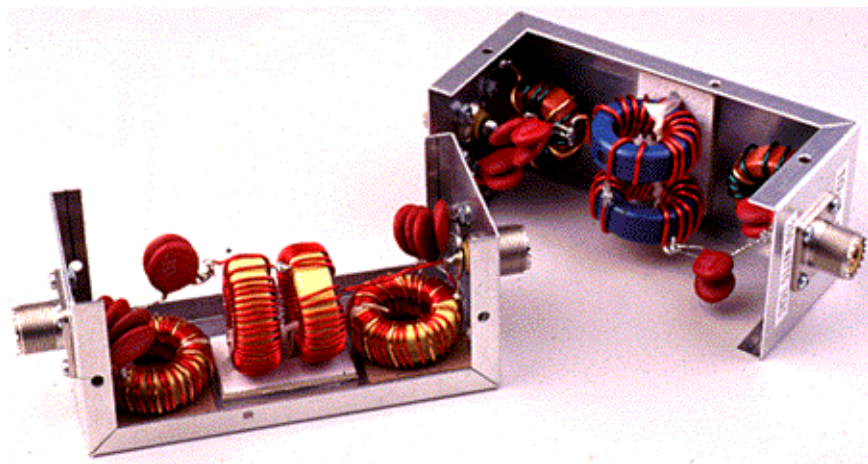


# Clean Up Your Signals with Band-Pass Filters

**Part 1—These inexpensive, easily built filters can be the buffer you need between the signals you want to hear and send and those you don't!**

By Ed Wetherhold, W3NQN



**An inside view of 160 meter and 10 meter BPFs housed in 2<sup>1</sup>/<sub>4</sub>×2<sup>1</sup>/<sub>4</sub>×5-inch (HWD) boxes equipped with SO-239 connectors at each end. With the exception of the 10 meter BPF, the filters are now housed in slightly larger boxes—2<sup>1</sup>/<sub>8</sub>×3×5<sup>1</sup>/<sub>4</sub>-inch (HWD)—to lessen component crowding and minimize response degeneration when the cover is installed.**

In January 1996, Tim Duffy, K3LR, chief operator of one of the top-three-ranked multi-multi contest stations, contacted me. Tim asked me to design a series of band-pass filters (BPFs) that he could use between his 150 W transceivers and 1500 W amplifiers. He wanted to reduce the transfer of harmonics and broadband phase noise to the amplifiers. The filters would also make the transceivers, when receiving, less susceptible to overload from the adjacent-band transmitters. This project is the result of my efforts in designing, constructing and testing BPFs for six amateur bands—160, 80, 40, 20, 15 and 10 meters.

These filters provide a level of selectivity and reliability unachieved in currently available filters—including commercial units. This performance is obtained by employing a three-resonator filter configuration using inductors wound on powdered-iron or phenolic toroidal cores, and series-parallel connected, high-voltage, low-loss NP0 ceramic capacitors. If you're a contester (especially one who's involved in multi-multi contesting and ARRL Field-Day activity), these filters are *what you need!* [1] (*Editor's note: You don't have to operate multi-multi to reap the benefits of these filters. Do remember that these are single-band filters and must be switched appropriately when changing bands or you'll let the smoke out.*)

## Background

Multiple-transmitter interference was discussed recently by Thomas Moliere, DL7AV, in his *CQ Contest* article. [2] Tom's article is an excellent list of the many interference sources common to this type of operation. Multiple-transmitter operation at a single site creates an unusual RF environment that results in many unexpected interference problems not normally encountered with single-station setups. For example, in addition to transmitter harmonics, there can be receiver blocking and damage, and the generation of harmonics and intermodulation at the nonlinear receiver input. Tom's article shows how the addition of 1500 W, high-power, low-pass filters at the transmitter's outputs proved helpful. Here, I'll concentrate on filters designed to be placed *between a transceiver and the input to a high-power amplifier*. The advantage of this approach is that the filters can be constructed using standard, readily available components for an ICAS power level of 200 W. (This is not the case for filter components required for use at a power level of 1500 W.)

