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TITLE  FOCAL VERSION OF RC ACTIVE FILTER

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SOURCE LANGUAGE  FOCAL

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Get something extra in filter design.

One BASIC program works for Butterworth and Chebyshev low-pass or high-pass RC-active circuits.

A time-shared computer program can do much more than free the engineer from the tedium of routine calculations in filter design. A single program in BASIC, derived from two fundamental equations, can be used to design Butterworth or Chebyshev filters, and either low-pass or high-pass versions of each.

The program, written in a language resembling simple English, determines the component values for N-pole filters. The design uses two-pole active sections with only Rs and Cs, no Ls, as the basic building blocks for higher-order filters. N-pole filters are created by cascading 2 two-pole sections. The R and C values in each section are selected to achieve the desired filter response.

Low-pass and high-pass sections are used in the filters shown in Fig. 1. Two capacitors, two resistors, and a unity-gain active element (Table 1) synthesize a complex pair of poles in the filter characteristic.

The filters described in this article are relatively inexpensive. They may be built as either discrete circuits or hybrid microcircuits and for either commercial or military use.

As hybrid microcircuit designs they possess the following advantages:

- Since they use no Ls, the resulting circuit is potentially smaller, more stable and has a higher Q at low frequencies than passive LC designs.
- The Cs can be chosen as standard values. Even though the Rs are non-standard, they are relatively easy to obtain.
- The frequency response can be adjusted by varying only the Rs. One filter can therefore be readily tuned into phase track with another, or trimmed to a given specification.
- In addition this design approach:
  - Uses a minimum of Rs and Cs to synthesize a two-pole function.
  - Requires only one unity-gain active element for each filter section.
  - Has low sensitivity to parameter changes.

Several of the many possible types of unity-gain active elements are shown in Table 1. The most important figure of merit for these voltage follower elements is their current gain $\beta$ because accurate filter synthesis requires a high input impedance and low output impedance. The equations used to calculate the filter component values assume a perfect active element, $\beta = \infty$. In practice the active elements are imperfect, especially at higher frequencies. Finite input impedance causes insertion loss and frequency response distortion; non-zero output impedance causes reduced stop-band attenuation; and variations from unity-gain change the resonant response of the section.

In view of these effects, it makes little sense to use 1% components to obtain a precise filter response, unless the input impedance of the active element is greater than $100R_s$ and the output impedance is less than $R_s/100$. It is also senseless to seek high stop-band attenuation in a frequency region where $\beta$ is significantly decreased.

Align sections by adjusting only resistors

Component values (Fig. 1) for the basic low-pass or high-pass filter sections are computed from the equations for the pole locations $(\sigma_i + j\omega_i)$ of the normalized functions:

- $\sigma_i = X_1 \cos (P_i)$
- $\omega_i = X_2 \sin (P_i)$.

1. Two-pole circuit sections serve as basic building blocks that are cascaded to form multiple-pole filters, low-pass section above, and high-pass section, below. The component values in each section are computed (to obtain either a Butterworth or Chebyshev response).

Russell Kincaid and Frederick Shirley, Technical Staff, Sanders Associates, Inc., Nashua, N.H.
1. In Butterworth filters, 1.574 and 1.571 depend on the passband ripple and number of poles for Chebyshev filters. The equations for the component values are shown in Table 1.

The overall filter design is not limited to a particular ratio of component values. Each clockwise section may therefore be independently designed by adjusting only the two resistor values. Three cases occur:

1. When the component values are fairly close to the design values, the filter alignment can be improved by nearly an order of magnitude by adjusting only one of the two resistors so that the desired response is obtained at the cut frequency. For thick-film or potted sections, the adjustment may be made externally by adding a series trim resistor either to $R_1$ of the low-pass circuit or to $R_2$ of the high-pass circuit (Fig. 1).

