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QST Issue: Nov 2002
Title: A High Performance, Low Cost 1.8 to 54 MHz Low Pass Filter
Author: Bill Jones, K8CU

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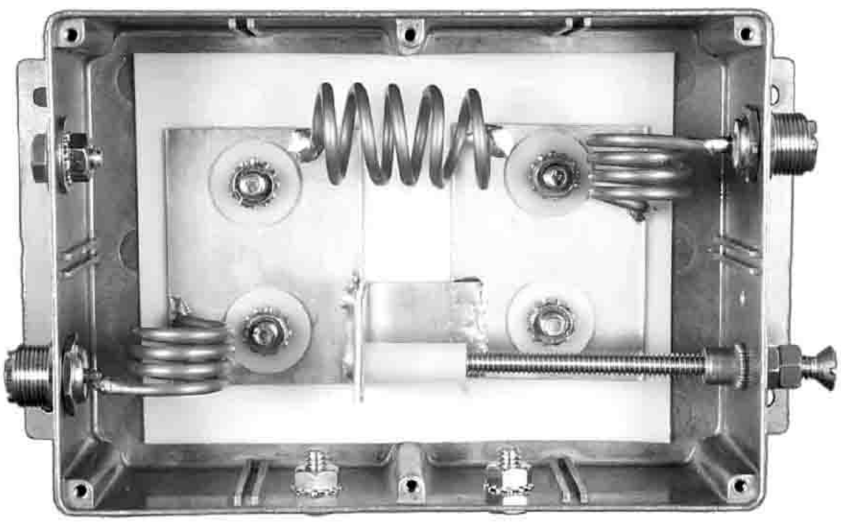
By Bill Jones, K8CU

A High Performance, Low Cost 1.8 to 54 MHz Low Pass Filter

This high performance low pass filter, designed with software available to radio amateurs at no cost, is easily constructed with common hand tools.



This low pass filter design project for 6 meters started with goals of low insertion loss, mechanical simplicity, easy construction and operation on all HF amateur bands including 6 meters. Originally built as an accessory filter for a 1500 W 6-meter amplifier, the filter easily handles legal limit power. It attenuates harmonic radiation in the VHF and higher frequency bands and is made with low cost commonly available materials. No complicated test equipment is necessary for alignment.

Although primarily intended for coverage of the 6-meter band, this filter has low insertion loss and presents excellent SWR characteristics for all HF bands. Although harmonic attenuation at low VHF frequencies near TV channels 2, 3 and 4 does not compare to filters designed only for HF operation, the use of this filter on HF is a bonus to 6-meter operators who also use the regular HF bands. Six-meter operators may easily tune this filter for low insertion loss and SWR in any favorite band segment, including the higher frequency FM portion of the band.

Electrical Design

The software tool used to design this low pass filter is named *Elsie*. Jim Tonne, WB6BLD, of Trinity Software has made a student/demo version of his *Elsie* filter design software available at no charge. The program is a professional design tool for those interested in filter design/network analysis. The student/demo version is limited to seven stages. This limitation does not affect the usefulness of this program for many Amateur Radio filter requirements. In addition, there is no time limit on how long this student version will remain active on your computer. This program may be downloaded from Jim's site, at **www.qsl.net/wb6bld/** (go to *Software*, and then select *ELSIE.ZIP*). Program documentation and example data files are included. The *Elsie* format data file for this filter, *DC54.lct*, may be downloaded for your own evaluation from the author's Web site at **www.realhamradio.com**.

The *Elsie* menu options and intuitive program design make it relatively easy to get started. The user has a choice of manual filter design or design assisted by the computer. I used a low pass filter design with inductor input and having five poles. After making other filter choices, such as design frequency, the program can calculate all performance parameters and display the predicted filter response. You can use keyboard arrow keys to select an

