# Band-Stop Filters for Attenuating High-Level Broadcast-Band Signals

## Eliminating AM BC interference can be a problem for the 160-meter operator. Here's a solution.

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## Introduction and Background

This article was prompted by a request from Paul Elliott, W5DM, of Hobbs, New Mexico, for a filter to attenuate the signal of a nearby 1.48-MHz broadcast-band station that was causing receiver overload and preventing reception in the 160-m band. An examination of *The 1996 ARRL Handbook* showed that the only filter design intended to attenuate broadcast-band signals was not suitable for this particular application because it provided only about 24 dB of attenuation at 1.48 MHz when more than 60 dB is needed.[1]

A request from a *QST* reader in "The Doctor is IN" column asking what to do about a receiver overload problem caused by a nearby BC-band transmitter also indicates the need for a band-stop filter designed specifically for attenuating a particular broadcast-band signal.[2] One of the Doctor's suggestions was to use the *Handbook* high-pass rejection filter. However, this filter will solve the overload problem only if the BC-station frequency is below 1.3 MHz, where the filter provides at least 60 dB of attenuation.

It appears that a tabulation of band-stop filters (BSF) covering the broadcast-band frequency range and using only standard-value capacitors would be a useful addition to the tables of standard-value-capacitor low-pass and high-pass filter designs currently in the *ARRL Handbook*.

This article discusses the procedures involved in designing and testing BSFs. A table of 25 computer-calculated broadcast-band BSFs is presented in which only standard-value capacitors are used, to simply the filter construction. An example of the construction and testing of a BSF is given, and sufficient background information is provided so the design principles may be applied to other BSF applications.

## Design Approach

Before starting the filter design, you should first confirm that the interfering signal is entering the receiver via the antenna and not by other paths. This can be done by disconnecting the antenna from the receiver and placing a 50-Ω resistor across the antenna terminals. If the interference disappears, the interfering signal path is probably via the antenna, and a BSF placed between the antenna and the receiver input terminals may solve the overload problem. Also, the amount of filter insertion loss needed to prevent overload can be estimated by placing a resistive attenuator having about 60 dB of loss between the antenna and receiver. If receiver overload is eliminated, 60 dB of filter attenuation will be sufficient.

The usual procedure in designing a band-stop filter is to first design a high-pass prototype having a cutoff frequency equal to the desired bandwidth (*BWAp*) of the BSF and also having an appropriate reflection coefficient. The high-pass prototype is then transformed into a BSF by resonating the high-pass elements to the desired center frequency of the BSF.

For generating a table of BSFs, this procedure is slightly modified by using several pairs of standard-value capacitors to evaluate designs for a particular BSF center frequency and then picking one design that has suitable parameters for the final tabulation. The filter impedance level is fixed at 50 Ω because this is the impedance level of most receiving systems. For these designs, a total BSF attenuation of about 60 dB is assumed to be sufficient, and a third-order high-pass filter (to be transformed into a three-resonator BSF) is used.

Fig 1 shows the proposed 3-resonator filter in a T-network configuration. Because it needs only one ground connection, the T-network was chosen over the alternate pi-network. High-level circulating ground currents are anticipated, and there might be a problem in finding a "clean" ground; consequently, it is advisable to minimize the number of ground connections.

Of the two choices between the Butterworth and Chebyshev filter types, the Chebyshev was chosen because of its better selectivity and because it permits several different pairs of capacitor values to be considered, whereas the Butterworth has only one pair of values. Fig 2 shows the typical insertion- and return-loss responses of a lossless 3-resonator Chebyshev BSF having a reflection coefficient (RC) of about 6% and with an arbitrarily chosen center frequency of 4 MHz. The significant points on the insertion-loss response curve are the upper and lower ripple cutoff frequencies (+*FAp* and -*FAp*), the upper and lower 3-dB frequencies and the center frequency (*Fc*). Note that the upper and lower insertion-loss and return-loss responses intersect at the 3-dB level when the filter components are lossless. The ripple and 3-dB bandwidths are determined from their corresponding upper and lower ripple and 3-dB cutoff frequencies. The filter stop band (*BWAp*) is defined as existing between the upper and lower ripple cutoff frequencies on the response curve, and it is this ripple bandwidth that corresponds to the ripple cutoff frequency of the high-pass prototype from which the BSF is derived.

The lower and upper *FAp* frequencies are those frequencies where the insertion loss first exceeds the maximum passband ripple amplitude of *Ap*= 0.0155 dB. Also note that the frequencies of maximum passband ripple amplitude (at 1.53 and 10.45 MHz in Fig 2) are also the frequencies of minimum return loss, maximum RC and maximum VSWR.

The maximum ripple amplitude, *Ap*, is directly related to the filter RC and VSWR and inversely related to the return loss. Those designs having the lowest possible RC were preferred for the BSF tabulation.

Having selected the filter parameters of order, network configuration, impedance level and different pairs of standard-capacitor values, several Chebyshev BSF designs were computer calculated based on previously published Chebyshev design equations.[3] The designs were then compared, and the one having the lowest RC, and also having an upper ripple cutoff frequency (+*FAp*) less than 1.8 MHz, was selected for inclusion in a tabulation of designs ranging over a center frequency of 1.48 MHz to 0.56 MHz in decrements of 40 kHz. Table 1 shows the 25 BSF designs that were selected. The BASIC computer program used to calculate and tabulate these designs was modified to calculate individual designs based on the center frequency and capacitor values specified by the user. The modified program appears in the "BASIC Program" sidebar.

Those BSFs with center frequencies near 1.8 MHz were designed with reflection coefficients greater than 12% to assure that their upper bandstop would not intrude into the lower edge of the 160-m band. For example, see designs 1 and 2 in Table 1 where the RC levels are relatively high, at 12.3 and 19.2%. Those BSF designs having center frequencies further removed from 1.8 MHz, such as designs 11 through 25, can have a wider stopband with a correspondingly lower RC.

To attenuate a high-level BC-band signal having a frequency between two of the listed frequencies in Table 1, use the capacitor values of the nearest listed design and tune the inductors to resonate the three capacitors to the frequency of the BC-band signal. The resulting BSF response will be similar to that of the nearest design. For example, for a desired center frequency *F* of 1.34 MHz, use the capacitor values of 5600 and 1200 pF or 5600 and 1500 pF and resonate the capacitors to 1.34 MHz with appropriate inductors. The resonating inductance is calculated from the equation: $L = 25330.3/(CF^2)$ where *L*, *C* and *F* are in µH, pF and MHz, respectively. The resulting design may be confirmed by using the BASIC program.

The G2/G1 ratio (RA in line 50 of the BASIC program) is equal to $39.4784 \times C1 \times C2 \times (F \times R)^2 \times 10^{-12}$, where C is in pF, F is in MHz and R is the system impedance level in ohms. For example, for C1=5600 pF and C2=1200 pF, F=1.34 MHz and R=50, the G2/G1 ratio is 1.19091. If the G2/G1 ratio is greater than 1.17 and less than 1.59, the corresponding reflection coefficient will be between 13% and 3.96%, respectively. (This chosen range of reflection coefficient is arbitrary. Similar values are equally satisfactory as long as the RC does not become too high, with a correspondingly high VSWR and greater sensitivity to component and termination impedance tolerance.)

For a center frequency of 1.34 MHz and C1=5600 pF and C2=1500 pF, the G2/G1 ratio is 1.4886 and the corresponding RC is 5.758%. Any BSF design within the 3.96 to 13% RC range will be satisfactory for a center frequency less than 1.4 MHz. For those frequencies above 1.4 MHz, which are closer to the lower edge of the 160-m band, BSFs with a higher reflection coefficient must be used in order to obtain a narrower bandwidth so any significant loss will not extend into the 160-m band. However, since the noise level in the 160-m band is usually high, a few dB of filter loss in the 160-m band will probably not be noticeable.

## How to Confirm the Computer-Calculated BSF Designs

If you are using an unfamiliar computer-operated filter design program, you should always check at least one design by manual calculation to confirm the computer program is operating correctly. If just one design can be demonstrated as being correct, then probably all the computer-calculated designs are correct as the same program was used to calculate the rest of the designs.

The values of *BW*(*Ap*) in Table 1 are listed so the reader can independently confirm each design. This can be done by referring to Table 2 ("The Normalized L and C Values"), where the normalized C and L values are listed for each design in Table 1. The normalized C and L values corresponding to the selected RC level are used to calculate the final C and L component values using the procedure explained in the *Handbook*.[4] For example, use the following procedure to confirm design #2, for *Fc*=1.48 MHz and RC=19.165%.

1. Refer to Table 2 and select the low-pass L-in/out configuration for transformation into a high-pass prototype. For the design with RC=19.165%, the corresponding normalized low-pass values of L1,3 and C2 are 1.16314 and 1.15467, respectively.