2. When both C values are out of tolerance by comparable large percentages, the section may be aligned by a two-step procedure. First, impedance-scale the section by off-adjusting the two resistors by the same percentage as the capacitors but in the opposite direction. This will improve the frequency response of the section. It will modify the section impedance level to accommodate the varied C values. Second, trim the response of the section at the cut frequency by adjusting one of the two resistors, as previously described. It is not advisable to trim both resistors since their effects on the frequency response are interdependent.

3. When the two C values are out of tolerance by different large percentages, the section response may best be improved by off-adjusting the Rs to recomputed values. The revised R values are obtained by rerunning the computer program with the actual C values inserted in place of the nominal ones. One of the two resistors may then be trimmed, if desired.

Sensitivity influences filter response

If the circuit component values are out of tolerance—due to initial selection error, environmental variation or aging—the filter response will vary from nominal. The variation of filter gain $\Delta G/G$ with component value variation $\Delta V/V$ is determined by the sensitivity factor $S$:

$$\Delta G/G = S \times \Delta V/V.$$

If $S = 1$, the equation shows that a component variation of 1% is equivalent to $20 \log_{10} (1-0.01)$, resulting in a gain variation of only 1 dB. For a large value of $S$—say, $S = 100$—the same equation shows that a component variation of 1% is equivalent to $100 \times (0.01) = 1$ (or a 100% increase). As the component varies by 1%, $G$
<table>
<thead>
<tr>
<th>Table 2. Filter component value formulas*</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Low-pass section</strong></td>
</tr>
<tr>
<td>Formula</td>
</tr>
<tr>
<td>$C_1 = C$</td>
</tr>
<tr>
<td>$C_2 = C/M$</td>
</tr>
<tr>
<td>$R_1 = \frac{-\frac{4}{C}}{2\pi F}$</td>
</tr>
<tr>
<td>$R_2 = \frac{-\frac{4}{C}}{2\pi F}$</td>
</tr>
<tr>
<td>$M &gt; R_1/\sqrt{\bar{Q}}$</td>
</tr>
</tbody>
</table>

*Resistor values are scaled to cut frequency $F_c$.

Increases 100%, or from $G$ to $2G$, a gain variation of 6 dB (20 log$_{10} 2 = 6$ dB).

Since a sensitivity factor is associated with each component, the worst-case variation for the complete section occurs when each component has a maximum error in an additive direction.

The sensitivity factors for components in the basic active filter sections (Fig. 1) vary with frequency and section $Q$. For the worst-case frequency, the sensitivity, $S$, for each of the $R$ and $C$ components (Fig. 1) is:

$$Q = \frac{1}{T}$$

and for variations in gain of the active element is

$$S = \frac{1}{T}$$

The high-gain sensitivity factor is not harm-
Synthesize complete filter from sections

N 2 filter sections must be cascaded to synthesize an even-pole filter. The component values of each section are computed for a different conjugate pole pair in the desired transfer function. The sections can be assembled in any order provided only that each section is driven from a low-impedance source. Odd-pole filters may also be synthesized, but single-pole sections are inefficient and three-pole sections are difficult to design. The "RC FIL" computer program therefore considers only even-pole filters.

Check by calculating gain vs frequency

After the N-pole filter has been completely designed the actual frequency response can be compared with the desired response. Compute the actual response analytically by adding the individual section gains (in dB) at each of several test frequencies. For a two-pole, low-pass section, the magnitude of the gain is $L'(j\omega)$:

$$L'(j\omega) = \left[ 1 - \frac{1}{(R_1 + R_2)C_1 \omega^2} \right]^{1/2}$$

For a two-pole high-pass section, the magnitude of the gain is $H'(j\omega)$:

$$H'(j\omega) = \left[ 1 - \frac{1}{R_1 C_1 \omega^2} \right]^{1/2}$$

In both cases the dB gain is found by taking the common logarithm of the voltage gain and multiplying by 20.

Sample designs illustrate technique

The calculations for designing low-pass or high-pass Chebyshev and Butterworth RC filters have been incorporated in the computer program. The program, listed in Fig. 2, is written in BASIC for use on a time-shared computer.