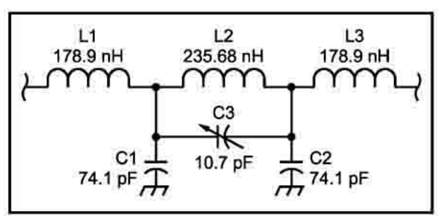


Figure 1—The low pass filter schematic.
C1, C2—74.1 pF. 2 inch by 2.65 inch brass plate sandwiched with 0.03125 inch thick Teflon sheet. The metal enclosure is the remaining grounded terminal of this capacitor.
L1, L3—178.9 nH. Wind with 1/8 inch OD soft copper tubing, 3.5 turns, 0.75 inch diameter form, 0.625 inch long, 1/4 inch lead length for soldering to brass plate. The length of the other lead to RF connector as required.
L2—235.68 nH. Wind with 1/8 inch OD soft copper tubing, 5 turns, 0.75 inch diameter form, 1.75 inches long. Leave 1/4 inch lead length for soldering.

item, tune it and immediately see the result. A variety of program options are available for fine-tuning the initial design to allow specific design goals to be realized. The data files may be exported into such other applications as *Touchstone* and *Pspice*. The *Elsie* software has auxiliary tools that help in filter design. These tools run within the program and do not require exiting the software and then restarting again.

I've found that my existing external scientific graphing software could take advantage of the *Elsie* standard two-column format export option for all charts. This helps when adding an *Elsie* chart into a document already using a standardized plotting format. For most uses, the *Elsie* internal video screen and hard copy printer outputs are fine. Figure 1 is a schematic diagram of the filter.

The Components

See the Figure 1 caption for the parts list. The use of low self-inductance capacitors with Teflon dielectric easily allows legal limit high power operation and aids in the ultimate stop band attenuation of this filter. Capacitors with essentially zero lead length will not introduce significant series inductance that upsets filter operation. This filter also uses a trap that greatly attenuates second harmonic frequencies of the 6-meter band.

Mechanical Design, Assembly, and Construction

One design goal of this filter was easy tuning with modest home test equipment. See Figure 2. To realize this, build the coils carefully according to the component values table. The homemade coils solder directly to the top surface of the brass capacitor plates. The capacitors are made using a brass to Teflon to aluminum case sandwich. An easy to make variable capacitor is made from two pieces of 0.032-inch thick brass plate and a Teflon insulator. The filter inductors are mounted at right angles to each other to help maintain good stop band attenuation.

One *Elsie* software tool will calculate the details of each inductor. Inductors L1 and L3 are designed with a half turn winding. This allows short connections to the brass capacitor plate and the RF connectors mounted on the enclosure