2. Transform the LP prototype into a high-pass by replacing the two inductors with capacitors and the one capacitor with an inductor. The normalized value of the two capacitors will now be the reciprocal of the former inductor value and the normalized inductor value will now be the reciprocal of the former capacitor value. Thus, C1,3=1/1.16314 =0.85974 F and L2=1/1.15467=0.86605 H.

3. Design a 3-element C-in/out high-pass prototype filter having a RC of 19.165%, an impedance of 50 Ω and a cutoff frequency equal to the ripple bandwidth (0.4887 MHz) of the BSF. The 0.4887-MHz bandwidth was obtained from the *BW*(*Ap*) tabulation for design #2 in Table 1.

(a) Calculate the inductance and capacitance scaling factors, *Ls* and *Cs*:

$$L_s = \frac{R}{2\pi BW_{AP}} = \frac{50}{2\pi 0.4887 \times 10^6} = 16.2835 \times 10^{-6}$$

$$C_s = \frac{1}{R 2\pi BW_{AP}} = \frac{1}{50 2\pi 0.4887 \times 10^6} = 6513.4 \times 10^{-12}$$

(b) Using the inductance and capacitance scaling factors, calculate L2 and C1 and C3 of the high-pass filter prototype (see Fig 1) by multiplying the normalized *L* and *C* values from step 2 by the *Ls* and *Cs* scaling factors:

$$L2 = L_s \times 0.86605 H = 16.2835 \times 10^{-6} \times 0.86605 = 14.10 \mu H$$

These manually calculated values of C1,3 and L2 confirm the values given in Table 1 for design #2. Next, convert the 3-element high-pass prototype into a BSF design by resonating each C and L at the center frequency of 1.48 MHz:

4. Use the equations:

$C=25330.3/(F^2L)$ and $L=25330.3/(F^2C)$ to find C2 and L1,3 where $F$ is the BSF center frequency in MHz and $C$ and $L$ are in pF and µH.

(a) Calculate $C2=25330.3/(1.48^2\times 14.10)=820$ pF

(b) Calculate $L1,3=25330.3/(1.48^2\times 5600)=2.065$ µH

These manually calculated values of C2 and L1,3 also confirm the computer-calculated values listed in Table 1 for design #2. The other computer-calculated designs may therefore be viewed with confidence because the same BASIC program used to calculate design #2 was also used to calculate the other designs.

Further confirmation of BSF design #2 was obtained using the *ELSIE Filter Design and Analysis* software.[5] The plot of insertion loss and return loss over the 1 to 2-MHz frequency range is shown in Fig 3. (Note: This computer-generated plot is upside down from the plot of Fig 2 because the programmer of the filter-analysis software prefers this orientation. In contrast, I prefer to show increasing values of attenuation going up.)

Fig 3 shows that the Trinity Software calculated minimum return-loss levels at 1.08 and 2.00 MHz are in agreement with the minimum return loss value (14.35 dB) of design #2 listed in Table 1. In particular, note that the calculated return loss over the 160-m band (1.8-2.0 MHz) is greater than 14.35 dB. This level of return loss indicates that only a small amount of the passband signal is reflected at the filter input, and most of the signal power over the filter passband goes into the filter and receiver.

If the filter of design #2 is lossless and the receiver has a perfect 50-Ω input impedance, the percentage of signal power going through the filter and into the receiver at the frequency of maximum VSWR can be approximated by squaring the reflection coefficient of the filter at this frequency ($0.19165^2=0.03673$), changing it to percent (3.673%), and then subtracting it from 100 (100-3.673) to find that about 96% of the input power is getting to the receiver. In comparison, at the center of the BSF filter at 1.48 MHz, the return loss is less than 1 dB, indicating that virtually all of the signal power is reflected, with virtually none going into the receiver.

## The Importance of Insertion and Return Loss

The design and evaluation of any filter is not complete until both the insertion loss and return loss are evaluated. Usually in amateur-radio applications, only the filter insertion loss is plotted; the equally important return-loss measurement is ignored. In the past, I have been guilty of this omission, and it is only in the last few years that I have come to appreciate the importance of having both the insertion- and return-loss plots of a filter to provide confirmation that the filter was properly designed and assembled. For example, it is possible for improperly calculated component values to produce what appears to be a satisfactory BSF insertion-loss response where the typical attenuation peak is observed. However, if the corresponding return-loss response does not have a sufficiently high level in the filter passband (preferably greater than 14 dB), it is likely that the design or assembly was incorrectly performed and unnecessary passband signal loss will occur. As you can see from Table 1, almost all of the BSF designs have minimum return-loss levels greater than 18 dB.

Filter return loss is not difficult to measure. The *Handbook* provides circuits for both audio-frequency and radio-frequency return loss bridges (RLB); for example, see pages 26.38 and 26.39, where a 100-Hz to 100-kHz RLB and an RF RLB are described.[6] Procedures for measuring both the RF insertion loss and return loss of a filter are explained in “Insertion-Loss and Return-Loss Measurement Procedures.”

## Filter Construction

For attenuating the 1.48-MHz signal of the nearby broadcast-band station, design #2 of Table 1 was selected for assembly. Design #1 would have been equally suitable, as the parameters of both these designs are satisfactory. In particular, note that the ratio of the larger to smaller inductance and capacitance values is less than ten to one, and the reactances of L1,3 and L2 are about 19 and 131 Ω at 1.48 MHz. As a general rule, it is desirable to minimize the component value spread and also to keep the inductor and capacitor reactance values at resonance between 5 and 500 Ω in a 50-Ω system. When the inductor or capacitor reactance falls below 5 Ω, either the equivalent series resistance of the inductor, or the series inductance of the capacitor, becomes significant and degrades the circuit Q. And when the inductive reactance becomes greater than 500 Ω, the inductor is very likely approaching self-resonance and the circuit Q is again degraded.

Capacitors C1 and C3 were each realized by paralleling 2700 and 3000-pF polystyrene capacitors that were measured with a digital capacitance meter and selected from a group of capacitors to get within 1/2 percent of the 5600-pF design value. Single capacitors of the desired 5600-pF value were not available at the time, otherwise they would have been used. Capacitor C2 was selected from a group of 820-pF polypropylene capacitors that were on hand. Both capacitor types have a low dissipation factor (0.1% or less) and are appropriate for low-power RF filtering applications such as this.

Inductors L1 and L3 were wound on Micrometals T80-17 (blue/yellow) powdered-iron cores, using between 18 and 20 turns of #22 magnet wire. The *AL* of this core is 2.2 $nH/N^2$. The -17 mix was developed by Micrometals as a temperature-stable alternative to the older -12 mix, and this newer mix is recommended for all new designs. Although this -17 mix is suggested for use in the 20-200 MHz range, it is preferred for this lower-frequency application instead of the higher permeability -7 mix. The greater number of turns required by the -17 mix as compared to the -7 mix permits a finer adjustment of tuning while still providing excellent Q at 1.48 MHz. L2 was wound with 32 turns of #20 magnet wire on a Micrometals T106-7 (white) core. The *AL* for this core is 13.3 $nH/N^2$. The larger inductance of L2 requires a larger core with a higher *AL* than that used for L1 and L3.

The three resonator circuits were individually tuned to 1.48 MHz using the test circuit and procedure described in Fig 4. Tuning was accomplished by first removing or adding turns to the inductors and then by squeezing or spreading the turns so resonance occurred at exactly 1.48 MHz, as indicated by a digital frequency meter. Resonance was indicated when a peak response was obtained on the ac VTVM. The Qs for L1,3 and L2 were measured in the Fig 4 circuit as 110 and 160, respectively. The Qs were calculated by dividing 1.48 MHz by the 3-dB bandwidth of the tuned circuit. These Q values appear to be on the low side, which is probably due to the loading effect caused by the 50- Ω signal-generator impedance plus the 4.7-kΩ resistor and the ac VTVM.

After all resonators were tuned, they were installed in a 2-1/4 × 2-1/4 × 5-inch aluminum minibox in accordance with the schematic diagram of Fig 1. A 1-7/8-inch square PC board was placed in the approximate center of the box, and the foil was grounded to provide shielding between the input and output resonators. A small Teflon feed-through on the PC board was used to provide a connection between the input and output resonator circuits. UHF-type RF connectors provide input and output connections to the filter. Fig 5 is a photograph of the completed filter.

### *Filter Testing*

The completed band-stop filter was tested for insertion and return loss over the 1.2 to 2.0-MHz frequency range using the test procedures explained in the sidebar “Insertion-Loss and Return-Loss Measurement Procedures.” Fig 6 shows the measured insertion- and return-loss responses of the filter in a 50- Ω test system. The insertion-loss response shows a loss of more than 65 dB at 1.48 MHz. The single-peak response is the result of carefully tuning each resonator to 1.48 MHz.