A BASIC program consists of a series of typed lines, each beginning with a line number followed by a command word. Unless otherwise instructed the computer works on one line at a time in order of increasing line number. To understand a BASIC program, the user must first learn the command words that make up the vocabulary. Some of the command words together with their meanings are listed in Table 3.

Let's examine two applications of the RC FIL program. The first example is a six-pole Butterworth low-pass filter with a 3-dB cut frequency at 1 kHz and a maximum C value of 33 nanofarads. The second is a four-pole Chebyshev high-pass filter with a cut frequency at 1 kHz, which will be done in line 0.
Table 3. BASIC commands

<table>
<thead>
<tr>
<th>Type</th>
<th>Word</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nonexecutable</td>
<td>REM</td>
<td>Allows the insertion of remarks in the program listing</td>
</tr>
<tr>
<td></td>
<td>DIM</td>
<td>Reserves extra memory room for large variable arrays</td>
</tr>
<tr>
<td></td>
<td>DATA</td>
<td>Stores numerical data to be used in the problem solution</td>
</tr>
<tr>
<td>Input/Output</td>
<td>READ</td>
<td>Obtains numerical data from DATA statements</td>
</tr>
<tr>
<td></td>
<td>PRINT</td>
<td>Types output statements and numerical answers</td>
</tr>
<tr>
<td>Computational</td>
<td>LET</td>
<td>Computes variable values according to algebraic formulas</td>
</tr>
<tr>
<td>Sequencing</td>
<td>GO TO</td>
<td>Alters the normal order of computation</td>
</tr>
<tr>
<td></td>
<td>IF...THEN</td>
<td>Conditionally alters the order of computation</td>
</tr>
<tr>
<td></td>
<td>FOR...TO NEXT</td>
<td>Causes the intervening commands to be repeated several times</td>
</tr>
<tr>
<td></td>
<td>GO SUB RETURN</td>
<td>Routes computation to and from a subroutine (subsection) of the program</td>
</tr>
<tr>
<td>Termination</td>
<td>STOP</td>
<td>Stops computation (at any point in the program)</td>
</tr>
<tr>
<td></td>
<td>END</td>
<td>Stops computation (this must be the last sequential command in a program)</td>
</tr>
</tbody>
</table>

Table 5. Variables used in program

<table>
<thead>
<tr>
<th>Name</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>T</td>
<td>Type of filter (1 = Low-pass, 2 = High-pass)</td>
</tr>
<tr>
<td>N</td>
<td>Number of poles</td>
</tr>
<tr>
<td>F</td>
<td>Cut frequency (in kHz)</td>
</tr>
<tr>
<td>R</td>
<td>Chebyshev passband ripple (in dB)</td>
</tr>
<tr>
<td>C</td>
<td>Maximum circuit capacitance (in nanofarads)</td>
</tr>
<tr>
<td>Qφ</td>
<td>$2\pi$ (phase conversion constant from radians to degrees)</td>
</tr>
<tr>
<td>Q1</td>
<td>In 10 (gain conversion constant from natural logs to common logs)</td>
</tr>
<tr>
<td>I</td>
<td>Iteration index ($I = 1$ to $N/2$) for the 2-pole sections</td>
</tr>
<tr>
<td>F (37)</td>
<td>Frequency values (independent variable)</td>
</tr>
<tr>
<td>G (37)</td>
<td>Gain values (dependent variable)</td>
</tr>
<tr>
<td>C (26)</td>
<td>Standard capacitance values per decade</td>
</tr>
<tr>
<td>X1</td>
<td>Minor Chebyshev ellipse radius</td>
</tr>
<tr>
<td>X2</td>
<td>Major Chebyshev ellipse radius</td>
</tr>
<tr>
<td>R</td>
<td>Chebyshev ripple factor</td>
</tr>
<tr>
<td>D</td>
<td>Intermediate Chebyshev parameter</td>
</tr>
<tr>
<td>P</td>
<td>Root location phase angle</td>
</tr>
<tr>
<td>S</td>
<td>Real component ($s$) of pole location</td>
</tr>
<tr>
<td>W</td>
<td>Imaginary component ($\omega$) of pole location</td>
</tr>
<tr>
<td>A</td>
<td>Squared magnitude of pole location</td>
</tr>
<tr>
<td>$R_\phi$</td>
<td>Nominal resistance level</td>
</tr>
<tr>
<td>R1,R2,C1,C2</td>
<td>Component values (kilohms and nanofarads)</td>
</tr>
<tr>
<td>M</td>
<td>Ratio of $C1/C2$ in low-pass sections</td>
</tr>
<tr>
<td>K6</td>
<td>Number of standard capacitance values per decade</td>
</tr>
<tr>
<td>K,N1,11</td>
<td>Iteration loop indices</td>
</tr>
<tr>
<td>N2,K7</td>
<td>Normalization constants</td>
</tr>
<tr>
<td>G,12</td>
<td>Intermediate variables used in graph routine</td>
</tr>
</tbody>
</table>