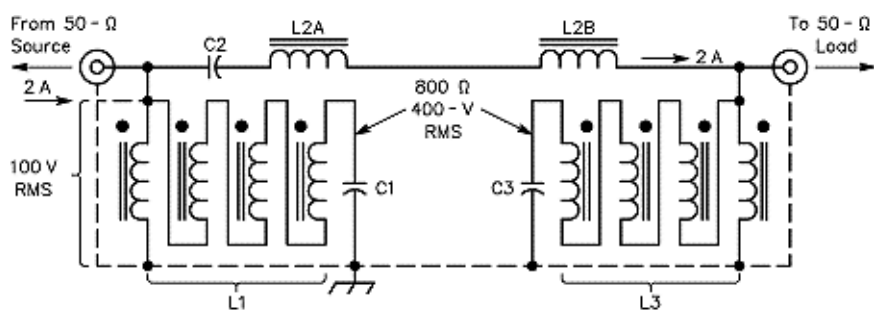
A recent *QST* harmonic-attenuation BPF article describes a three-resonator design. [3] Although the BPF performance is

satisfactory, it is limited to a power level of 100 W, and the L1 and L3 reactances are too low for good Q. Also, the design information is limited, so readers can't confirm the author's designs and try others. Another QST project uses capacitively coupled input and output resonators. [4] The omission of a series inductor in the coupling circuit, however, results in poor stopband attenuation above the upper cut-off frequency. A commercially available BPF used by many multi-multi contesters also exhibits similar poor, high-frequency attenuation.

The new BPFs provide for higher-power handling, increased reliability and greater attenuation. To help you evaluate many different designs and select the most-promising ones for trial, I've included a 62-line BASIC program that allows you to change component values and explore the resultant effect on the BPF bandwidth, return loss and stopband attenuation. [5]

## Band-Pass Filter Design

I selected a three-resonator Chebyshev BPF for use on the six bands (see Figure 1). This filter is a satisfactory compromise between adequate selectivity and acceptable complexity. The filter consists of input and output parallel-tuned shunt resonators with their tops initially coupled by a series-tuned resonator. The resonators, capacitors and inductors are numbered from left to right as 1, 2 and 3.



### Notes:

1. The listed RMS voltages and current in the diagram are for an input power of 200 W.
2. L1 and L3 are quadrifilar wound with 50-Ω taps.
3. L2A and L2B are wound on separate toroidal cores.
4. ● = Phasing

**Figure 1—Schematic of a three-resonator band-pass filter (BPF). L1 and L3 are *quadrifilar* wound and equipped with a 50-Ω tap point. L2A and L2B are wound on separate toroidal cores. The RMS voltages and currents shown represent a filter input power of 200 W.**

## Component Values

Resonators 1 and 3 have identical component values. To minimize the component-value spread to less than 3.6 to 1, the filter impedance is made 450 or 800 Ω, and the input and output shunt inductors tapped appropriately to obtain 50 Ω. This allows L1 and L3 to have a reactance of more than 100 Ω, assuring a reasonable Q. By comparison, the three-resonator BPF designs in the September 1988 QST article (see Note 3) have L1 and L3 reactances of only 25 Ω.

## Winding Type and Inductance Value

Figure 1 is the basic circuit for all the filters, but shows the *quadrifilar-wound* inductors used in the 160, 40, 15 and 10 meter BPFs. Although a quadrifilar winding is generally preferred for all designs to minimize component value spread, inductance-value limitations with the quadrifilar winding prevent using that configuration for the 80 meter filter. On that band, *trifilar windings* are used for L1 and L3. *Trifilar windings* were also used in the 20 meter BPF because they give an attenuation maximum at the second harmonic frequency of the 14-MHz signal.

Using a trifilar or quadrifilar winding means that a particular inductance value cannot be obtained by simply adding or removing one or two turns. Instead, any turns added or removed must be done *as multiples or submultiples* of three or four turns to maintain the trifilar or quadrifilar configuration. This winding limitation makes it more difficult to obtain a particular inductance value. In spite of this, the trifilar and quadrifilar windings are preferred because much better interwinding coupling results over the entire inductor. This provides a correspondingly greater stopband attenuation than is possible with the more common progressive winding.