The return loss over the 160-m band is also satisfactory, staying above 20 dB from 1.8 to 1.89 MHz and above 17 dB up to 2.0 MHz. Although the minimum return loss was calculated to be 14.35 dB, the measured value is about 2.6 dB greater than the calculated value. The reason for this difference is not known. The measured return loss over the filter stopband (from about 1.3 to 1.7 MHz) is very low, as expected. Below 1.3 MHz, the return loss again rises to another peak similar to that in the upper frequency range. The return loss above 2.0 MHz was not measured, but a measurement of input impedance versus frequency using a Hewlett-Packard Model 4193A vector impedance meter showed that when the filter was terminated in a 50-Ω load, its input impedance varied less than 2 Ω relative to 54 Ω over the 3.5 to 30-MHz range. The corresponding phase angle gradually increased from -7 degrees at 3.5 MHz to +10 degrees at 30 MHz. This means that the BSF can be left connected to the receiver over the 160 to 10-m band range with no significant effect on the receiver performance.

The satisfactory measured insertion- and return-loss responses indicate the filter was properly designed and assembled and should perform as expected when inserted between the antenna and receiver. An earlier version of the filter, shown in Fig 5, was sent to W5DM, and he reported that his receiver overload problem was eliminated after the filter was installed.

## Summary

Paul Elliott, W5DM, was experiencing a receiver overload problem due to a nearby high-power broadcast-band transmitter at 1.48 MHz. The overload problem was solved by inserting a specially designed 3-resonator band-stop filter in front of his receiver. The design and analysis of the filter was accomplished using a DOS-based filter design and analysis program called *Elsie* from Trinity Software. The filter was assembled and tested for both insertion-loss and return-loss in a 50-Ω system, and the measured responses were in good agreement with the computer-calculated values.

Because of the usefulness of this particular design, a number of similar designs covering the 0.56 to 1.48-MHz broadcast-band range were also calculated along with their associated design parameters and component values. A 38-line BASIC program is included so the interested reader can calculate other 3-resonator band-stop designs based on the exact capacitor values on hand. A method was explained how the reader could confirm the correctness of the computer-calculated filter designs, and procedures were explained for making insertion-loss and return-loss measurements on the completed filters.

The amateur now has complete and convenient band-stop filter-design information that previously was not available. This design information can be applied in the design of any 3-resonator band-stop filter for center frequencies less than 30 MHz and where lumped L-C components are feasible.

## Acknowledgments

I gratefully acknowledge the assistance of Wes Hayward, W7ZOI, Rex Cox and Heyward Preacher for their review and comments on this article.

## Notes

(1) *The 1996 ARRL Handbook*, (Newington: ARRL) “A BC-Band Energy-Rejection Filter,” p 16.36, Fig 16.68.

(2)The Doctor is IN” column, *QST*, July 1995, p 56.

(3)Wetherhold, Edward E., W3NQN, “Calculate 5- and 7-Element Filter Components,” *QEX*, May 1987, p 4.

(4) *The 1996 ARRL Handbook*, (Newington: ARRL) “Band-Pass Filters,” pp 16.15-16.17.

(5)Trinity Software, 3526 Highway 66, Suite B-174, Rowlett, TX 75088.

(6) *The 1996 ARRL Handbook*, (Newington: ARRL) “Return Loss Bridges,” pp 26.38 and 26.39.

(7)See the Micrometals catalog #3, Issue D. Contact Micrometals at 1190 Hawk Circle, Anaheim CA 92807; tel: 800-356-5977 or 714-630-7420.

### Insertion-Loss and Return-Loss Measurement Procedures

#### *Insertion Loss*

Measurement of insertion loss can be performed using the test set-up of Fig B, as follows:

 

1. For a given frequency and with both coax switches set to the FLTR position, adjust the signal generator amplitude and tune the receiver until the signal is received as indicated by the deflection of the receiver S-meter.

2. Optimize the receiver controls for a maximum S-meter deflection and adjust the signal generator level until a suitable reference indication is obtained on the S-meter. For example, the +20 dB-over-S9 scale marker can serve as a convenient reference indication.

3. Change the coax switches to the ATTN position and add or remove attenuation until the same S-meter deflection is obtained as with the filter. Do not change any receiver control settings during this part of the measurement procedure.

4. Record the dB setting on the step attenuator and the corresponding frequency. When it is not possible to obtain the exact same reference level indication on the receiver S-meter scale because a 1-dB step change is either too large or too small, take the lower dB setting and add 1/2 dB to obtain the closest estimation of the attenuation.

5. Change the signal generator to the next test frequency and repeat steps 1 to 4.

***Notes:***

1. All coaxial cables are 50-Ω type RG-58/U.

2. All resistors are 1/4-W, 1% metal film.

3. The 50-Ω pads are used to stabilize the impedance level.

4. See the *1995 Handbook* for a description of the 50-Ω step attenuator. *The 1995 ARRL Handbook*, (Newington: ARRL) “Low-Power Step Attenuators,” p 26.40-41.

### *Return Loss*

Use the set-up of Fig C to measure return loss:

1. Switch the RLB “?Z” port to the input of the terminated filter with the step attenuator set to 0 dB.

2. Set the signal generator to the desired frequency and tune the receiver to pick up the signal.

3. Adjust the signal generator level and optimize the receiver controls until a reference level of +20 dB over S9 is obtained on the S-meter.

4. Switch the RLB “?Z” port to the open-circuit position and note that the S-meter indication will increase if the terminated filter has some return loss.

5. Insert attenuation with the step attenuator until the S-meter returns to the previous reference level. Do not change any receiver control settings during this part of the measurement procedure.

6. Read the return loss from the step attenuator and record it with the frequency. When it is not possible to obtain the exact same reference level indication on the receiver S-meter scale because a 1-dB step change is either too large or too small, take the lower dB setting and add 1/2 dB to obtain the closest estimation of the return loss.

7. Change the signal generator to the next test frequency and repeat steps 1 to 6.

Note: To check the accuracy of the return-loss measurement procedure, replace the terminated filter first with a grounded 75-Ω resistor, then with a grounded 100-Ω resistor. The corresponding measured return-loss levels should be 14 and 9.5 dB, respectively.

***Notes:***

1. All coaxial cables are 50-Ω type RG58/U.

2. The 50-Ω pads are used to stabilize the impedance level.

3. See Fig B for the 50-Ω pad resistor values.

4. See the *ARRL Handbook* for a description of the RF return loss bridge. *The 1996 ARRL Handbook,* (Newington: ARRL) “An RF Return-Loss Bridge,” p 26.39, Fig C.

5. See the *ARRL Handbook* for a description of the 50-Ω step attenuator. *The 1995 ARRL Handbook*, (Newington: ARRL) “Low-Power Step Attenuators,” p 26.40-41.