Table 4. Program block outline

<table>
<thead>
<tr>
<th>Line numbers</th>
<th>What is accomplished</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 – 90</td>
<td>Data input and instructions to user</td>
</tr>
<tr>
<td>100 – 120</td>
<td>Constant definition and variable dimensioning</td>
</tr>
<tr>
<td>130 – 170</td>
<td>Heading print-out (using subroutine 2000 – 2230)</td>
</tr>
<tr>
<td>180 – 670</td>
<td>Calculations for each 2-pole section</td>
</tr>
<tr>
<td>220 – 410</td>
<td>Calculation of root pair locations</td>
</tr>
<tr>
<td>420 – 620</td>
<td>Calculation of low-pass component values</td>
</tr>
<tr>
<td>630 – 670</td>
<td>Calculation of high-pass component values</td>
</tr>
<tr>
<td>680 – 750</td>
<td>Component value print-out</td>
</tr>
<tr>
<td>770 – 930</td>
<td>Selection of frequency values and calculations of gain values for graph</td>
</tr>
<tr>
<td>940 – 950</td>
<td>Graph print-out (using subroutine 4000 – 4440)</td>
</tr>
<tr>
<td>2000 – 2230</td>
<td>Print subroutine for page headings</td>
</tr>
<tr>
<td>4000 – 4440</td>
<td>Print subroutine for graph</td>
</tr>
</tbody>
</table>

To solve the first filter design, we must retype line 0 as follows:
0 DATA 1, 6, 1, 0, 33.

The remark ("REM") statements in Fig. 2 explain how the desired filter specifications are entered into the program (see Table 4). The variables used are listed in Table 5. When the program is run with this "DATA" line, a two-page print-out (Fig. 3) is generated. Each page begins with a descriptive heading. Figure 3A shows the first page, which gives the component values, and Fig. 3B the second page, containing a graph of gain versus frequency.

For low-pass designs, the $C_1$ value in each of the sections is set equal to the maximum $C$ value specified in the DATA line. In this case $C_1$ is 33 nF in each of the three sections. The $C_2$ value is then chosen as the largest value that can be realized from a standard decade list of $C$ values.
3. Computer printout of component values (A) and frequency response curve (B) for six-pole Butterworth low-pass filter (C) is shown above.

(contained in line 450 of the program, Fig. 2). The list may be changed, as required, to reflect available C values. The first number in the list (in this case, 6) is the number of values in the list. The following numbers, are the C values arranged in increasing order of magnitude. In the print-out (Fig. 3A) the values of C₁ for the three sections are 2.2 nF, 15 nF and 22 nF. The R values, which are computed from these C values and the filter specifications, are non-
Deriving the fundamental filter equations

Modern filter design theory is based upon an analysis of the filter transfer function, the ratio of output to input in the complex frequency plane, the s-plane. Attention is centered on the location of the "poles" of the transfer function. The poles are the values of s for which the denominator of the transfer function vanishes, or is equal to zero.

