Yˣ
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.

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

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

EXAMPLES: Find the closest standard values for the following:

$R_1 = 432\Omega$

$R_2 = 114\ K\Omega$

$R_3 = 3.5\ M\Omega$

SOLUTION:

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

      3.5+06 GSB2
   3.3000+06  ***     R'3

     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

```
01 *LBL1
02    1
03    2
04    0
05    ÷
06   10ˣ
07  ST02         10^tol/120
08   R/S
09 *LBL2
10   LOG
11  ENT↑
12   INT
13  ST04
14    -
15    1
16    +
17   10ˣ
18  ST03
19    1
20  ST-4
21    1
22    0
23  ST05
24 *LBL0
25  RCL3
26  RCL5
27  X>Y?         This step >
28  GT09         Normal R?
29  RCL2
30    x
31  ST05
32  GT00
33 *LBL9
34  GSB8
35  ST07         This step
36  RCL5
37  RCL2
38    ÷
39  GSB8
40  ST06         Last step
41  RCL7
42    x
43   √X          √(This step)*(Last
44  RCL3                      step)
45  X≤Y?
46  GSB7
47  RCL7
48  RCL4
49   10ˣ
```

```
50    x          10 EXP R7
51   R/S
52 *LBL8         *** R
53    .          Finds standard R
54    5          value from multiple
55    +          of step size
56   INT         Round up
57  ST06
58    2
59    6
60  X>Y?
61  GT06
62    4
63    7
64  RCL6
65  X>Y?
66  GT03
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  ST07
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

$\sigma$ = voltage standing wave ration

SWR = standing wave ratio expressed in decibels

$\rho$ = reflection coefficient

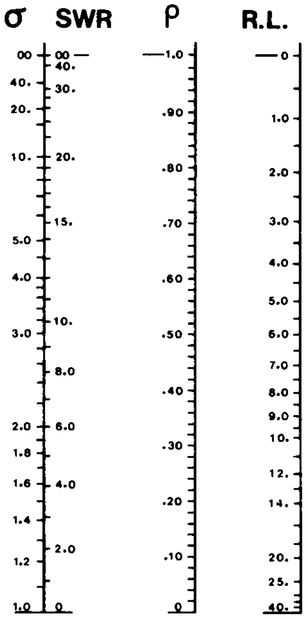
R.L. = return loss

are related as follows:

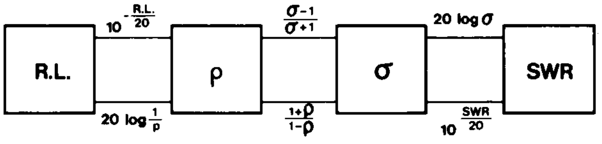
$$SWR = 20 \log \sigma$$

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

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



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 $\sigma$.
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

```
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   10ˣ
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  ST05
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  ST05
46    R↓
47  GSB0
48   R/S     *** ρ
49   X⇄Y
```

```
50   R/S     *** φ
51 *LBL0     ||∠
52    →R     Re Im
53  ST04
54   X⇄Y
55  ST03
56   X⇄Y
57  RCL5
58  ST-4     Add in rectangular
59     +     form
60    →P     |1| ∠ 1
61  ST02
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 |

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.

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