## BASIC Program

This BASIC program calculates and prints to screen the parameters and component values of a 50-Ω, 3-resonator BC-band reject filter based on the center frequency and C1 and C2 capacitor values given by the user. Designs are restricted to those having reflection coefficients between 3.8 and 27.2%. This program can be downloaded from the ARRL BBS (860-594-0306) or via the Internet from http://www.arrl.org/qexfiles or ftp://ftp.arrl.org/pub/qex. The file name is qexbsf.zip.

```
10 REM FILE NAME: 'QEXBSF.ASC' FOR USE IN 11/95 QEX BSF ARTICLE. 01 NOV 95.
20 REM Program writes RC%, RET LOSS & OTHER PARAMETERS OF 3rd-ORDER BSF.
30 PI=4*ATN(1) : Z=50 : N=3          : REM  Z = SOURCE & LOAD IMPEDANCE IN OHMS.
40 PRINT: INPUT "ENTER FC, C1 & C2 in MHz and pF";FC,C1,C2 : PRINT
50 RA = C1*C2*((2*PI*FC*Z)^2)*1E-12 : REM RA=LOWPASS G2/G1 RATIO FOR RC CALCS.
60 IF RA>1.6 GOTO 370 : IF RA<.8   GOTO 370 : REM  OMITS OUT-OF-RANGE RATIOS.
70 FOR C=1 TO 4        : REM START OF CALCS TO FIND %R.C. FOR CALC'D RA.
80 A(C) = SIN(.5*PI*(2*C-1)/N) : B(C)=SIN(PI*C/N)^2 : NEXT C
90 K2 =A(2)/(RA*A(1))            : REM  RA IS LOWPASS G2/G1 RATIO FOR %RC CALC.
100  M =SQR(B(1)/(K2-1))        : X =M+SQR((M^2)+1)
110 AP=8.68589*LOG(((X^(2*N))+1)/(((X^(2*N))-1))) : REM AP = Ap(dB)
120 R1=100*SQR(1-(.1^(.1*AP)))        : REM  REFLECTION COEFF (%)
130 RC = R1/100 : VS = (1+RC)/(1-RC) : REM VS = VSWR BASED ON RC (REFL COEFF).
140 RL = -20*(1/LOG(10))*LOG(R1/100) : REM RL = RETURN LOSS IN dB.
150 REM  START OF CALCS TO FIND G1 AND G2 BASED ON PREVIOUSLY CALC'D R.C.
160 A = AP/17.3718 : B=LOG((EXP(A)+EXP(-A))/(EXP(A)-EXP(-A)))
170 D = (EXP(B/(2*N))-EXP(-B/(2*N)))/2
180 FOR K=1 TO N   : A(K)=SIN((((2*K)-1)*PI)/(2*N))
190 B(K) = ((D)^2)+(1-COS((2*K*PI)/N))/2 : NEXT K
200 G(1) = 2*A(1)/D               : REM G(1) = NORMALIZED VALUE OF FIRST ELEMENT
210 FOR K=2 TO N : G(K) = 4*A(K-1)*A(K)/(B(K-1)*G(K-1)) : NEXT K
220 G1 =G(1) : G2 =G(2)  : REM  LP G-VALUES (USE RECIPROCALS FOR HP G-VALUES)
230 L2 = 25330.3/(FC^2*C2)        : REM BASED ON GIVEN FC & C2.
240 L1 = 25330.3/(FC^2*C1)        : REM BASED ON GIVEN FC & C1.
250 E=SQR(RC^2/(1-(RC^2)))        : REM RIPPLE FACTOR 'E' BASED ON RC.
260 V=1/N*LOG(1/E+SQR(1/E^2-1))  : F3=(EXP(V)+EXP(-V))/2 : REM F3=F3/FAp RATIO
270 BW =1000000!/(C1*G1*Z*2*PI)  : B3=BW/F3 : REM BASED ON C1 AND CALC'D G1.
280 BL =SQR(FC^2 + (BW^2)/4) -BW/2    : REM CALCS LOWER BAND EDGE FOR FC & BW.
290 BU =BL + BW         : REM CALCS UPPER BAND EDGE BASED ON BL AND BW
300 PRINT "F-CENTR BW(Ap) BW(3dB) + FAp  R.C.  R.L.  C1,3   C2    L1,3    L2    LP
G2/G1"
310 PRINT " (MHz)  (MHz)   (MHz)  (MHz)    (%)    (dB)  (pF)  (pF)   (uH)   (uH)
RATIO"
320 PRINT USING " #.## ";FC;  : PRINT USING "  #.####";BW; : PRINT USING "   #.###
";B3;
330 PRINT USING " #.### ";BU; : PRINT USING " ##.##";R1;   : PRINT USING "
##.#";RL;
340 PRINT USING " ##### ";C1; : PRINT USING " ####";C2;
350 PRINT USING "   ##.## ";L1;: PRINT USING " ##.##";L2; : PRINT USING "
#.#####";G2/G1
360 PRINT : PRINT "      END OF RUN." : END
370 PRINT "RA=";RA; : PRINT "    G2/G1 RATIO (RA) MUST BE BETWEEN .8 & 1.6."
380 PRINT "                 TRY AGAIN WITH DIFFERENT CAP VALUES." : GOTO 40
```

Example of program output to screen for FC, C1 and C2 = 1.48, 5600 and 820.

| F-CENTR | BW(Ap) | BW(3dB) | +FAp | RC | RL | C1,3 | C2 | L1,3 | L2 | LP G2/G1 |
|---|---|---|---|---|---|---|---|---|---|---|
| (MHz) | (MHz) | (MHz) | (MHz) | (%) | (dB) | (pF) | (pF) | (μH) | (μH) | RATIO |
| 1.48 | 0.4887 | 0.372 | 1.744 | 19.16 | 14.3 | 5600 | 820 | 2.07 | 14.10 | 0.99272 |

BASIC Program

BASIC Program--This BASIC program calculates and prints to screen the parameters and component values of a 50-Ω, 3-resonator BC-band reject filter based on the center frequency and C1 and C2 capacitor values given by the user. Designs are restricted to those having reflection coefficients between 3.8 and 27.2%. This program can be downloaded from the ARRL BBS (860-594-0306) or via the Internet from http://www.arrl.org/qexfiles or ftp://ftp.arrl.org/pub/qex. The file name is qexbsf.zip.

**Example of program output to screen for FC, C1 and C2 = 1.48, 5600 and 820.**

| F-CENTR (MHz) | BW(Ap) (MHz) | BW(3dB) (MHz) | +FAp (MHz) | RC (%) | RL (dB) | C1,3 (pF) | C2 (pF) | L1,3 (µH) | L2 (µH) | LP G2/G1 RATIO |
|---|---|---|---|---|---|---|---|---|---|---|
| 1.48 | 0.4887 | 0.372 | 1.744 | 19.16 | 14.3 | 5600 | 820 | 2.07 | 14.10 | 0.99272 |

**Table 1—Computer-calculated designs for 50-Ω 3-resonator band-stop filters for center frequencies between 1.48 and 0.56 MHz in decrements of 40 kHz.**

| *No* | *Ctr Freq (MHz)* | *BW(Ap) (MHz)* | *BW(3 dB) (MHz)* | *Max +FAp (MHz)* | *Min Refl Coef (%)* | *Ret Loss (dB)* | *C1,3 (pF)* | *C2 (pF)* | *L1,3 (mH)* | *L2 (mH)* |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1.48 | 0.4993 | 0.342 | 1.751 | 12.320 | 18.19 | 6800 | 820 | 1.701 | 14.103 |
| 2 | 1.48 | 0.4887 | 0.372 | 1.744 | 19.165 | 14.35 | 5600 | 820 | 2.065 | 14.103 |
| 3 | 1.44 | 0.6132 | 0.372 | 1.779 | 7.717 | 22.25 | 6800 | 1000 | 1.796 | 12.215 |
| 4 | 1.40 | 0.6708 | 0.434 | 1.775 | 9.839 | 20.14 | 5600 | 1200 | 2.308 | 10.770 |
| 5 | 1.36 | 0.6200 | 0.420 | 1.705 | 11.734 | 18.61 | 5600 | 1200 | 2.446 | 11.412 |
| 6 | 1.32 | 0.7938 | 0.462 | 0.775 | 6.614 | 23.59 | 5600 | 1500 | 2.596 | 9.692 |
| 7 | 1.28 | 0.8629 | 0.533 | 1.782 | 8.239 | 21.68 | 4700 | 1800 | 3.289 | 8.589 |
| 8 | 1.24 | 0.8878 | 0.479 | 1.761 | 5.012 | 26.00 | 5600 | 1800 | 2.942 | 9.152 |
| 9 | 1.20 | 0.9762 | 0.557 | 1.784 | 6.122 | 24.26 | 4700 | 2200 | 3.743 | 7.996 |
| 10 | 1.16 | 0.8681 | 0.534 | 1.673 | 8.123 | 21.81 | 4700 | 2200 | 4.005 | 8.557 |
| 11 | 1.12 | 0.8824 | 0.478 | 1.645 | 5.090 | 25.87 | 5600 | 2200 | 3.606 | 9.179 |
| 12 | 1.08 | 0.9655 | 0.555 | 1.666 | 6.291 | 24.03 | 4700 | 2700 | 4.621 | 8.043 |
| 13 | 1.04 | 1.0470 | 0.644 | 1.688 | 8.108 | 21.82 | 3900 | 3300 | 6.005 | 7.097 |
| 14 | 1.00 | 1.2262 | 0.680 | 1.786 | 5.525 | 25.15 | 3900 | 3900 | 6.495 | 6.495 |
| 15 | 0.96 | 1.0588 | 0.647 | 1.626 | 7.896 | 22.05 | 3900 | 3900 | 7.047 | 7.047 |
| 16 | 0.92 | 1.0600 | 0.571 | 1.592 | 4.986 | 26.05 | 4700 | 3900 | 6.367 | 7.674 |
| 17 | 0.88 | 0.8970 | 0.541 | 1.436 | 7.517 | 22.48 | 4700 | 3900 | 6.959 | 8.387 |
| 18 | 0.84 | 1.0706 | 0.573 | 1.531 | 4.861 | 26.26 | 4700 | 4700 | 7.638 | 7.638 |
| 19 | 0.80 | 0.8910 | 0.540 | 1.361 | 7.638 | 22.34 | 4700 | 4700 | 8.421 | 8.421 |
| 20 | 0.76 | 0.8531 | 0.473 | 1.298 | 5.539 | 25.13 | 5600 | 4700 | 7.831 | 9.331 |
| 21 | 0.72 | 0.7067 | 0.443 | 1.155 | 8.725 | 21.18 | 5600 | 4700 | 8.725 | 10.396 |
| 22 | 0.68 | 0.6654 | 0.383 | 1.090 | 6.336 | 23.96 | 6800 | 4700 | 8.056 | 11.655 |
| 23 | 0.64 | 0.6312 | 0.331 | 1.029 | 4.526 | 26.89 | 8200 | 4700 | 7.542 | 13.158 |
| 24 | 0.60 | 0.4954 | 0.306 | 0.897 | 8.209 | 21.71 | 8200 | 4700 | 8.581 | 14.970 |
| 25 | 0.56 | 0.4503 | 0.260 | 0.829 | 6.412 | 23.86 | 10000 | 4700 | 8.077 | 17.185 |

1. The BW(Ap) and BW(3 dB) column headings refer to the computer-calculated ripple and 3-dB bandwidths, which are based on perfect components. The +*FAp* frequency is the calculated upper limit of the filter stopband and is designed to be less than 1.8 MHz.
2. For typical inductor and capacitor Qs, the actual bandwidths will be about 8% greater than the listed bandwidths. For example, the anticipated actual 3-dB bandwidth of design #2 is about 400 kHz for L and C Qs of 100 and 500, respectively.
3. All BSF designs were based on the listed standard-value capacitors and a return loss of preferably

greater than 18 dB for a +*FAp* frequency less than 1.8 MHz. As the center frequency decreased, it was possible to calculate designs having higher levels of return loss as compared to designs with center frequencies nearer 1.8 MHz.