The poles of the normalized Butterworth low-pass function are equally spaced on a unit circle centered at the origin of the s-plane. For an \( N \)-pole function, the phase angles, \( P_i \), of the pole locations are:

\[
P_i = \frac{\pi}{2} + \frac{\pi}{2N}(2i-1), \quad i = 1 \text{ to } N. \tag{1}
\]

The real (\( \sigma_i \)) and imaginary (\( j\omega_i \)) Cartesian coordinates of the pole locations are therefore:

\[
\sigma_i = \cos (P_i) \tag{2a}
\]
\[
j\omega_i = j \sin (P_i) \tag{2b}
\]

The poles of the normalized Chebyshev low-pass function are unequally spaced on an ellipse centered at the origin of the s-plane. The minor radius \( X1 \) of the ellipse is parallel to the real (\( \sigma \)) axis, and the major radius \( X2 \) is parallel to the imaginary (\( j\omega \)) axis of the s-plane. The values of \( X1 \) and \( X2 \) depend on the peak-to-peak ripple \( R \) (in dB) of the voltage waveform in the passband, and on the number of poles, \( N \). It is convenient to define a ripple factor, \( \epsilon \), in terms of \( R \) according to the following convention:

\[
\epsilon \triangleq (10^{R/20} - 1)^{1/4}. \tag{3}
\]

If we use this definition then \( X1 \) and \( X2 \), the radii of the ellipse, are:

\[
X1 = \sinh \left[ \frac{1}{N} \sinh^{-1} \left( \frac{1}{\epsilon} \right) \right] \tag{4a}
\]
\[
X2 = \cosh \left[ \frac{1}{N} \sinh^{-1} \left( \frac{1}{\epsilon} \right) \right] \tag{4b}
\]

Since it is inconvenient to work with hyperbolic functions, the standard mathematical relations

\[
\sinh x = (e^x - e^{-x}) / 2 \tag{5a}
\]
\[
\cosh x = (e^x + e^{-x}) / 2 \tag{5b}
\]
\[
\sinh^{-1} x = \ln [x + (x^2 + 1)^{1/2}] \tag{5c}
\]

will be used to obtain the more convenient form:

\[
X1 = \left[ D - (1/D) \right] / 2 \tag{6a}
\]
\[
X2 = \left[ D + (1/D) \right] / 2, \tag{6b}
\]

where

\[
D = \left[ \frac{1}{\epsilon^2} \right]^{1/4}. \tag{7}
\]

The real and imaginary components of the pole locations for both types of filters can therefore be expressed in terms of ONE set of equations:

\[
\sigma_i = X1 \cos (P_i) \tag{8a}
\]
\[
j\omega_i = j X2 \sin (P_i) \tag{8b}
\]

where \( P_i \) is defined in Eq. 1.

If the number of poles is even, an \( N \)-pole function may be factored into \( N/2 \) conjugate pairs, since each pole, \( s_n \), has a conjugate pole \( s_{n+1} \). Let

\[
A_i \triangleq (\sigma_i + j\omega_i)(\sigma_i - j\omega_i) = \sigma_i^2 + \omega_i^2. \tag{9}
\]

The normalized transfer function \( L_i(s) \) of a low-pass pole pair is then:

\[
L_i(s) = \frac{1}{A_i \left( s^2 - 2\sigma_i s + \omega_i^2 \right)} = \frac{1}{A_i s^2 + (2\sigma_i^2 + A_i) s + 1} \tag{10}
\]

shown in Table 1. Tests showed that it did have the frequency response predicted in Fig. 3B.