## Achieving a 50-W Tap

The taps on L1 and L3 are used as the input and output connections to the filter and should be terminated in a 50  $\Omega$  impedance. (These taps also serve as the final connection points for the series-resonant circuit of C2 and L2.) Because the impedance of an inductor varies as the square of turns, the input/output tap is placed at a point having  $1/3$  or  $1/4$  of the total number of turns so that the tap impedance is  $1/9$  or  $1/16$  of the total impedance. For example, on a trifilar-wound inductor of a 450  $\Omega$  resonator, the impedance at the  $1/3$  tap is  $450/3^2 = 50 \Omega$ . The impedance at the  $1/4$  tap of a quad-rifilar-wound inductor of an 800  $\Omega$  resonator is  $800/4^2 = 50 \Omega$ .

## Calculating BPF Component Values

I'll use the calculation of the 160 meter filter components as an example of the procedure followed to design all the filters. First, a preliminary design is made to find trial component values, then the BASIC program (see Note 5) is used to evaluate a number of designs using a range of C1 and C2 values near the trial C1 and C2 values. The most-promising design is assembled and tested. If its performance is satisfactory, the design is accepted.

To calculate the preliminary 160 meter BPF component values, I use the procedure described in *The ARRL Handbook*. [6] Because the 160 meter bandwidth is 0.20 MHz, I first design a 50  $\Omega$  Chebyshev low-pass filter having a ripple cut-off frequency of 0.28 MHz, slightly greater than the actual bandwidth. (A Chebyshev filter has many possible designs and is preferred to a Butterworth, which has only one possible design.) To minimize reflective losses, I use a return loss greater than 22 dB.

Referring to *Handbook* Table 16.2, the normalized component values associated with  $N = 3$  and  $RL = 26$  dB, where  $C1, C3 = 0.6292$  F and  $L2 = 0.9703$  H, are used to calculate a C-in/out low-pass filter having a cutoff frequency of 0.28 MHz. The capacitive and inductive *scaling factors* based on a 50  $\Omega$  filter are  $11368 \times 10^{-12}$  and  $28.421 \times 10^{-6}$ , respectively. Multiplying the normalized C and L values by the respective scaling factors gives C1, C3 and L2 values of 7153 pF and 27.58  $\mu$ H, respectively.

The 50  $\Omega$  low-pass filter is transformed into a band-pass filter by resonating C1, C3 and L2 at 1.87 MHz, the geometric center frequency of the band-pass filter. For example,  $L1$  and  $L3 = 25330/((F^2) \times C1)$ , and  $C2 = 25330/((F^2) \times L2)$ , where F, C and L are in megahertz, picofarads and micro-henries, respectively. The three-resonator BPF has shunt input and output parallel-tuned resonators with C1 and C3 = 7153 pF and L1 and L3 = 1.013  $\mu$ H; the series-tuned resonator has C2 and L2 values of 262.6 pF and 27.58  $\mu$ H. Although this BPF has the desired theoretical response, the design is *not optimum* because of the wide spread in the ratio of the C1 and C2 values. For example, the ratio of  $C1/C2 = 27$ . At the center frequency, the reactances of C1 and C3 and L1 and L3 are only 11.9  $\Omega$ ; this is too low a reactance to obtain a reasonable Q. In comparison, the C2 and L2 reactances are satisfactory at 324  $\Omega$ , where a satisfactory Q is much easier to achieve.

To improve the Qs of the C1 and L1 and C3 and L3 shunt resonators, and to reduce the component-value spread, the impedance of the shunt resonators can be raised by a factor of 4, 9 or 16, to 200, 450 or 800  $\Omega$ , respectively. The 50  $\Omega$  series C2/L2 resonator then connects to input/output taps at  $1/2$ ,  $1/3$  or  $1/4$  of the turns above the ground connection. For the 160 meter BPF used in this example, L1 and L3 are quadrifilar wound with the 50  $\Omega$  taps connected to the top of the first quarter winding above ground. The L1 and L3 and C1 and C3 values then become 16 and  $1/16$  times the 50  $\Omega$  values, or 16.2  $\mu$ H and 447 pF, respectively. By using a quadrifilar tap, the component spread is reduced to about 1.7, and the L1 and L3 reactance at the center frequency is 16 *times greater* than before, or 190  $\Omega$ . This level of reactance is much more suitable for achieving a satisfactory inductor Q.

