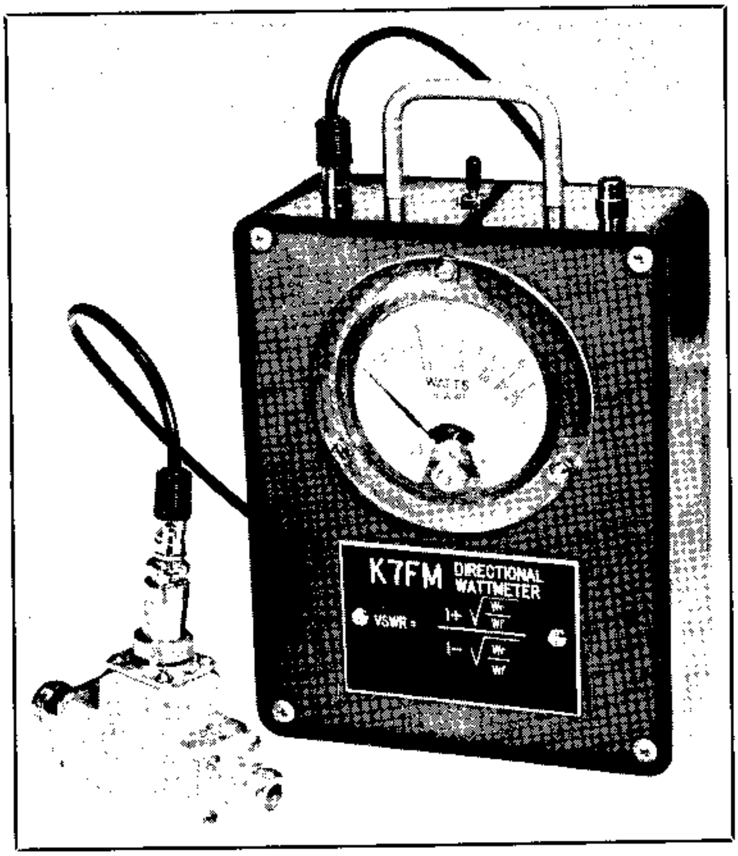
+ Cav Filter

New Ideas for the VHF Wattmeter



You say that good vhf/uhf wattmeters are expensive? Not this one!

By Colin Lamb,* K7FM

A calibrated, directional wattmeter is treasured by the vhf/uhf enthusiast. Commercial equipment is accurate, but expensive — and most often cannot be used remotely.

The line sampler described over a decade ago in *QST* by McMullen, W1SL, has become a classic in homebuilt directional couplers.[1] It can be built from inexpensive, common plumbing parts, but I decided to construct it differently, avoiding the need for a blowtorch and also to allow for a reversible sensing element. Before attempting to build the unit, you should review McMullen's original article (or a subsequent description in *The ARRL Antenna Book* or *FM and Repeaters*) for construction technique and theory.

Construction

This wattmeter can be built using only simple hand tools, and calibrated to the same accuracy as many commercial units. The line sampler is built around a 1/2-in. *square stock* brass "T" fitting (Fig. 1).[2] This common plumbing item has exactly the same width as the flange of a type N or uhf connector. Since the ID of the T fitting is actually 3/4 in., a piece of 5/16-in.-OD copper tubing is used as the inner conductor, which turns the T into a 50-ohm section of transmission line.

The T should be drilled and tapped to a 4-40 thread for the coaxial connectors (Fig. 1). Use a punch to line up the holes before drilling. When tapping, do not turn the tap more than 1/2 turn without backing it off to clear the threads. After the holes