**Table 2—Normalized L and C Values**

Element values of 3rd-order Chebyshev low-pass filters in Fig A normalized for a ripple cutoff frequency (*F-Ap*) of one radian/sec and 1-Ω terminations. Use the top column headings for the low-pass C-in/out configuration and the bottom column headings for the low-pass L-in/out configuration.

| *No* | *RC (%)* | *F3/F-Ap Ratio* | *C1, 3 (F)* | *L2 (H)* | *G2/G1 RATIO* |
|---|---|---|---|---|---|
| 1 | 12.320 | 1.4594 | 0.937474 | 1.13007 | 1.20544 |
| 2 | 19.165 | 1.3133 | 1.16314 | 1.15467 | 0.99272 |
| 3 | 7.717 | 1.6467 | 0.763425 | 1.06244 | 1.39168 |
| 4 | 9.839 | 1.5449 | 0.847377 | 1.10154 | 1.29994 |
| 5 | 11.734 | 1.4773 | 0.916784 | 1.12463 | 1.22672 |
| 6 | 6.614 | 0.7167 | 0.716017 | 1.03433 | 1.44455 |
| 7 | 8.239 | 1.6182 | 0.784846 | 1.07367 | 1.36800 |
| 8 | 5.012 | 1.8539 | 0.640239 | 0.979386 | 1.52972 |
| 9 | 6.122 | 1.7534 | 0.693752 | 1.01950 | 1.46954 |
| 10 | 8.123 | 1.6243 | 0.780137 | 1.07128 | 1.37319 |
| 11 | 5.090 | 1.8459 | 0.644181 | 0.982562 | 1.52529 |
| 12 | 6.291 | 1.7404 | 0.701485 | 1.02477 | 1.46086 |
| 13 | 8.108 | 1.6251 | 0.779530 | 1.07097 | 1.37386 |
| 14 | 5.525 | 1.8040 | 0.665605 | 0.999203 | 1.50119 |
| 15 | 7.896 | 1.6366 | 0.770836 | 1.06643 | 1.38347 |
| 16 | 4.985 | 1.8568 | 0.638883 | 0.978285 | 1.53124 |
| 17 | 7.517 | 1.6583 | 0.755053 | 1.05781 | 1.40097 |
| 18 | 4.861 | 1.8700 | 0.760127 | 1.06063 | 1.39534 |
| 20 | 5.539 | 1.8027 | 0.666290 | 0.999717 | 1.50042 |
| 21 | 7.873 | 1.6379 | 0.769891 | 1.06593 | 1.38452 |
| 22 | 6.336 | 1.7370 | 0.703536 | 1.02614 | 1.45855 |
| 23 | 4.526 | 1.9083 | 0.615023 | 0.958211 | 1.55801 |
| 24 | 8.209 | 1.6198 | 0.783635 | 1.07306 | 1.36933 |
| 25 | 6.412 | 1.7313 | 0.706981 | 1.02844 | 1.45469 |
| 26 | 4.796 | 1.8772 | 0.629196 | 0.970296 | 1.54212 |
| *No* | *RC (%)* | *F3/F-Ap Ratio* | *L1, 3 (H)* | *C2 (F)* | *G2/G1 RATIO* |

Notes:
1. The normalized values of nos 1 to 25 were used in calculating the twenty-five band-stop filters listed in Table 1. The no. 26 values are included to allow them to be confirmed by comparing them with the published values in Table 16.2 of *The 1996 ARRL Handbook* for N=3.
2. The G2/G1 ratios were obtained by dividing L2 by C1.

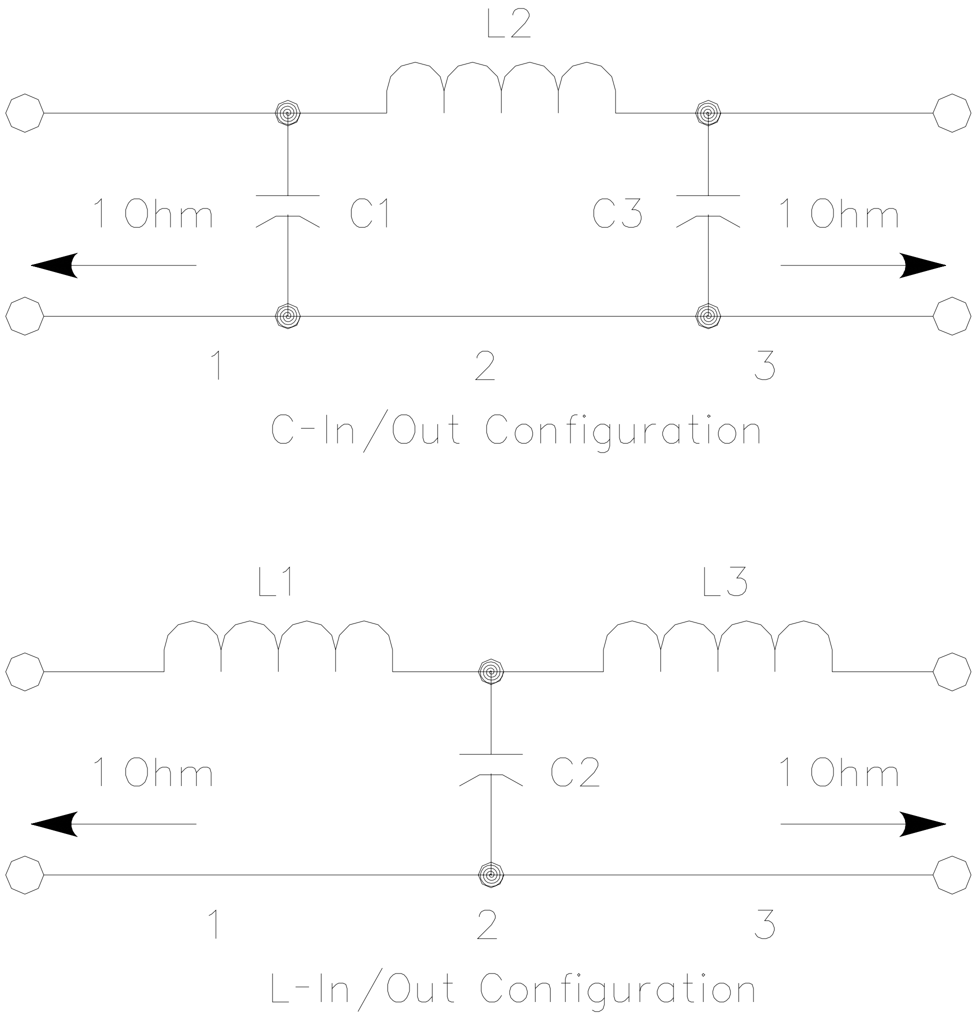


Fig A--Schematic diagrams of 3rd-order Chebyshev low-pass filters.