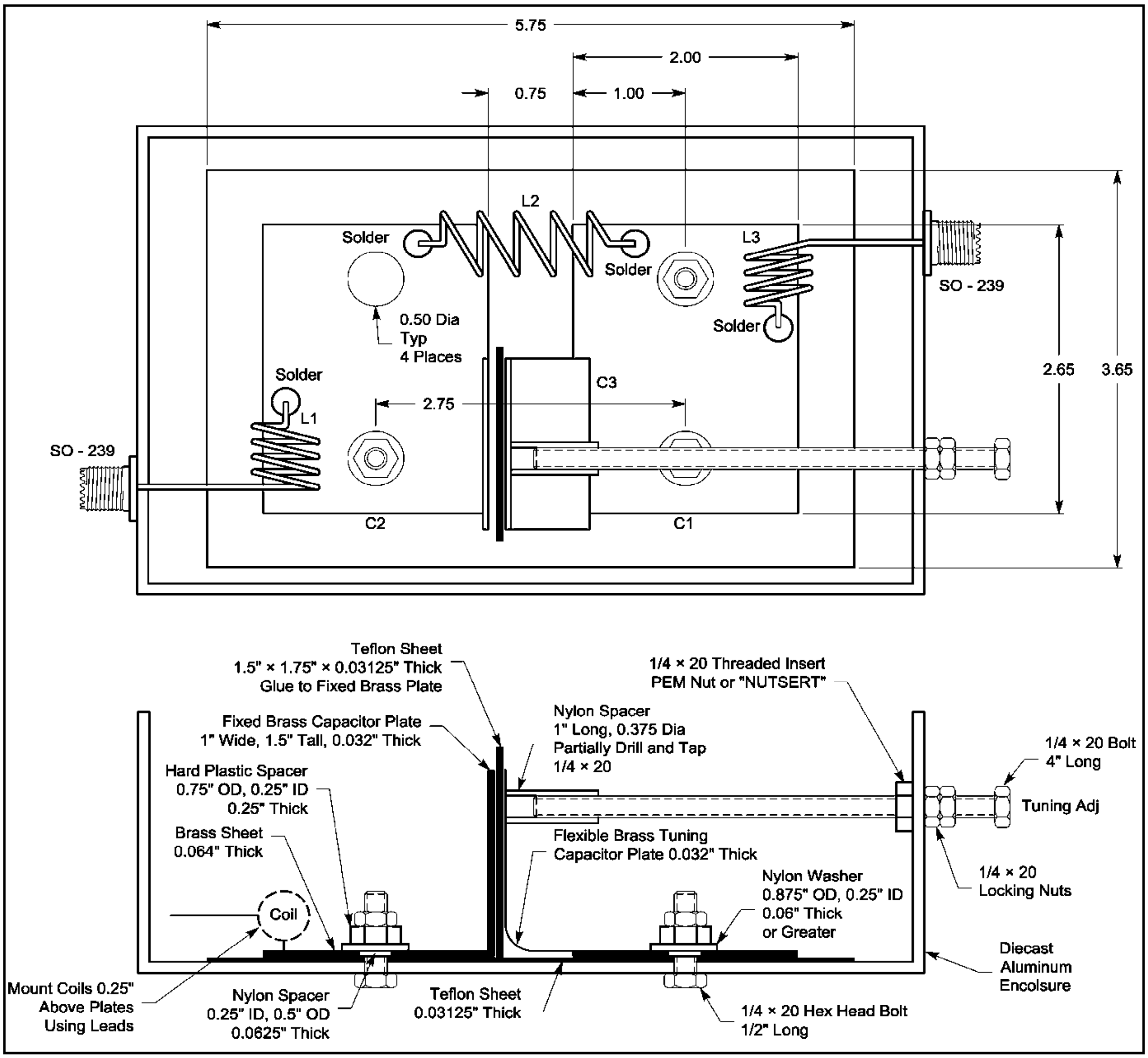


Figure 2—Assembly drawing for the low pass filter. All dimensions are in inches.

walls. The coils are physically spaced with 1/4-inch lead lengths, and then soldered to the brass plates.

Many of the parts required to make this filter are available at hardware stores. In particular, the 1 and 2 inch wide brass strips (sold as Hobby or Miniature brass), 1/8 inch diameter soft copper tubing, nuts, bolts, and nylon spacers and washers are commonly available at low cost. It is important that the specified 0.03125-inch thickness of Teflon be used since another size will result in a different capacitor value. If you have another Teflon thickness available, you will need to calculate the specific capacitor values depending upon the new thickness and brass plate sizes.

The opaque white color Teflon used here has a dielectric constant of 2.1. The clear varieties of Teflon typically have values less than this, and will result in different capacitor values for the same size brass plates. The capacitance will decrease if the assembly bolts are loose, so be sure to have the bolts tightened. Also, use the 0.064-inch thick brass plate for the bolted down capacitors. When under compression, the thinner brass size used for the variable capacitor tends to flex more and doesn't fit as flat to the Teflon.

A separate Teflon sheet, also used in the variable capacitor, is glued to the stationary brass plate. This insulator is used to prevent a short circuit in case the tuning screw is tightened too much. Teflon is extremely slick, and doesn't glue well unless chemically prepared. One way to get acceptable glue joint performance between the brass support plate and the insulator is to scuff the Teflon and brass surfaces with 240-grit sandpaper. The intention is to increase the available surface area as much as possible, and provide more places for the glue to fasten to. Glue the Teflon in place with a bead of RTV or epoxy. After drying, the Teflon sheet can be intentionally peeled from the brass plate, but it appears to hold reasonably well. Special Teflon that has been treated to allow good adhesion is available, but the expense isn't justified for this simple application. This Teflon variable capacitor insulator sheet measures 1.5 inches wide by 1.75 inches tall and is larger than the two brass plates. This gives an outside edge insulation some safety margin.