## BASIC Program Calculates Many BPF Designs

Having decided on a winding style for L1 and L3, and finding trial values for C1 and C2, I then employ the BASIC program to evaluate many different designs (see Note 5). Although the program designs 160 meter BPFs, it is easily modified for other bands by changing the center-frequency variable (FC) from 1.87 to a new center frequency, and changing the C1 and C2 values to those appropriate for the new band.

To use the program, enter values for the variables TR, FC, C1 and C2. TR is the tap ratio, with the digits 3 and 4 indicating trifilar and quadrifilar windings, respectively. FC is the center frequency in megahertz (MHz), and C1 and C2 values are in picofarads (pF). The trial values of C1 and C2 were previously hand-calculated to be 447 pF and 263 pF, respectively, and some preliminary computer trials confirmed that the acceptable range of C1 is between 440 to 450 pF; consequently, this range is used for C1. C2's range was specified to be between 250 to 300 pF. When the program is run with these variables, the result lists six designs each for C1 = 440 and 450 pF, and for C2 ranging from 250 to 300 pF. If necessary, smaller capacitance increments can be used. For this demonstration, a step of 10 for C1 and C2 is adequate.

See **Table 1** for the tabulation of 160-meter BPF parameters for TR = 4 with an L1 and L3 impedance of 800  $\Omega$ . Of all the

possibilities, I considered only the design for C1 and C2 = 440 and 250 because I had capacitors on hand to realize those values. The 16.46  $\mu\text{H}$  inductance value is obtained by using a quadrifilar winding on a Micrometals T130-6 core. Examination of the ripple cutoff frequencies of 1.75 and 1.99 MHz, the frequencies of 1.16 and 3.02 MHz at the 35-dB level and the return loss of 30 dB show that all are satisfactory. This design is acceptable, and its design, performance and construction parameters are listed in **Table 2A** for reference.

**Table 1—Tabulation of 160 Meter Band-Pass Filter Parameters for TR=4, Z(W)=800**

F-C	-FAp (MHz)	+FAp	BW 3 dB (%)	F-	35 dB (MHz)	F+	RL (dB)	RC (%)	C1, C3 (pF)	C2 (pF)	L1, L3 ( $\mu\text{H}$ )	L2 ( $\mu\text{H}$ )	XL1 ( $\Omega$ )
1.87	1.75	1.99	27.4	1.16		3.02	30.0	3.15	440	250	16.46	28.97	193
1.87	1.74	2.01	28.1	1.15		3.03	27.7	4.12	440	260	16.46	27.86	193
1.87	1.73	2.02	28.8	1.15		3.05	25.8	5.11	440	270	16.46	26.83	193
1.87	1.72	2.03	29.4	1.14		3.07	24.3	6.11	440	280	16.46	25.87	193
1.87	1.71	2.04	30.0	1.13		3.09	22.9	7.13	440	290	16.46	24.98	193
1.87	1.70	2.05	30.7	1.13		3.11	21.8	8.15	440	300	16.46	24.15	193
1.87	1.75	2.00	27.2	1.17		3.00	28.6	3.70	450	250	16.10	28.97	189
1.87	1.74	2.01	27.9	1.16		3.01	26.6	4.70	450	260	16.10	27.86	189
1.87	1.73	2.03	28.5	1.15		3.03	24.8	5.72	450	270	16.10	26.83	189
1.87	1.72	2.04	29.1	1.15		3.05	23.4	6.76	450	280	16.10	25.87	189
1.87	1.71	2.05	29.8	1.14		3.07	22.2	7.80	450	290	16.10	24.98	189
1.87	1.70	2.06	30.4	1.13		3.08	21.1	8.85	450	300	16.10	24.15	189