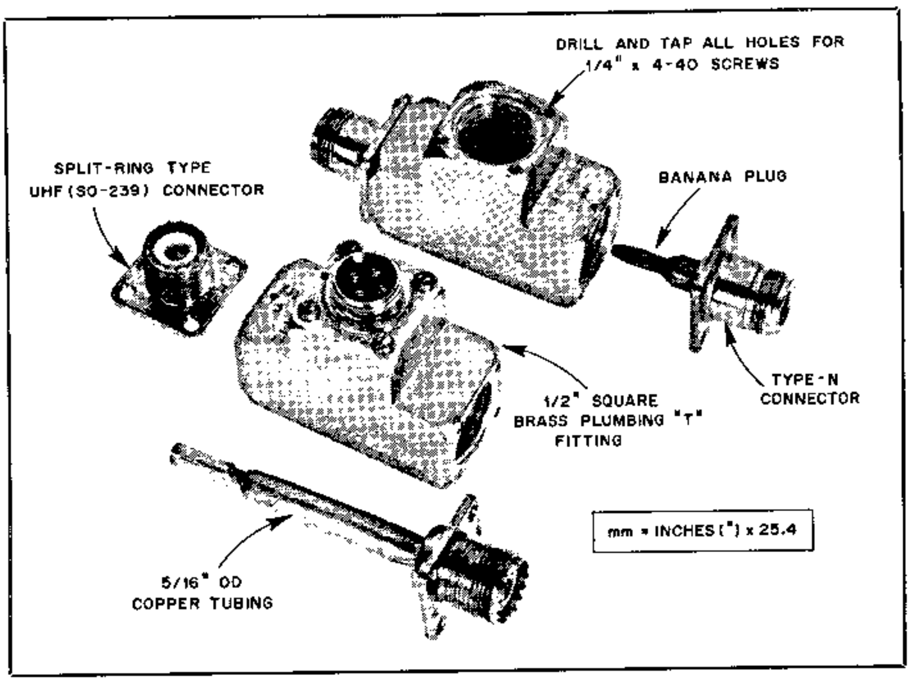


Fig. 1 — Exploded view of two line samplers, illustrating various construction techniques. The sampler at the top uses type-N coaxial connectors, and a banana plug/jack combination for the center conductor. In the bottom sampler, split-ring uhf (SO-239) connectors are used.

[1]Notes appear on page 13.

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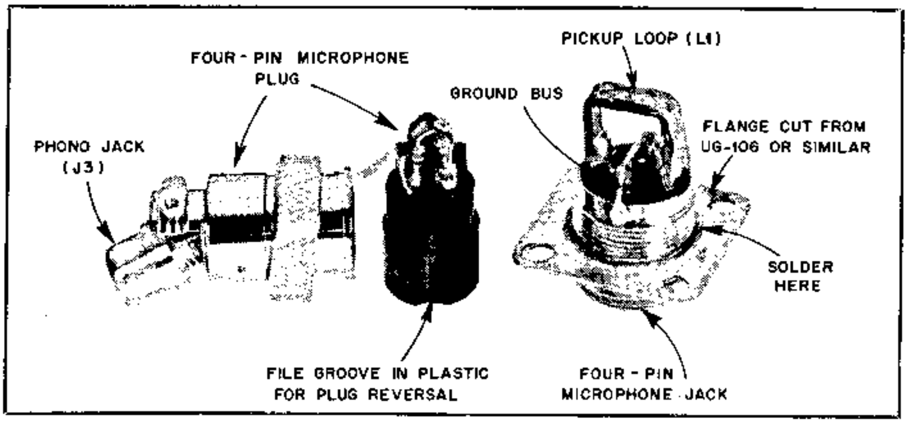

Fig. 2 — Detail of the pickup loop and detector assembly. See text for details.

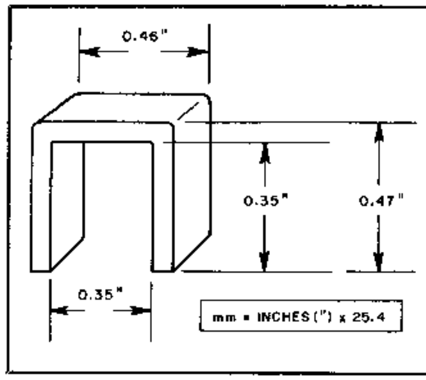

Fig. 3 — Dimensions of the pickup loop, L1. It is constructed from tinned shield braid taken from RG-59/U cable.

are completed, 1/4-in. long 4-40 brass screws are used to hold the connectors in place.