Calculating Capacitance

The 0.064-inch thick brass capacitor plates have two 0.5-inch holes in them for the mounting bolts and washers. The surface area of each hole is πR^2, so the two holes combined have a total surface area of 0.3925 square inch. The brass plate size is 2 inches by 2.65 inches. This equals 5.3 square inches of surface area. Subtracting the area of the two holes gives a total surface area of 4.9 square inches. The formula for capacitance[1] is:

$$C = 0.2248\ (kA/d)$$

where

C = capacitance in pF
K = dielectric constant of Teflon
A = surface area of one plate in square inches
d = thickness of insulator

The dielectric constant of the Teflon used here is 2.1, and the thickness used is 0.03125 inch. The calculated capacitance of each plate equals 74.1 pF. Measured values agree closely with this number. When built as described, the capacitor plates measured between 2% and 2.5% of the calculated value. This is acceptable for a practical filter.

The brass sheet material acts like a large heat sink, so an adequate soldering iron is required. A large chisel point 125-W iron will work well. The soldering heat does not affect the Teflon material. However, beware of the temptation to use a small propane torch. Two bolts in each capacitor hold the Teflon sheet and brass plates firmly together. The bolts are insulated from the brass plates by nylon spacers the same thickness as the brass. The nylon plunger for the tuning capacitor needs to be drilled and tapped to accept the 1/4 × 20 thread of the adjustment bolt. A threaded insert or PEM nut in the enclosure provides support for the tuning bolt.

Tuning Capacitor and Input SWR Adjustment

The small variable capacitor is shunted across coil L2. This coil and capacitor combination acts like a tunable trap for second harmonic frequencies when operating in the 6-meter band. After soldering into place, the flexible tuning plate of this capacitor is simply bent toward the adjustment screw. Brass of this thickness has a definite spring effect. Just bend the plate well toward the tuning screw, and then tighten the tuning bolt inward. This will result in a stable variable capacitor.

Six-Meter Alignment Procedure

If you are not concerned with 6-meter operation, ignore this procedure. Simply set the variable capacitor plates 0.1-inch apart and disregard the following steps. If you wish to use this filter on the HF amateur bands from 1.8 to 30 MHz only, the adjustable tuning capacitor adjustment is not critical and does not affect HF SWR performance. However, don't eliminate the capacitor entirely. The software predicts degraded VHF response with it missing. For use on the HF bands only, the tuning screw and associated nylon plunger may be omitted.

Normally, tuning this filter would be a challenge, since three variables (with two interacting) are involved (L1, L2 and the variable capacitor). I realized that the *Elsie* software "Tune" mode held the answer. After studying what the software predicted, I generated this tuning procedure. My very first attempt to exactly tune this filter was successful, and was completed in just a few minutes. This method was predicted by software and then confirmed in practice. A common variable SWR analyzer is required. These steps may seem complicated, but are actually pretty straight forward once you get a feel for it. Read first before you start adjusting.

Step One

After the filter is constructed, adjust the variable capacitor until the top plate spacing is about 0.1 inch apart. Using a variable SWR analyzer, sweep the 6-meter band area, searching for a very low SWR null anywhere in the vicinity of about 45 to 60 MHz or so. If a low SWR value (near 1:1) can be found, even though the frequency of the low SWR isn't where you want it, proceed to step two. Otherwise, adjust the input coil L1 by expanding or compressing the turns until a low SWR can be obtained anywhere in the range of about 45 to 60 MHz. If you have a way to measure the notch response at 100.2 MHz, proceed to step two. Otherwise, proceed to step three.

Step Two

Now apply 100.2 MHz to the filter input. Adjust the variable capacitor until the 6 meter second harmonic at 100.2 MHz is nulled on the filter output. Hook up the SWR analyzer again, and sweep the 6-meter band with the SWR analyzer. If the low SWR frequency is too low, adjust middle coil L2 for less inductance (expand turns apart), and then readjust the variable capacitor to bring the notch back on frequency. Continue these iterations until the SWR null is where you want, and the notch frequency is correctly set. Alternately, if the desired SWR low spot is too high in frequency, adjust L2 for more inductance (compress the coil turns), and then readjust the variable capacitor for the second harmonic notch. Continue this until both the low SWR frequency location and the notch null are set where you want. You may need to unsolder one end of coil L2 to allow the adjustment for a longer or shorter coil length as you expand or compress turns. Just solder the end again after you make your length correction. Note that you will probably need to install the enclosure lid during the very final tuning steps. I was able to reduce the second har-

[1] *The ARRL Handbook*, 72nd Ed., Newington, CT, ARRL, 1995, p 6.9.

monic into the noise floor of an IFR-1200S spectrum display, but the lid needed to be installed. The lid also interacts with the variable capacitor. Once the SWR and the notch frequency are set, the tuning process is complete and the filter is optimally adjusted. Do not perform step three below.