 

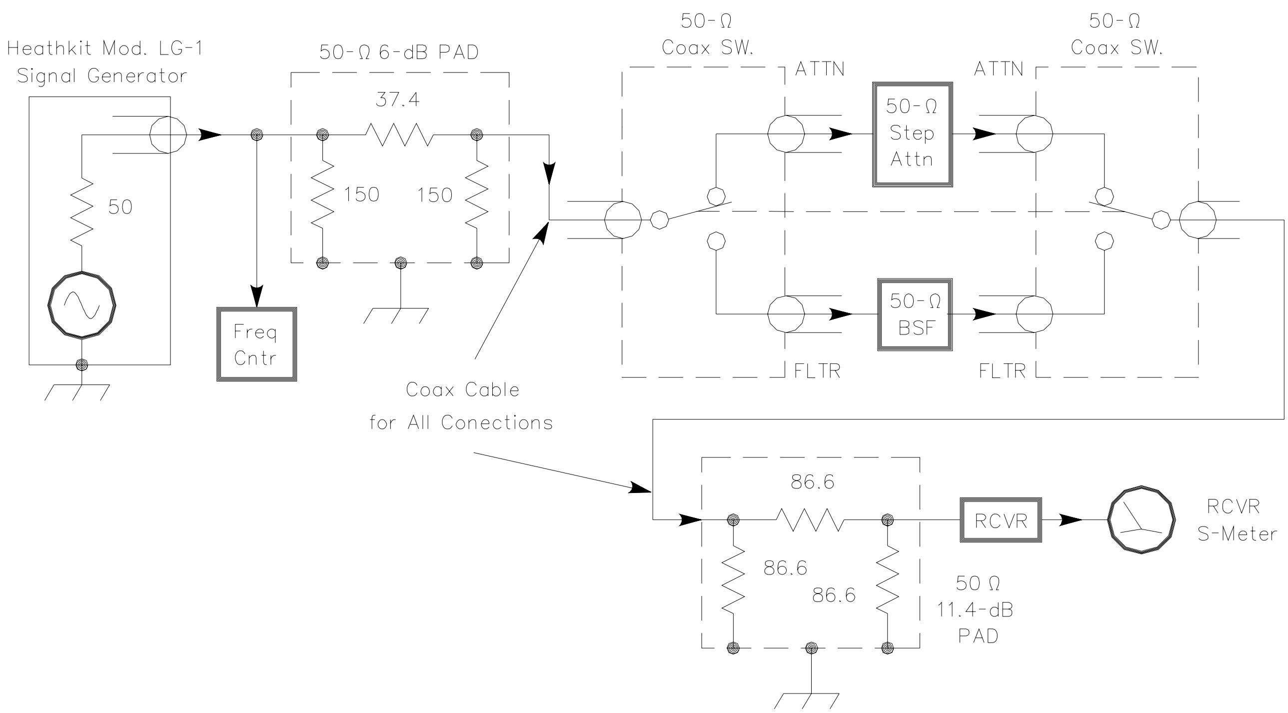


Fig B—Test set-up used to measure the insertion loss of the band-stop filter in a 50- Ω test system.

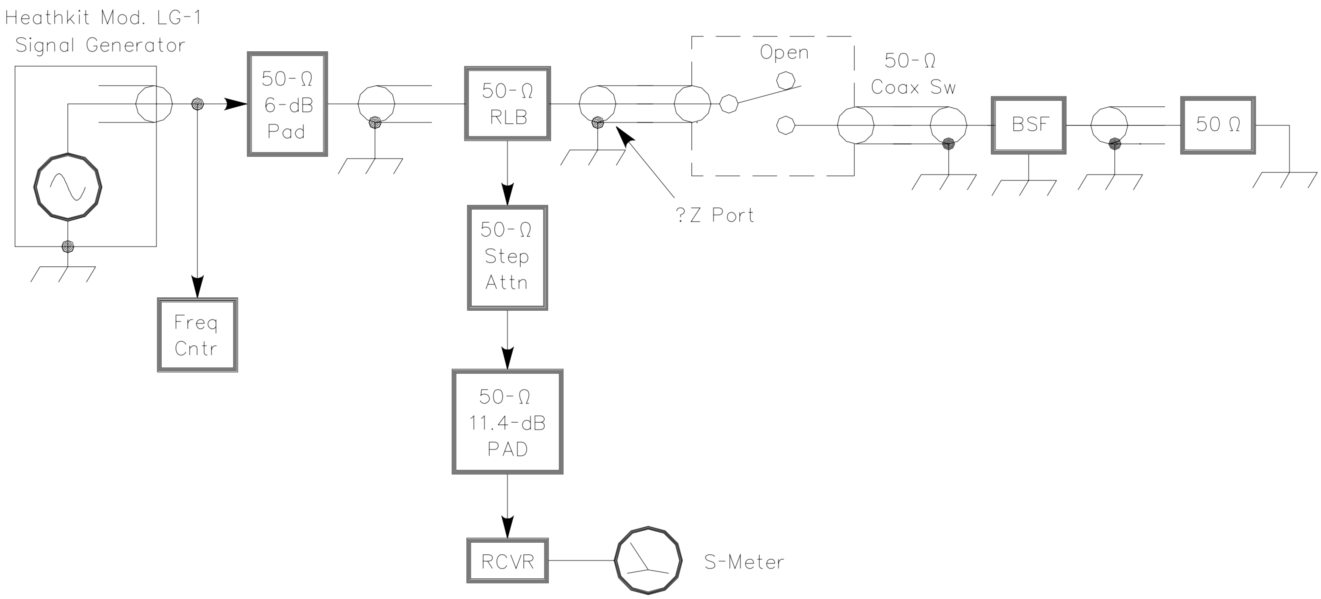


Fig C—Test set-up used to measure the return loss of the band-stop filter when it is terminated in 50 Ω.

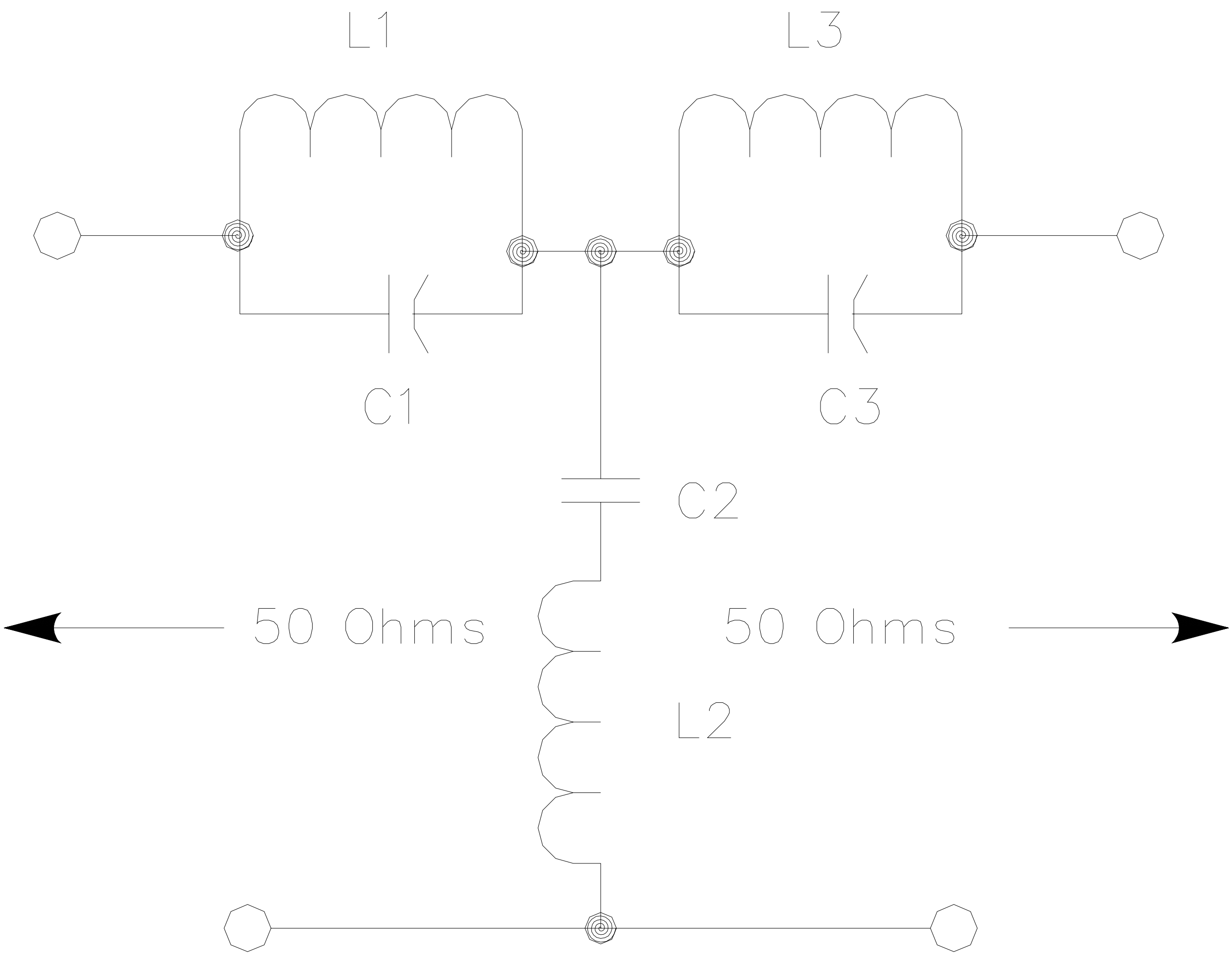


Fig 1—Schematic diagram of the 50-Ω, 3-resonator band-stop filter.