In the example of the four-pole Chebyshev high-pass filter, line 0 in the computer program (Fig. 2) is in the correct format for solving the filter design. The solution is shown in Fig. 4. Figure 4A gives the component values, Fig. 4B the frequency response, and Fig. 4C the complete circuit schematic.

The headings provided in the computer print-out (Figs. 4A and 4B) for the Chebyshev filter are similar to those for the Butterworth case, but they include the definition of an additional parameter—the passband ripple. The plot of Fig. 4B shows every data point (rather than every other point as in Fig. 3B), to more clearly define standard.

The second page of the print-out (Fig. 3B) is a plot of the logarithmic gain in decibels versus linear frequency in kilohertz. Plus signs are used to form the graph grid, and asterisks indicate the data points. The lines connecting the asterisks were drawn in after the print-out was completed to make the response curve more legible. The curve in Fig. 3B agrees with the standard six-pole Butterworth characteristic.
where the constant factor $1/A_i$ in Eq. 10 normalizes the maximum value of $L_i(s)$ to unity gain. Since the low-pass section (Fig. 1) must have unity gain at $dc$, the factor $1/A_i$ cannot be accommodated by Eq. 12 for the Chebyshev case. 

Chebyshev filters designed in this way will have unity gain ripple at $dc$ rather than the more

rejection also holds for high-pass design.

The normalized transfer function $H_i(s)$ of a high-pass pole pair is obtained by replacing the variable $s$ in (10) by $1/s$:

$$H_i(s) = \frac{1}{\frac{\alpha_i}{A_i} - \frac{2\sigma_i}{A_i}s + 1} \quad (11)$$

The transfer function $L'(s)$ of the two-pole low-pass RC filter section (Fig. 1) is

$$L'(s) = \frac{1}{R_C R_i C s^2 + (R_1 + R_2) C s + 1} \quad (12)$$

To realize $L_i(s)$ with $L'(s)$, Eqs. 10 and 12 must be equated, term by term, if the constant factor is neglected, this leads to two equations in four unknowns, $R_1$, $R_2$, $C_1$, and $C_2$:

$$R_C R_i C_1 = 1/A_i \quad (13a)$$

$$(R_1 + R_2) C_2 = -2\sigma_i/A_i \quad (13b)$$

If $C_1$ and $C_2$ are selected as standard values,

$$C_1 = C \quad (14a)$$

$$C_2 = C/M \quad (14b)$$

then the normalized values of $R_1$ and $R_2$ are determined from

$$R_1 = -\frac{\alpha_i M}{A_i} \left[1 + \left(1 - \frac{A_i}{\sigma_i M}\right)^{1/2}\right] \quad (15a)$$

$$R_2 = -\frac{\alpha_i M}{A_i} \left[1 - \left(1 - \frac{A_i}{\sigma_i M}\right)^{1/2}\right] \quad (15b)$$

From Eq. 15 it can be seen that the value of $M$ selected in Eq. 14b must satisfy the inequality

$$M \geq A_i/\sigma_i^2 \quad (16)$$

The minimum standard value of $C_2$ may be found by first choosing $C_1 > C$ and then trying successively smaller standard values for $C_2$ until Eq. 16 is satisfied.

The transfer function $H'(s)$ of the two-pole high-pass RC filter (Fig. 1) section is

$$H'(s) = \frac{1}{R_C R_i C s^2 + C_1 + C_2} \quad (17)$$

As in the low-pass case, $H_i(s)$ may be realized with $H'(s)$ by selecting standard $C$ values and then computing the normalized $R$ values. The latter are derived by equating the denominators of Eqs. 11 and 17:

$$C_1 = C \quad (18a)$$

$$C_2 = C \quad (18b)$$

$$R_1 = -\frac{\alpha_i}{C} \quad (19a)$$

$$R_2 = -\frac{A_i}{\sigma_i C} \quad (19b)$$

The component value formulas are summarized in Table 2.

The faster-moving Chebyshev response.