Step Three

This step is only performed if you don't have a way to generate the 100.2 MHz input signal, and then detect a null on the filter's output terminal. The variable capacitor will become your SWR adjustment to move the SWR null spot to the portion of the 6-meter band you desire. If you run out of adjustment range on the variable capacitor (turned all the way in), just compress the L2 turns together, and try again. Alternately, if the variable capacitor is backed completely off, just expand the L2 turns, and try again. After your SWR is set, you are finished. Although the second harmonic notch probably isn't exactly on frequency, you will still have good (but not optimum) suppression since the notch is very deep. Table 1 is a list of parts.

Table 1
Parts List

Qty	*Description*
1	Miniature brass strip, 1 × 12″, 0.032″ thick (variable tuning capacitor)
1	Miniature brass strip, 2 × 12″, 0.064″ thick (main filter capacitors)
5′	1/8 inch diameter soft copper tubing
4	¼ × 20 × ½″ long hex head bolt
4	Plastic spacer or washer, 0.5″ OD, 0.25″ ID, 0.0625″ thick
6	1/4 × 20 hex nut with integral tooth lock washer
1	1/4 × 20 × 4″ long bolt
1	1/4 × 20 threaded nut insert, PEM nut, or "Nutsert"
1	1 × 0.375″ diameter nylon spacer. ID smaller than 0.25″ (used for variable capacitor plunger).
4	Nylon spacer, 0.875″ OD, 0.25 to 0.34″ ID, approximately 0.065″ or greater thickness (used to attach brass capacitor plates).

Aluminum diecast enclosure is available from Jameco Electronics (**www.jameco.com**) part no. 11973. The box dimensions are 7.5 × 4.3 × 2.4″.
The 0.03125″ thick Teflon sheet is available from McMaster-Carr Supply Co (**www.mcmaster.com**), item #8545K21 is available as a 12 × 12″ sheet.

Performance Discussion

Assuming the 6-meter SWR is set to a low value for a favorite part of the band, the worst case calculated forward filter loss is about 0.18 dB. The forward loss is better in the HF bands, with a calculated loss of only 0.05 dB from 1.8 through 30 MHz. The filter cutoff frequency is about 56 MHz, and the filter response drops sharply above this. There are parasitic capacitors on coils L1 and L3. These are also included in this filter analysis. The calculated self-capacity of each coil is almost 1 pF. These small capacitors are included on the schematic and are also included in the software for the model. These capacitors occur naturally, so do not solder a 1-pF capacitor across each of the

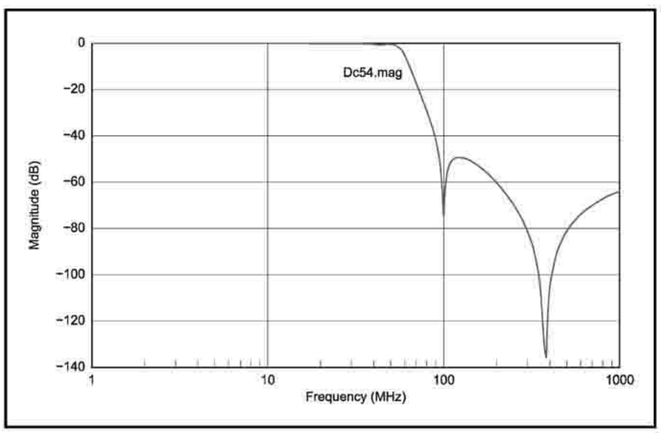


Figure 3—The filter response from 1 to 1000 MHz.