Since the coaxial connectors cannot be soldered after assembly, it is necessary to secure the inner conductor by an alternative method. I prefer to use an N connector that has a removable center pin retained by a split-ring washer. This is the method described in McMullen's article. However, most N connectors available today do not use a split-ring retainer. Fortunately, Amphenol still makes one; the part no. is 82-368. This item is approximately twice the price of a regular N connector, because it is silver plated and has a gold-plated center conductor. If you use the split-ring method of construction, it is only necessary to use one of the special connectors per sampler.

I have found that many of the more common uhf (SO-239) connectors have split-ring retainers. These have been found in surplus stores, and seem to be salvaged from imported CB equipment. If you wish to use these, remove the retainer and center pin. Ream out the dielectric just enough so that the pin can be reinserted from the back. Since the center pin is soldered to the 5/16-in. tubing, this provides a rigid method of construction.

A third method of assembly uses a banana plug and jack along the center conductor. By using this method of construction, any type of coaxial connector can be employed. The banana plug should be installed near one of the coaxial connectors, and you should try to use one with a diameter of approximately 5/16 in. to avoid an impedance bump in the line. I tried this method, and at first considered it inferior because it contained an unsoldered joint. Upon afterthought, I realized that *every* coaxial connector relies on an unsoldered joint, so this method is not such a bad one after all!

Probe and Pickup Loop Assembly

The diode and pickup loop (L1) termination are located inside a nonpolarized plug that allows forward and reflected power readings by merely reversing it (Fig. 2). My first probe assembly was housed in a twin-contact uhf plug and jack set, and worked perfectly. Externally, these plugs and jacks look like standard uhf fittings, but have two small-diameter pins inside. Amphenol still manufactures them, but they must be specially ordered. Because they are difficult to purchase, I substituted a four-conductor microphone connector set — and it also works fine. As purchased, the plug is polarized. To allow reversal, remove the plastic insert and file a groove opposite the existing one. It is wise to use a plug that secures the metal shield to the plastic with a setscrew, avoiding rotation of the shield after assembly. The socket half should be soldered onto a coaxial hood (UG-106, UG-372, or UG-177) that has had the flared portion sawed off.

I constructed the pickup loop (L1) by stretching and flattening out a piece of RG-59/U shield braid and filling it with solder (Fig. 3). This makes a loop that is just a bit wider than necessary, but easy to file down for calibration purposes. The loop is soldered between pins 1 and 3 of the socket, while pins 2 and 4 are soldered to ground (Fig. 4). The plug must be wired with sufficient care so that all the components will fit inside the shield. Miniature capacitors are necessary, and 1/4-W resistors easily fit, although there is sufficient room for 1/2-W types. Pin 2 of the plug must be removed to provide space for the 1-kΩ resistor.

A panel-mount phono jack designed for a 1/4-in. mounting hole is used as J3, facilitating connection of the shielded cable to the meter. All the components are first soldered to the plug, and an insulated wire from C2 is left to connect to the phono jack. The shield is installed and the wire is soldered to J3. Tighten the microphone-

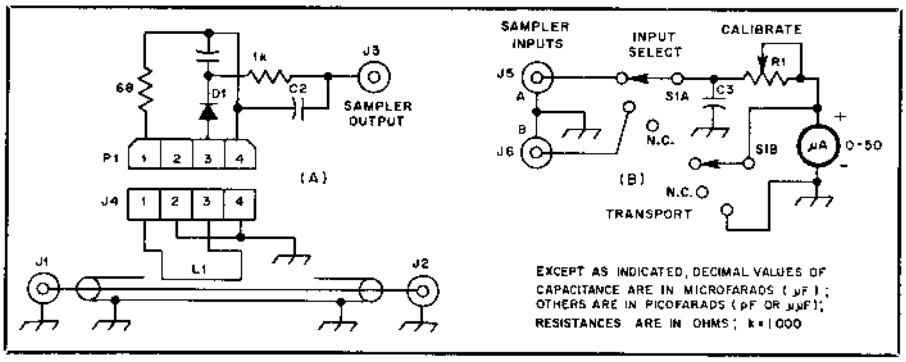

Fig. 4 — Schematic diagram of the complete wattmeter. As wired, the meter will show *reflected* power when the load is at J2.