The standard decade list of $C$ values is not utilized in the high-pass design (Fig. 4A) since both $C_1$ and $C_2$ are set equal to the maximum $C$ value specified in the DATA line. The high-pass graph (Fig. 4B) uses an inverse-linear frequency scale to emphasize the inverse symmetry of the high-pass design with respect to its low-pass prototype. The two filter sections of the complete schematic (Fig. 4C) use the basic high-pass rather than the low-pass circuit. ***

References:


Electronic Design 13, June 21, 1969
RC ACTIVE FILTER PROGRAM BY KINCAID AND SHIRLEY
MODIFIED FOR FOCAL BY TOM BEAN & WILLIAM ROMANS

T: TYPE OF FILTER (ENTER L FOR LOWPASS; H FOR HIGHPASS)
N: NUMBER OF POLES (MUST BE EVEN NUMBER)
H: CUTOFF FREQUENCY IN KHZ
R: ALLOWABLE RIPPLE IN PASSBAND (Ø FOR BUTTERWORTH DESIGN)
C: MAXIMUM CAPACITANCE VALUE IN NANGFARADS

R1, R2 GIVEN IN KOHMS

C-FOCAL, 1969

*01.02 Ask ' ? T N H R C1 ? , ::; Sxy=3.14159; Sx=5(6)=1; Sx=C(0)=1 Ø

*01.04 Set C(1)=6.8; Sx=C(2)=4.7; Sx=C(3)=3.3; Sx=C(4)=2.2; Sx=C(5)=1.5

*01.06 For l =1, N/2; D3

*03.08 l= (-R3.16; SxX1=1; SxX2=1; G=3.28

*03.16 Set E=FSQT(FEXP(R*2.30259/10)-1)

*03.18 Set D=FEXP(FLOG(1/E+FSQT(1/E+T2+1))/N)

*03.20 Set X1=(D-1/D)/2; SxX2=(D+1/D)/2

*03.28 Set S=x1*FCOS(Pi/2+Pi*(2*l-1)/2*pi)

*03.30 Set W=x2*FSIN(Pi/2+Pi*(2*l-1)/2*pi)

*03.32 Set A=S*T2+W*T2

*03.34 Set X3=2*Pi*H*C1

*03.36 If (1-12/T)7.04; E, N1=-1, 9; D4

*04.04 Set P=FITR(FLOG(C1)/2.30259)-N1; E, K=1, 6; D5

*05.02 If (-P)S9.08

*05.04 Set C2=C(K)/10*T(-P); Sx=C3=C(K-1)/10*T(-P); G=5.12

*05.08 Set C2=C(K)*10*T; Sx=C3=C(K-1)*10*T

*05.12 Set M=C1/C2; l (M-A/S*T2)+5.16; D6

*05.16 Return

*06.04 Set R1=(-S*10*T3/(X3))*(M/A)*(*1+FSQT(1-A/(S*T2*M)))

*06.06 Set R2=(-S*10*T3/(X3))*(M/A)*(*1-FSQT(1-A/(S*T2*M)))