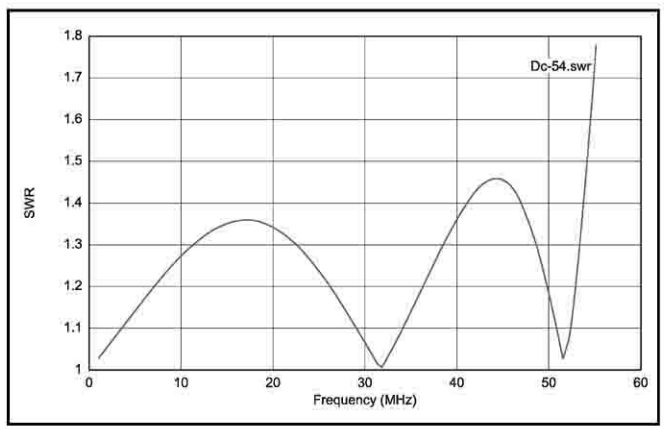


Figure 4—The filter SWR from 1 MHz to 55 MHz.

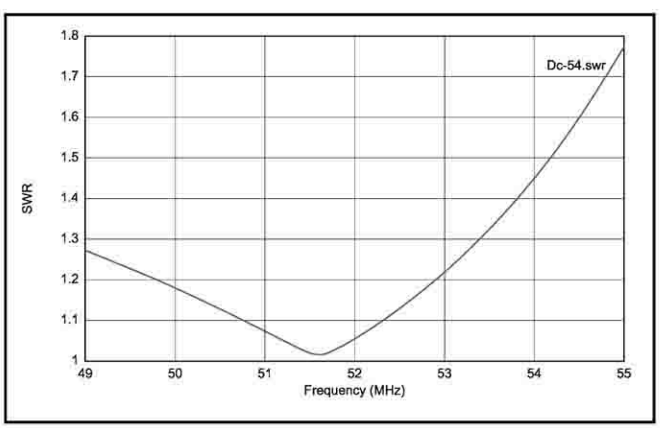


Figure 5—Six-meter filter SWR.

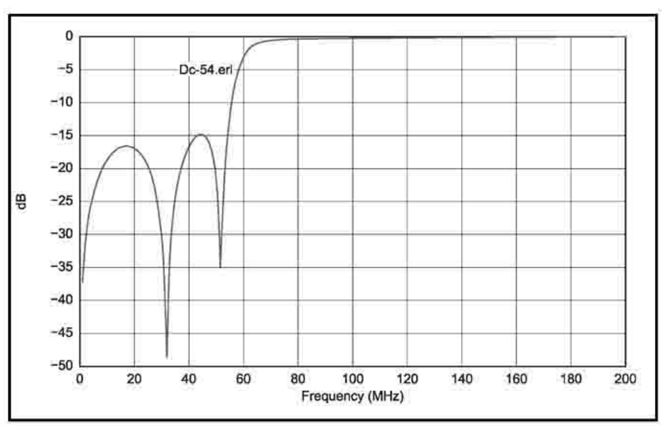


Figure 6—Calculated filter return loss.

end coils in this filter. The capacitors have the effect of placing additional notches somewhere in the UHF region. The calculated self-resonant frequency of L1 and L3 is about 365 MHz.

Figure 3 shows the filter response from 1 to 1000 MHz. The impressive notch near 365 MHz is because of these inherent stray capacitances across each of the coils. Slight variations in each coil will make slightly different tuned traps. This will introduce a stagger-tuned effect that results in a broader notch.

These exact capacitance values are hard to predict because of variations in home made coil dimensions and exact placement of each coil inside the enclosure. The best way to determine their effect is to physically measure the UHF response of this filter. Using low self-inductance capacitors in a VHF filter helps to take advantage of predicted filter attenuation at extended stop-band frequencies.

The SWR across the HF bands and 6 meters is shown in Figure 4. Figure 5 shows only the 6-meter band SWR.

Calculated return loss of the filter across 1 to 200 MHz is shown in Figure 6. Notice that the 10-meter region has particularly good return loss. Component values in this filter were adjusted so that this return loss spike was moved from about 40 MHz to around 28-30 MHz.

Summary

This filter meets the original design objectives. Since I use 6 meters as well as the regular HF bands, this project has produced a doubly useful station accessory. Low insertion loss makes this filter useful for receiving applications also. The *Elsie* filter software tool made the electrical design portion of this project fun. Thanks to Jim Tonne, WB6BLD, for the *Elsie* design software and for his informal consultation and helpful comments about this filter. Jim also suggested this filter topology and offered component values to consider.