**Table 2A—Parameters for 160, 80, and 40 Meter Band-Pass Filters**

Parameters/Band (MHz)	160 Meters (1.8 - 1.94)	80 Meters (3.5 - 3.91)	40 Meters (7 - 7.3)
Fc, BW (MHz), %BW	1.870, 0.120, 6.42%	3.700, 0.410, 11.1%	7.150, 0.300, 4.20%
F-Ap, +BW Ap (MHz)	1.753, 1.995, 0.242	3.366, 4.067, 0.701	6.740, 7.584, 0.844
RL (dB), RC%	30.0, 3.15%	22.8, 7.22%	30.2, 3.08%
3-dB BW (MHz) and %BW	0.5128, 27.4%	1.174, 31.7%	1.801, 25.2%
Calc freqs (MHz) @ 35 dB	1.16, 3.02	2.18, 6.27	4.60, 11.1
L1,L3; Qu & XL @ Fc	16.46 $\mu\text{H}$ , 195, 193	4.93 $\mu\text{H}$ , 170, 115	3.96 $\mu\text{H}$ , 150, 178
Core & AL (nH/N2)	T130-6, 9.6	T130-17, 4.0	T130-17, 4.0
Total wire turns and gauge	40: 10 #16, 30 #18	33: 11 #16, 22 #18	28: 7 #16, 21 #18
No. and type of turns	10 quadrifilar	11 trifilar	7 quadrifilar
Wire lengths (inches) and gauge	17.5 #16; 45.7 #18	19 #16; 34 #18	13 #16; 33 #18
L2( $\mu\text{H}$ ), Q & XL @ Fc	28.97, 320, 340	11.94, 250, 287	8.26, 220, 371
L2a and L2b ( $\mu\text{H}$ )	14.8, 14.2	5.97, 5.97	4.13, 4.13
No. turns (a, b) and core type	39, 38 on T130-6	37, 37 on T130-17	30, 30 on T130-17
Wire lengths (inches) and gauge	60 and 59, #18	58 and 57, #18	47 and 48, #18
C1, C3 (pF)	440=110 p 110 p 110 p 110	375=110 p 110 p 110 p 30 p 15	125=(220 s 220) p 15
C2 (pF)	250=110 p 110 p 30	155=31 p 31 p 31 p 31 p 31	60=30 p 30
C1/C2 Ratio	1.76	2.42	2.08

**Notes**

In the C1 and C3 capacitance declarations, a *p* or an *s* indicates that two or more capacitors are connected in *parallel* or *series*, respectively, to obtain the design capacitance value (ie, 30 p 30 means two 30 pF capacitors are connected in parallel (60 pF total); 15 s 15 means two 15 pF capacitors are connected in series (7.5 pF total).

The 110, 30 and 15 pF capacitors are Tusonix NP0 10% disc ceramics with voltage ratings of 2, 3 and 4 kV, respectively. The 220 pF disc ceramic capacitors are Ceramite NP0 5% 1 kV, type 10TCCT22.

Toroidal cores are Micrometals T130-6 (yellow) or T130-17 (blue/yellow).

L1 and L3 are tuned by injecting a signal at the center frequency into the 50 Ω tap through a 2.2 kΩ resistor. A 50 Ω detector is coupled to the inductor with a one-turn loop and the inductor turns are adjusted for a maximum signal level indication on the detector output meter.

For tuning L2, the assembled filter is terminated at one end with a 50 Ω load while the other end of the filter is connected to a return loss bridge. While monitoring the detected output of the return-loss bridge with an oscilloscope, adjust the L2 windings for an optimum return-loss response over the filter passband.