C1 — 200-500 pF miniature disc-ceramic or Mylar® capacitor.
C2 — 500-1000 pF miniature disc-ceramic or Mylar® capacitor.
C3 — 0.005-μF disc-ceramic capacitor.
D1 — 1N34, 1N60, 1N270 or equiv. germanium diode.
J1-3, J5, J6 — Phono jack (Radio Shack 274-346).
J4 — Four-pin, chassis-mount, microphone socket (Radio Shack 274-002).
L1 — Pickup loop (see text).
P1 — Four-pin microphone plug with setscrew.
R1 — 50-kΩ, linear-taper potentiometer.

plug cable clamp around the threads of the phono jack for a perfect fit.

Calibration

Install the pickup-loop assembly into the T fitting, oriented so that it is parallel to the copper tube. Connect a 50-Ω dummy load to J2 and a vhf transmitter to J1. Orient the microphone plug to read *reflected* power. Set R3 to mid-position, and apply between 10 and 25 W of drive. Note the reflected power reading, and remove the pickup-loop assembly from the T. File the pickup loop a bit narrower, and reassemble. Check the reflected power again, and continue this procedure until the meter reads zero. This operation matches the impedance of L1 to that of the terminating resistor R1.

The easiest way to calibrate for power level is to place a wattmeter of known accuracy in series with your homemade unit. Apply power and adjust R3 until both meters coincide. R3 may then be replaced by a fixed-value resistor. You may calibrate your entire meter scale in this manner. A 2-meter multimode rig is ideal for this operation, since most usually have continuously variable output power.

My meter scale was made photographically, but you can produce one by any method you prefer. I chose 5 W for full-scale deflection, as this permits me to do all my antenna work with a portable 2-meter transceiver. It is a simple matter to increase the meter power range by inserting a spacer between the probe assembly and the T fitting. To determine the proper spacing, thread studs into the 4-40 holes and place nuts on them. Use the nuts to change the spacing until the desired meter power range is reached. Replace the studs and nuts with a permanent spacer. Since voltage at the diode is constant, meter calibration should remain the same, regardless of the power level applied. Just remember that the power reading of this wattmeter will only be correct for the band in which it was originally calibrated, although the linearity will be correct. To change bands, a scale multiplier can be used, or a spacer can be inserted to decrease the sensitivity of the instrument to the next higher calibrated range. The meter can also be used on the hf bands, but sensitivity decreases so that the minimum full scale reading will be considerably greater than 5 W.

Final Notes

The remote meter assembly includes a switch that should be used to short out the meter during transportation. I have also provided switching for the use of two different inputs. By constructing two samplers, you can use both of them simultaneously in remote locations, and switch between them at the meter. When both samplers are used in the forward mode, you can, for example, easily determine transmission-line loss.

The engraved plastic label was obtained because I can never remember the formula for SWR! One can be purchased for a few dollars from an engraver. This adds a final, professional touch to a project that I'm sure you will enjoy. Also, my thanks to Roy Mather, K7DFV, who took the photographs for this article.

Notes

[1]T. McMullen, "The Line Sampler," *QST*, April 1972, p. 21.

[2]mm = in. × 25.4.

Colin Lamb, K7FM, was first licensed as K7GYF at the age of 13. By profession, he is a lawyer and holds BA and JD degrees from Willamette University. Colin serves as president of the Chehalem Valley Amateur Radio Club, and maintains a homebuilt, wind-powdered fm repeater. The rest of Colin's station is also homebuilt and powered by two additional wind generators.

New Books

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The three microcomputer DiskGuides summarize all BASIC and operating system statements, commands and keywords. Apple EXEC files and PEEK and POKE locations, and ATARI 400/800 PEEK and POKE locations and sound and graphics programming are covered in their respective guides. Information concerning EDLIN is included in the IBM PC booklet.

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A Tunable CW Filter

Cascaded band-pass filters with voltage controlled center frequencies yield a cw filter with high selectivity and low ringing.