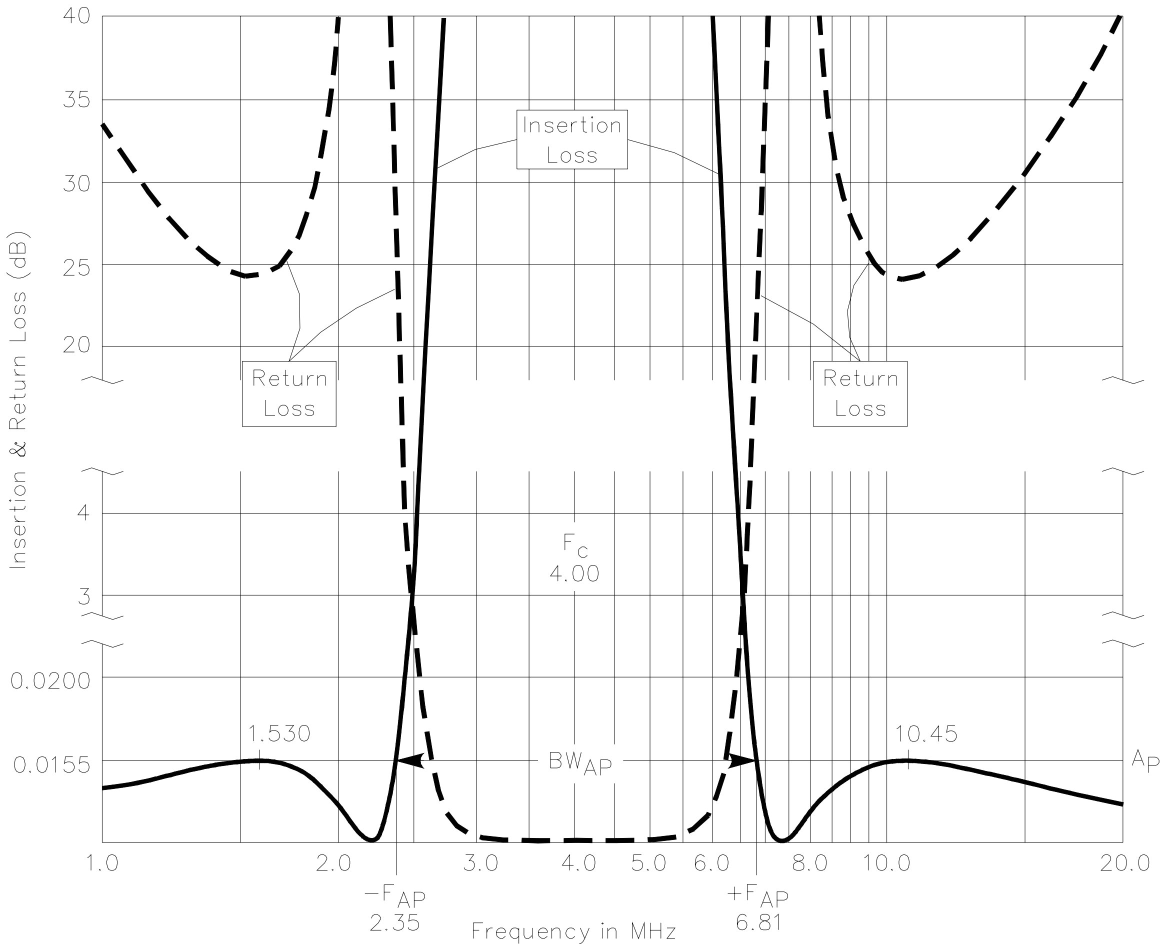


Fig 2—Typical insertion- and return-loss responses of a 3-resonator Chebyshev band-stop filter with the lower and upper ripple cut-off frequencies indicated by -*FAP* and +*FAP*, respectively.

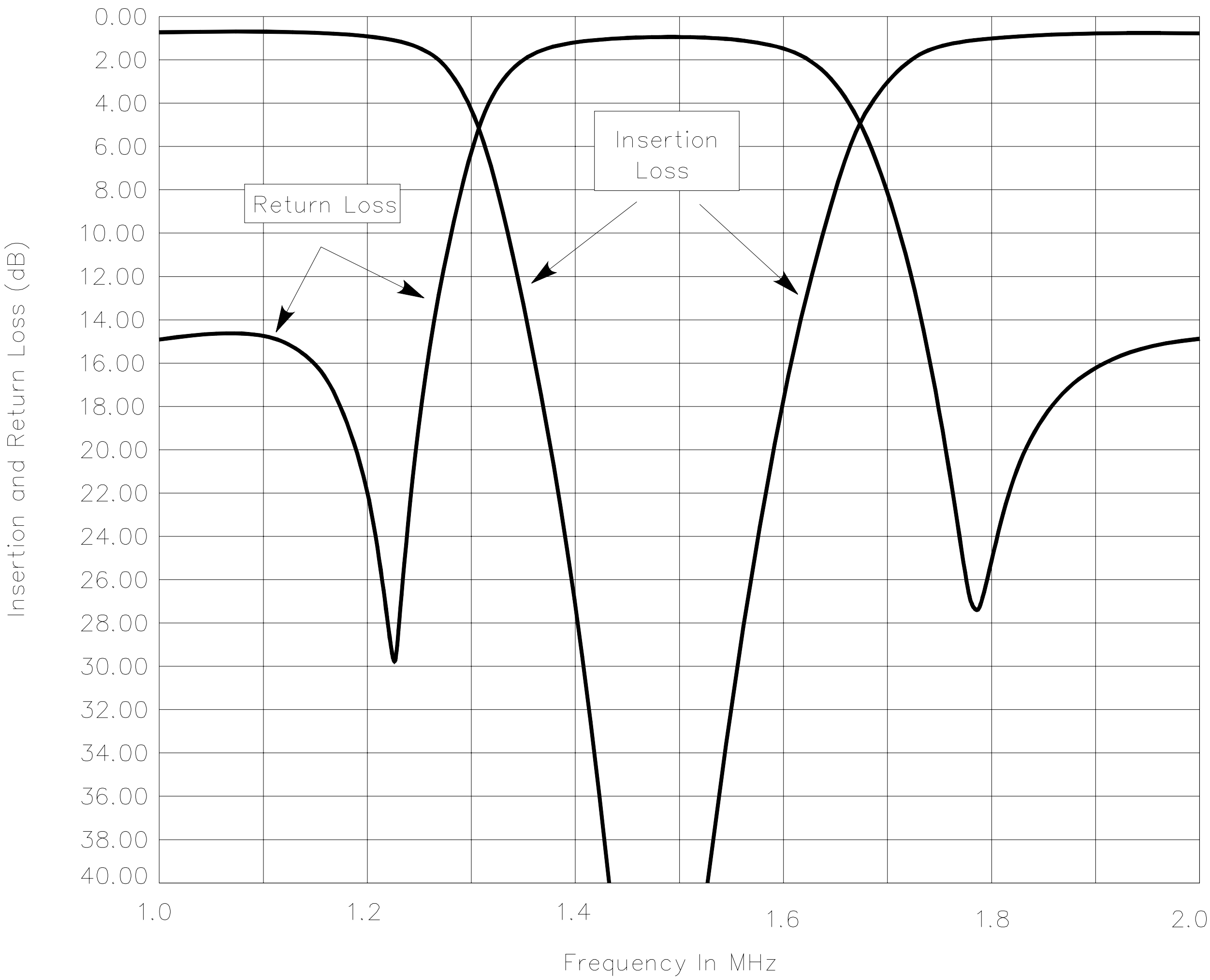


Fig 3—Computer-calculated insertion and return-loss responses of the 1.48-MHz band-stop filter of design #2 in Table 1. The inductor and capacitor Qs were specified as 78 and 500.

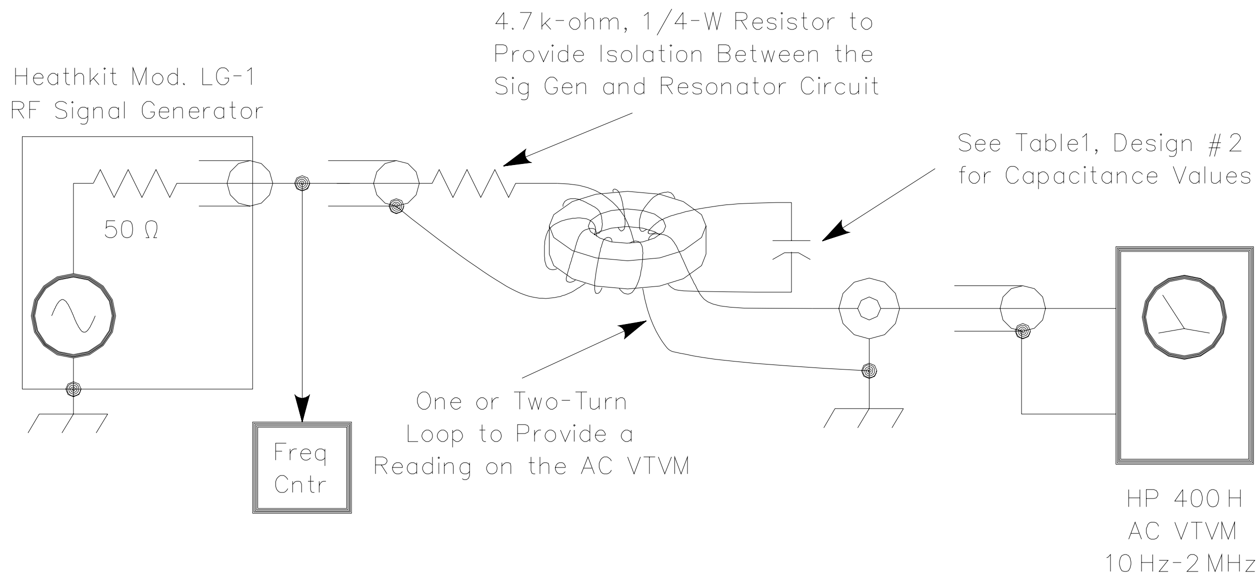


Fig 4—Equipment set-up and procedure used to tune each filter resonator to the center frequency of the band-stop filter.