**Table 2B—Parameters for 20, 15 and 10 Meter Band-Pass Filters**

Parameters/Band (MHz)	20 Meters (14 - 14.4)	15 Meters (21 - 21.45)	10 Meters (28 - 29.7)
F <sub>c</sub> , BW (MHz), %BW	14.88, 2.38, 16%	21.22, 0.450, 2.12%	28.84, 1.70, 5.89%
F-Ap <sub>-</sub> , BW Ap (MHz)	13.74, 16.12, 2.38	20.43, 22.04, 1.605	27.18, 30.60, 3.424
RL (dB), RC%	27.3 4.34	35.1, 1.75	24.4, 6.01
3 dB BW (MHz) and %BW	4.59, 30.9%	4.057, 19.1%	6.035, 20.9%
Calc freqs (MHz) @ 35 dB	8.79, 25.2	15.0, 30.0	20.1, 41.3
L1, L3; Q <sub>u</sub> , and X <sub>L</sub> @ F <sub>c</sub>	1.27 μH, 140, 119	1.053 μH, 120, 140	0.761 μH, 100, 138
Core and A <sub>L</sub> (nH/N2)	T130-17, 4.0	T130-0, 1.50	T106-0, 1.90
Total turns and gauge	15: 5 t #15, 10 t #15	20: 5 t #16, 15 t #16	16: 4 t #16, 12 t #16
No. and type of turns	5 trifilar	5 quadrifilar	4 quadrifilar
Wire lengths (inches) and gauge	10.2 and 17.8 15	10 #16; 25 #16	8 #16; 19.6 #16
L2 (μH), Q <sub>u</sub> and X <sub>L</sub> @ F <sub>c</sub>	3.18, 220, 297	3.75, 180, 500	2.36, 130, 428
L2a and L2b (μH)	1.70, 1.48	1.87, 1.88	1.10 and 1.26
No. turns (a, b) and core type	18, 17 on T130-17	19, 19 on T130-17	14, 15 on T130-17
Wire lengths (inches) and gauge	30, 28.5 #16	31.0, 31.0, #16 green	23.5, 25.1, #16
C1, C3 (pF)	90(30 p 30 p 30)	53.4=(100 s 100) p (6.8 s 6.8)	40.0=(15 p 15) p (20 s 20)
C2 (pF)	36(30 p 30 p 30)s (30 p 30)	15=(15 p 15) s (15 p 15)	12.9=[(15 s 15) p 15] s (15 p 15)
C1/C2 ratio	2.5	3.56	3.1

**Notes**

In the C1 and C3 capacitance declarations, a *p* or an *s* indicates that two or more capacitors are connected in *parallel* or *series*, respectively, to obtain the design capacitance value (ie, 30 p 30 means two 30 pF capacitors are connected in parallel (60 pF total); 15 s 15 means two 15 pF capacitors are connected in series (7.5 pF total).

The 15 and 30 pF capacitors are Tusonix, NP0, 10% disc ceramics with a 3 and 4-kV voltage rating, respectively. Other capacitors are CeraMite, NP0, 5%, disc ceramics rated at 1 kVDC @ 300 VAC RMS.

All cores are Micrometals T130-17, T130-0 or T106-0.

See notes of **Table 2A** for the suggested tuning procedures.

## ELSIE Confirms the Design

The correctness of the design selected from the 160 meter BPF tabulation was further confirmed by evaluating it with a filter analysis program named *ELSIE*, available from Trinity Software. [7] *ELSIE*-calculated plots of return loss and insertion loss are presented in the Appendix (next month) along with the component values used in the computer simulation. The design selected from the BASIC program 160 meter tabulation is confirmed by noting that the *ELSIE*-calculated return loss of 30 dB and the 35 dB frequencies of the plots are *identical* with the computer-calculated values obtained with the BASIC program. In the *ELSIE* insertion-loss plot, the measured insertion loss above 2.2 MHz is greater than the *ELSIE*-calculated curve. I'll explain the reason for this later.

If the first attempts to obtain a satisfactory L1 and L3 value are unsuccessful, try other quadrifilar windings with four more or four fewer turns, and find the exact C1 capacitance needed to resonate the inductor at the center frequency. Then, use the program with C1's value fixed and let C2 vary over a limited range to find an acceptable design. No doubt many possible designs will be available, but only those with a 3 dB percentage bandwidth of less than 32% are narrow enough to be useful.

## Toroidal-Core Selection

All inductors used in the BPFs are wound on powdered-iron or phenolic toroidal cores. Although this approach is more expensive than using simpler solenoidal-wound air-core coils, the toroidal type is preferred because of its self-shielding characteristic that allows the inductors to be physically close with little interaction, making for a more compact filter.

For power levels of less than 1 W, core sizes of 0.44 inches outer diameter or less are commonly used. At power levels of 150 to 200 W, however, the core size must be much larger to dissipate the heat resulting from core and winding losses without excessive temperature rise. Many years ago, it was a common misconception that core saturation was the primary limiting factor in high-power RF applications. However, Micrometals' core-loss measurements of their iron-powder cores at high frequencies show that, with sine-wave signals, *excessive temperature rise* resulting from the losses in the winding and core material is the limiting factor. [8, 9] Micrometals specifies the maximum permissible core temperature at 100°C, but any long-term temperature above 90°C accelerates the deterioration of the core's binding material. Consequently, a temperature rise of less than 40°C is preferred so that in an ambient of 90°F (typical temperature for a hot day), the core temperature will be not more than  $32 + 40^\circ\text{C} = 72^\circ\text{C}$ , or well below 90°C.