Richard A. Nelson,* WBØIKN

The benefits of an outboard audio filter in improving cw reception have been documented during recent years, and several designs have been examined in the literature.[1] Unfortunately, most of these filters suffer from at least one of two drawbacks: ringing and a fixed center frequency. Among the simple band-pass filter designs, the state-variable filter (also known as the biquad filter) is particularly useful because of simple construction, ease of tuning and stability (even at high Q).[2] High values of Q result in a tendency toward ringing, thus limiting the maximum usable selectivity of the filter. Ringing may be minimized by connecting low-Q filter sections in series. But to tune the filter requires the use of ganged, closely matched potentiometers.

I built a filter that utilizes a pair of two-pole, state-variable sections with voltage-controlled center frequencies. This design permits tuning with a single potentiometer while providing four filter poles for high selectivity with reduced ringing. An audio amplifier stage allows the filter to be used as an outboard accessory to an existing receiver, or as a complete audio section for a home-built receiver.

At the heart of this filter is the National Semiconductor LM13600 dual operational transconductance amplifier (OTA). OTAs are a specialized family of op amps that exhibit a transconductance (conductance being the inverse of resistance) that is programmable, generally by means of an external bias current. The OTA has a current-controlled gain stage that may be incorporated into a variety of useful circuits. Current-controlled amplifiers, multipliers, multiplexers, oscillators and a variety of filter designs are easily realized through the use of OTAs.

The LM13600 (Fig. 1) contains a pair of identical OTAs, each with an associated Darlington buffer stage and linearizing diodes at the input. The linearizing diodes, (not used in this design), are included to compensate for the logarithmic characteristics of the OTAs, enabling them to pass larger signals without distortion. With the output buffers, they represent a significant improvement over earlier OTA ICs.

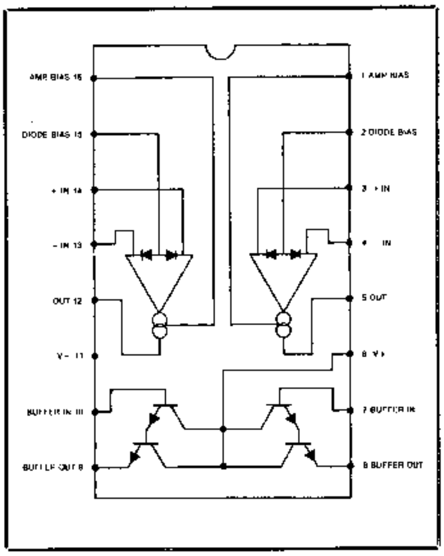

Fig. 1 — Pinout and internal block diagram of the LM13600. Each IC contains two identical sections, each with an operational transconductance amplifier stage and its associated buffer.

The tracking linearity of the LM13600 gain stages is accurate over a range of several decades. This allows two or more LM13600 gain stages to be configured as current-controlled integrators in a series of cascaded, state-variable filters. The filters, therefore, will track within close tolerance over a wide frequency range in response to a control current connected to each OTA bias input pin. The result is a tunable filter with high selectivity and low ringing.

Circuit Description

Refer to the block diagram (Fig. 2). You will notice that the current-controlled filter circuit consists of two major sections; a signal path and a control-current path. The audio signal is fed through the two series connected state-variable filter sections, while the control current pins are connected in parallel to a common variable current source. Although two filter sections are used in this design, any number of similarly connected filters may be used, limited only by the signal-to-noise characteristics of the circuit.

With this design it is possible to obtain two bandwidths simply by tapping the circuit at the output of each filter section. The output from the selected tap is fed to an audio power-amplifier stage that is capable of driving a loudspeaker or headphones. A bypass switch has been included to allow the operator to remove the circuit from the audio line when desired.

The schematic diagram (Fig. 3) shows the filter and amplifier circuits. The filter design is adapted from information found in the LM13600 data sheet.[3] Varying the bias current applied to the transconductance control pin changes the integrator time constant, shifting the band-pass center frequency. Since the frequency-control potentiometer will be supplying a variable voltage, it is necessary to convert this voltage to a variable current capable of biasing the transconductance stages. This is achieved by a voltage-to-current converter, R5, which is connected directly to the wiper of R7. Connect all control-current pins in parallel and route them to R5, which is located off the pc board. Note that the value of R5 will have to be scaled to maintain the same frequency range if more sections are added. The frequency range with the values shown is 350 Hz to 2800 Hz.