*06.08 If (A/S*T2-C1/C3)6.10; D8

*06.10 Return

*07.04 Set C2=C1; SxR1=-S*10*T3/(X3); SxR2=(-S*10*T3/(X3))*A/S*T2; D8

*07.06 Set R2=(-S*10*T3/(X3))*A/S*T2; D8


```plaintext
T : L N : 6 H : 1 R : ø Cl : 33
SEC.= 1
C1, C2, R1, R2= 33.00000= 2.00000= 20.01779= 17.42900
SEC.= 2
C1, C2, R1, R2= 33.00000= 15.00000= 9.76469= 5.24055
SEC.= 3
C1, C2, R1, R2= 33.00000= 22.00000= 10.72140= 3.25429

T : H N : 4 H : 1 R : 2.4 Cl : ø
SEC.= 1
C1, C2, R1, R2= 10.00000= 10.00000= 1.52734= 151.98800
SEC.= 2
C1, C2, R1, R2= 10.00000= 10.00000= 3.68732= 14.38040

* E A

* C GAIN VERSUS FREQUENCY PLOT FOR RC FILTER
* C RC ACTIVE FILTER PROGRAM BY KINCAID AND SHIRLEY
* C MODIFIED FOR FOCAL BY TOM BEAN & WILLIAM E ROMANS
* C INPUT: T IS TYPE OF FILTER (ENTER L FOR LOWPASS; H FOR HIGHPASS)
* C N IS NO. OF POLES (MUST BE EVEN)
* C H IS CUTOFF FREQUENCY IN KHZ
* C R IS PASSBAND RIPPLE IN DB (ø FOR BUTTERWORTH)
* C C1 IS MAXIMUM CAPACITANCE IN NANOFARADS
* C RE-ENTER VALUES FOR THE ABOVE WHICH WERE USED IN CALCULATING
* C R1 R2 C1 C2 AND ENTER THE CALCULATED VALUES FOR C2 R1 AND R2
```
T : H N : 4 H : 1 R : 2.4 C1 : 10
C2 : 10 R1 : 1.527 R2 : 151.98
C2 : 10 R1 : 3.68 R2 : 14.38
INSERTION GAIN (DB)

\[ \begin{align*}
-15 & \quad -12 & \quad -9 & \quad -6 & \quad -3 & \quad 0 & \quad 3 \\
+ & + & + & + & + & + & +
\end{align*} \\
\]

\[ \begin{align*}
+ & \ast & + & + & + & + & + & + & + & = 0.676 \\
+ & + & + & + & + & + & + & + & = 0.695 \\
+ & + & + & + & + & + & + & + & = 0.714 \\
+ & + & + & + & + & + & + & + & = 0.735 \\
+ & + & + & + & + & + & + & + & = 0.758 \\
+ & + & + & + & + & + & + & + & = 0.781 \\
+ & + & + & + & + & + & + & + & = 0.807 \\
+ & + & + & + & + & + & + & + & = 0.833 \\
+ & + & + & + & + & + & + & + & = 0.862 \\
+ & + & + & + & + & + & + & + & = 0.893 \\
+ & + & + & + & + & + & + & + & = 0.926 \\
+ & + & + & + & + & + & + & + & = 0.962 \\
+ & + & + & + & + & + & + & + & = 1.000 \\
+ & + & + & + & + & + & + & + & = 1.042 \\
+ & + & + & + & + & + & + & + & = 1.087 \\
+ & + & + & + & + & + & + & + & = 1.136 \\
+ & + & + & + & + & + & + & + & = 1.191 \\
+ & + & + & + & + & + & + & + & = 1.250 \\
+ & + & + & + & + & + & + & + & = 1.316 \\
+ & + & + & + & + & + & + & + & = 1.389 \\
+ & + & + & + & + & + & + & + & = 1.471 \\
+ & + & + & + & + & + & + & + & = 1.563 \\
+ & + & + & + & + & + & + & + & = 1.667 \\
+ & + & + & + & + & + & + & + & = 1.786 \\
+ & + & + & + & + & + & + & + & = 1.923 \\
+ & + & + & + & + & + & + & + & = 2.083 \\
+ & + & + & + & + & + & + & + & = 2.273 \\
+ & + & + & + & + & + & + & + & = 2.500 \\
+ & + & + & + & + & + & + & + & = 2.778 \\
+ & + & + & + & + & + & + & + & = 3.125 \\
+ & + & + & + & + & + & + & + & = 3.572 \\
+ & + & + & + & + & + & + & + & = 4.167 \\
+ & + & + & + & + & + & + & + & = 5.000 \\
+ & + & + & + & + & + & + & + & = 6.250 \\
+ & + & + & + & + & + & + & + & = 8.333 \\
+ & + & + & + & + & + & + & + & = 12.50 \\
+ & + & + & + & + & + & + & + & = 25.00 \\
\end{align*} \]