After each BPF design was complete, the filter was assembled and tested under a 200 W continuous load to confirm that the temperature rises of all inductors and capacitors is acceptable. Tim Duffy, K3LR, did most of the early power testing of the BPFs under load. John Brosnahan, W0UN, provided additional power testing later during the development of the BPFs. Both Tim and John provided network analyzer plots of insertion loss and return loss using Hewlett-Packard equipment usually not available to the average amateur experimenter. Their valuable assistance was crucial in confirming both the power capabilities and response performance of the BPFs, permitting the BPF development to progress with the assurance the designs were completely satisfactory. Several times different design variations were tried until Tim was satisfied that the BPF performance would be acceptable for the multi-multi applications.

For the 160 meter BPF, Micrometals T130-6 (yellow) cores are used for L1, L2 and L3. To minimize the temperature rise of L2, it is necessary to use two separate, series-connected inductors. For L1 and L3, a 10 turn quadrifilar winding (40 turns total) of #16 and #18 magnet wire delivered the design inductance of 16.46  $\mu\text{H}$  with a measured Q of 195 at the center frequency. L2 is made of two T130-6 cores with 39 and 38 turns of #18 wire. Its Q measures 320. Details associated with the 160 meter BPF inductor assemblies are listed in the second column in **Table 2A**.

Inductors for the higher bands were designed similarly; their assembly details are listed in Tables **2A** and **2B**. For the 80, 40 and 20 meter BPFs, the L1, L3 and L2 cores are also T130s, but the material is -17 (blue/yellow) with a lower  $\mu$  than the -6 material. L1 and L3 for the 15 and 10 meter BPFs are wound on T130 and T106 phenolic (tan) cores, while L2 remains two separate series-connected inductors, each wound on a T130-17 core.

## Capacitor Selection

The voltage across C1 and C3 is 300 and 400 V RMS, respectively, for a 200 W input to a 50  $\Omega$  terminated BPF having a trifilar or quadrifilar-wound L1 and L3. Consequently, the RMS voltage rating of C1 and C3 should be greater than 400 V. Based on a 2 A current flowing through C2, the RMS voltage across C2 can range from a low of 574 V to as much as 1 kV. The C2 voltage depends on the product of two times the reactance of C2 at the center frequency. The C2 voltage rating should be greater than 680 and 580 V for the 160 and 80 meter BPFs, respectively, and even higher for the 40 through 10 meter BPFs because of their higher C2

reactances.

In addition to a safe voltage rating, the capacitors must be capable of handling the current associated with a 200 W RF signal passing through the BPF. For C2, the RMS current level is 2 A. Finally, so that filter construction is economically practical, the capacitors must be readily available and reasonably priced.

I selected Tusonix NP0 10% ceramic capacitors, having an outer diameter of about 16 mm. [10] Although 5% tolerance units cost only a few cents more than the 10% tolerance capacitors, the 10% tolerance is specified so that the trimming operation associated only with the 5% tolerance can be omitted. [11] Harry Roseberry, W1HRZ, of the Tusonix Customer Engineering Dept, advised me that the nontrimmed 10% capacitors are better-suited for RF applications than the trimmed capacitors. Although this capacitor type is not formally rated by Tusonix for RF service, it is nevertheless widely used in nonstringent commercial and Amateur Radio RF applications. To minimize the chance of failure caused by greater-than-anticipated voltages or currents, and to derate the standard dc voltage rating by 50% for RF applications, capacitors with dc ratings of 2, 3 and 4 kV are used. To minimize the temperature rise caused by the 2 A current passing through C2, two or more capacitors in parallel are used at C2. The capacitors and their connection configurations used in each BPF are listed in Tables 2A and 2B.

The values of capacitance and voltage found to be most convenient are 110 pF/2 kV, 30 pF/3 kV and 15 pF/4 kV. Various series and parallel combinations of these three values make it possible to match all the design values. In some cases—because of tolerance variations in the powdered-iron cores used for L1 and L3—a few additional picofarads are needed across C1 and C3 to precisely tune both resonators to the center frequency. To achieve this, two small-value Ceramite 1000 VDC/300 VAC capacitors (type 10TCCQ) are wired in series and placed in parallel across the Tusonix capacitors. The Ceramite capacitors are available in small quantities from Newark Electronics. [12]

## Tune In Next Month...

...when I'll tackle filter assembly and tuning, and put the wraps on this project.