Notes:

1. Turns are removed or added to the inductor core and then squeezed together or spread apart until the circuit resonates at the desired center frequency.
2. Resonance is indicated by a peak reading on the ac VTVM.
3. The LG-1 signal generator output across a 4.7-kΩ resistor is about 500 mV. The signal level coupled into the ac VTVM by the 1 or 2-turn loop is about 300 µV.

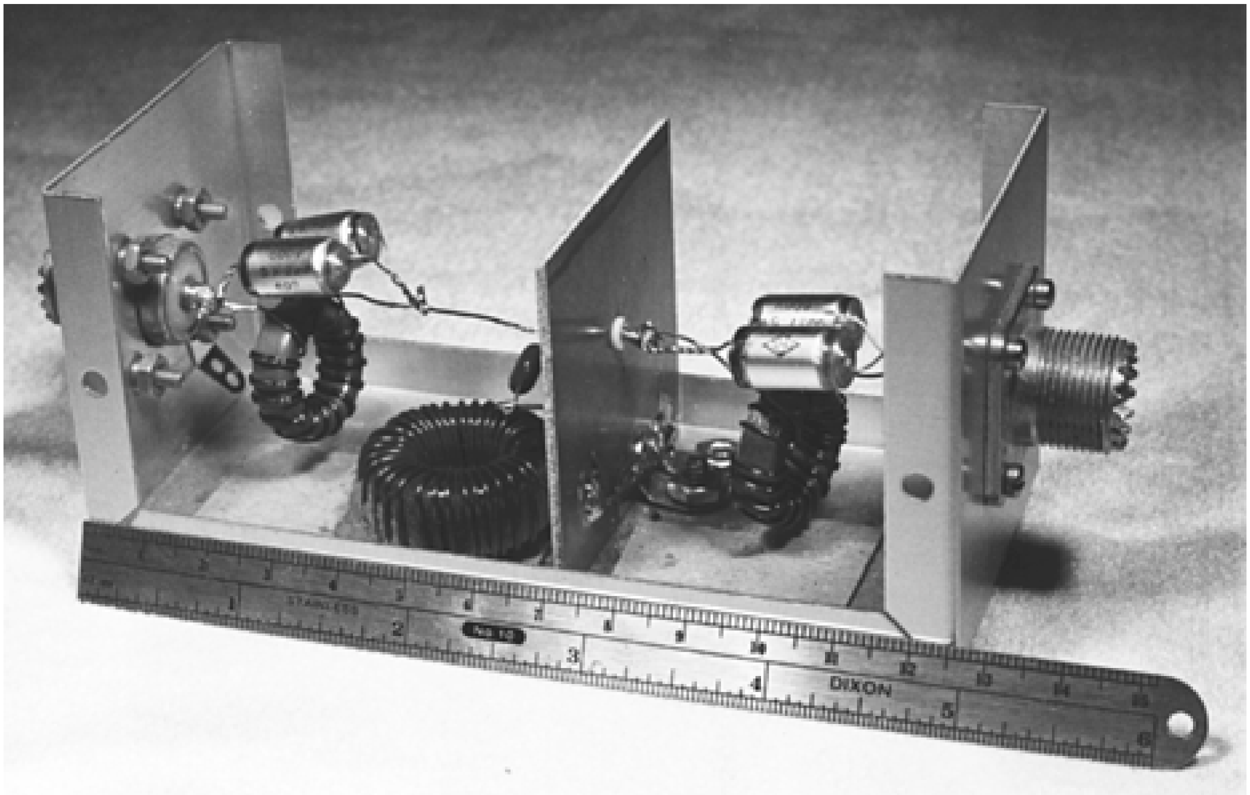


Fig 5—Photo of the assembled 1.48-MHz band-stop filter. Inductors L1 and L3 and capacitors C1, C2 and C3 are light enough to be supported by just their leads. The largest inductor, L2, is secured to a cardboard pad on the bottom of the aluminum box with RTV.

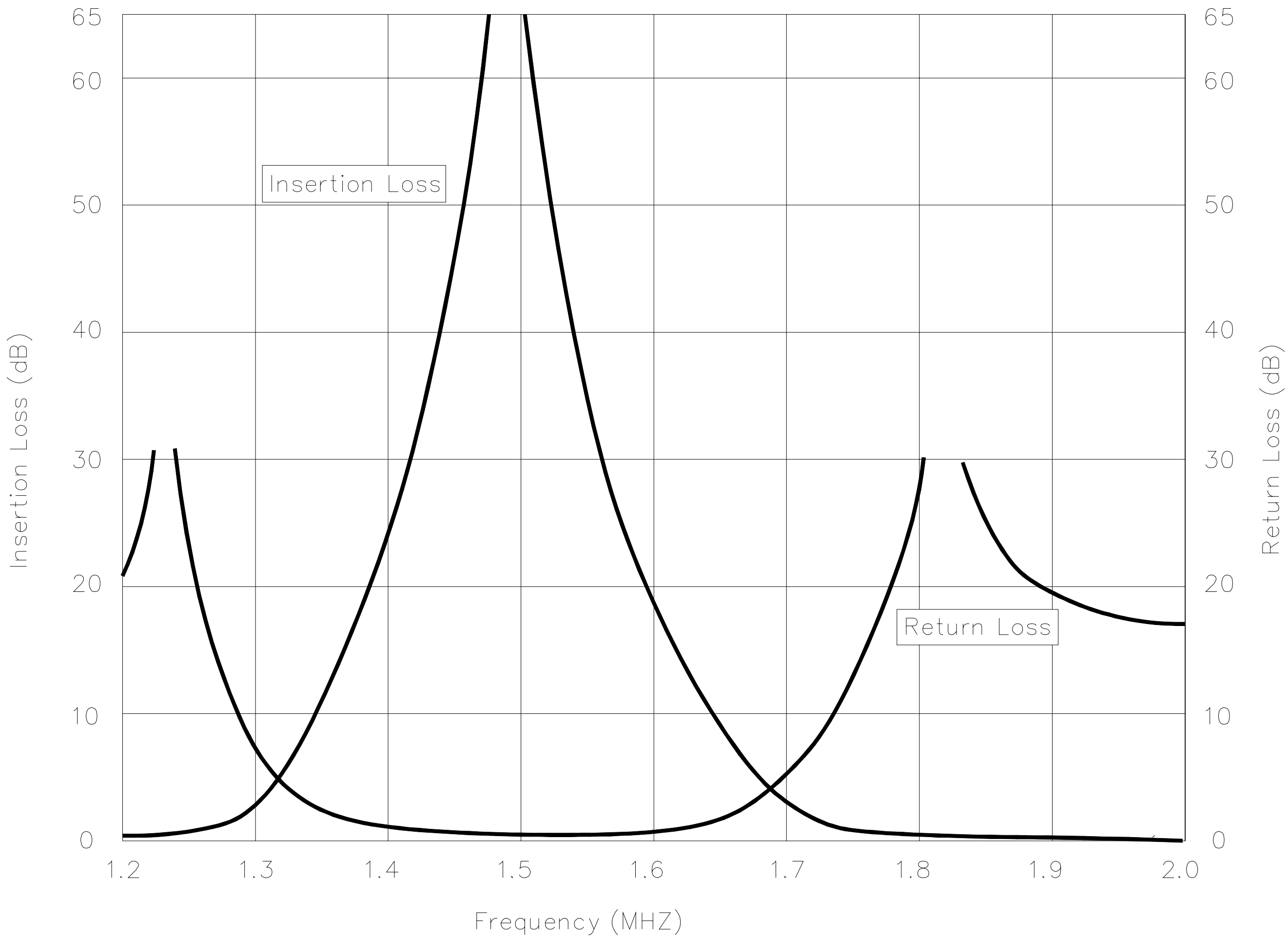


Fig 6—Measured insertion- and return-loss responses of the 1.48-MHz band-stop filter of design #2 in  Table 1. The mea-sured L1,3 and L2 inductor Qs are 110 and 160, respectively.