Bill Jones, K8CU, has been an active radio amateur, CW DXer and home project builder since first receiving his license in 1966 at age 17. Bill is an electronics professional with experience ranging from radar maintenance in Vietnam, analog and digital telephone PBX design, to embedded controller implementation. He spent 18 years at Optek, Inc, designing hardware and writing assembly language software for embedded microcontrollers used in specialized electro-optical industrial process controls. He is currently employed by the Ohio Department of Transportation, where he works in radio communications. Some recent interests include small gas engines, 6-meter DXing and maintaining his personal Web site, **www.RealHamRadio.com**. *A member of a nearby sportsman's club, Bill can sometimes be found fishing with his wife, Bonnie. You can contact Bill at* **k8cu@realhamradio.com**.

NEW PRODUCTS

MFJ'S 'DX BEACON' REAL-TIME PROPAGATION MONITOR

◊ Want up-to-the-minute information about worldwide band conditions on 20 through 10 meters? MFJ's new Model 890 DX Beacon Monitor can do just that, thanks to its ability to listen to transmitted information from the 18 stations around the globe that comprise the IARU International Beacon Network.

The DX Beacon Monitor lets you instantly see which propagation beacons are being received: An LED lights up on the unit's built-in world map to show you the beacon location and where to point your antenna. As data from each beacon is received, the corresponding LED lights to indicate that the radio path on that frequency is open between the beacon and your station.

Because the worldwide transmitter network uses precise timing intervals, the DX Beacon Monitor has a built-in atomic clock receiver and microprocessor control to maintain precise synchronization with the beacon network. The Model 890 is a standalone unit that requires no connections to your transceiver or receiver. Measuring about 5×7×3 inches HWD, the monitor requires 9-12 V dc.

Price: $99. For more information, see your favorite Amateur Radio products dealer or contact MFJ at 300 Industrial Park Rd, Starkville, MS 39759; tel 800-647-1800, fax 662-323-6551, **mfj@mfjenterprises.com**, **www.mfjenterprises.com**.

INTERNET-BASED HAM RADIO INSTRUCTION

◊ Boston-based J. Cunningham & Associates has just launched **www.hamtestonline.com**, a Web site aimed at helping new and experienced hams prepare for US Amateur Radio written exams. According to the publisher, this is the first Web site to incorporate computer-based training (CBT) technology for ham radio education.

HamTestOnline site tracks the questions you've seen, the questions you've learned and the questions you get right and wrong. It asks you questions based on your personal needs, concentrating on the areas where you are weak.

The easy-to-use service operates entirely online and there is no software to download or install. The system includes all questions from the latest Technician, General and Amateur Extra question pools.

HamTestOnline offers a free trial, which includes 20% of the questions from each question pool. A paid subscription costs $19.95 and provides access to all questions in all three question pools for a period of two years. The site offers a money-back guarantee if you are dissatisfied for any reason.

For more information, point your Web browser to **www.hamtestonline.com**.

TINY VFO KIT FROM DATAK MANUFACTURING

◊ Aimed at home-brewers and QRP enthusiasts, DATAK's new Model 80-1410 wide-range VFO kit can be made to cover frequencies from 100 kHz to 33 MHz by swapping a resistor and a capacitor. Using the new LTC 1799 precision oscillator IC chip, the kit is essentially a resistance-controlled oscillator that can be set up to cover multiple 200-kHz tuning ranges from VLF to VHF. Stability is rated at ±40 ppm per °C. Use it as a VFO or as an adjustable "crystal replacement" oscillator to drive mixers, front ends, etc. The VFO kit can be assembled in about 20 minutes, runs on 6 to 14 V dc (at 140 mA) and ships with parts for tuning 40 meters (6.9 to 7.2 MHz).

Price: $15.99 (includes complete instructions and a schematic for a companion 40-meter, 5-W, CW transmitter). For more information, contact DATAK at PO Box 6386, 3660 Publishers Dr, Rockford, IL 61125; tel 800-645-2262. To find a distributor in your area, point your web browser to **www.philmore-datak.com**.

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