Ed Wetherhold, W3NQN, received a degree in Radio Engineering from Tri-State University, Angola, Indiana, in 1956. From 1962 to 1992, he was employed at the Annapolis Signal Analysis Center of Alliant Techsystems, Inc (Alliant Techsystems was formerly the Defense Division of Honeywell, Inc), as a communications systems test engineer and as a certified TEMPEST Professional Level II.

Ed obtained his Amateur Radio license in 1947, while serving in the Air Force as a radio mechanic instructor at Scott AFB, in Illinois. For the past 15 years, he has been a technical advisor to the ARRL on passive LC filters.

Ed's many articles on simplified filter design have been published in the electronics trade and Amateur Radio journals, such as *Interference Technology Engineers' Master (ITEM)*, *QST*, *QEX*, *CQ* and *Practical Wireless*, and in professional EMC journals. *The 1998 ARRL Handbook* contains Ed's SVC filter design tables and an explanation of how to design passive LC filters.

While not working on filters, Ed is active as a tournament tennis player and is ranked Number 1 in the Men's 70 singles and doubles in the USTA's Middle Atlantic section. You can contact Ed at 1426 Catlyn PI, Annapolis, MD 21401, or by telephone at 410-268-0916.

## Notes

- <sup>1</sup>Assembled and tested band-pass filters are available from me. Send a business-size, self-addressed, stamped envelope for details to Ed Wetherhold, W3NQN, 1426 Catlyn Pl, Annapolis, MD 21401.
- <sup>2</sup>Thomas Moliere, DL7AV, "Band Reject Filters for Multi/Multi Contest Operation," *CQ Contest*, Feb 1996, pp 14-22.
- <sup>3</sup>Lew Gordon, K4VX, "Band-Pass Filters for HF Transceivers," *QST*, Sep 1988, pp 17-23.
- <sup>4</sup>Alan Bloom, N1AL, "Inexpensive Interference Filters," *QST*, Jun 1994, pp 32-36.
- <sup>5</sup>The program, in *BPFS.ZIP*, can be found on the Internet (ftp to **[oak.oakland.edu/pub/hamradio/arrl/qst-binaries](ftp://oak.oakland.edu/pub/hamradio/arrl/qst-binaries)**) and on the ARRL BBS 860-594-0306. Space limitations prevented its publication here.
- <sup>6</sup>*The 1998 ARRL Handbook for Radio Amateurs*, (Newington, ARRL, 75th ed), 1997, Table 16.2, pp 16.12 to 16.15.
- <sup>7</sup>Trinity Software, 7801 Rice Dr, Rowlett, TX 75088, (Jim Tonne, President); tel 972- 475-7132.
- <sup>8</sup>Iron powder cores catalog *RF Applications*, Issue F, Sep 1996. Micrometals, 5615 E La Palma, Anaheim, CA 92807; tel 800-356-5977; **<http://www.micrometals.com>**.
- <sup>9</sup>Zack Lau, W1VT, "Calculating the Power Limit of Circuits with Toroids," *QEX*, Mar 1995, pp 24-25.
- <sup>10</sup>Tusonix, Inc, 7741 N Business Park Dr, Tucson, AZ 85743, tel 502-744-0400; **<http://www.tusonix.com/tusonix>**.
- <sup>11</sup>Because the filter passband is generally much wider than required, it is not necessary to precisely tune a BPF to the exact center of the amateur band. (The center frequency to which all resonators are tuned can be about 0.6% above or below the design center frequency without the passband insertion loss rising within the amateur band.) However, resonators 1 and 3 must be tuned to within 0.2% of the *same* center frequency to assure that resonator 2 can be tuned for a proper return-loss response.
- <sup>12</sup>Newark Electronics, 4801 N Ravenswood Ave, Chicago, IL 06040-4496; tel 800-463-9275, 312-784-5100, fax: 312-907-5217; **<http://www.newark.com>**, catalog 115, p 81.