The Q of each filter section is determined by R8 (or R9). Larger values at R8 (or R9) will yield higher Q, but the gain at resonance will also increase. To maintain unity stage gain you must increase the value of R1 (R3) or decrease the value of R2 (R4), or both. I found that a Q of about 5 provides the best compromise between selectivity and ringing. R8 and R9 could be replaced by a ganged potentiometer to provide variable Q if desired. I made the selectivity switchable by means of a panel-mounted switch (S1). This switch taps the output of the first or second filter section and provides bandwidths of approximately 200 Hz and 120 Hz, respectively (−3 dB with a center frequency of 1000 Hz), with the values shown.

The audio signal from the selectivity switch is fed through volume control poten-

[1]Notes appear on page 16.

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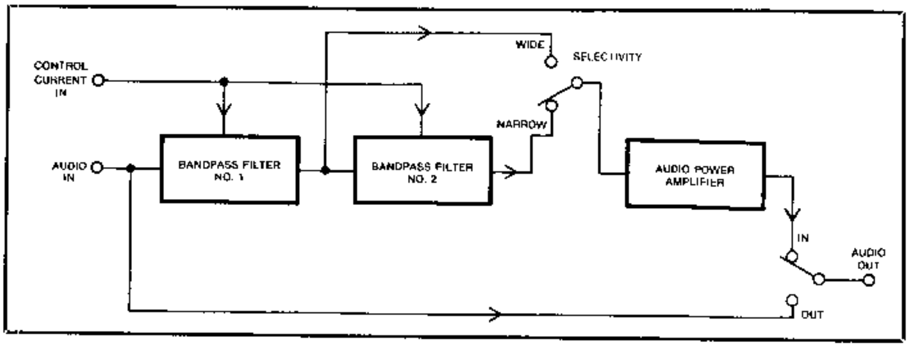

Fig. 2 — Block diagram of the tunable cw filter.

tiometer R10 to the audio amplifier. The amplifier uses the LM386 IC, chosen for its low external parts requirement and low idling current. It can supply up to 600 mW of audio — enough to drive most loudspeakers to a reasonable volume level. The amplifier audio output is connected to a spdt switch on the front panel (S2) that selects the filter circuit or the audio signal from the receiver.

Construction

A pc-board etching pattern (Fig. 4) is provided to speed construction and minimize wiring errors. Notice that the pc pattern is divided into two functional areas. One side of the pattern contains two state-variable filter sections, while the other side of the pattern contains the audio amplifier section. This allows the filter circuit or the amplifier to be used alone or incorporated into other designs, as well as permitting the use of an additional board to provide two more filter sections. The pattern fits nicely on a 3- × 4-inch pc blank. However, you may increase the width to 3.6 inches to conform to the standard suggested by Grabowski.[4,5]

Assembly of the board is straightforward, and with the exception of four jumpers on the foil side, all parts are top-mounted. These jumpers are used to connect the transconductance control pins on each board in parallel, and to route the output of one filter into the input of the next. Regardless of how many filter sections you use, remember to parallel all of the control-current pins, and connect them to the control-voltage source through a voltage-to-current converting resistor.

To assure proper matching of the filter sections, use only high-quality components. Use 5%-tolerance or better resistors and capacitors, if available, and avoid parts of unknown reliability. In particular, be sure the capacitors in the integrators (C1 through C4) are high-quality mica or polystyrene types and are as closely matched as possible.

A parts-placement diagram is shown in Fig. 5; Fig. 6 shows the locations of the foil-side jumpers. Use of IC sockets is recommended; it prevents damage during soldering and greatly speeds trouble-shooting. Be sure to double-check IC orientation when inserting them into the sockets.

The printed-circuit assembly should be mounted in a shielded enclosure to avoid rf pickup during transmit. All leads entering the enclosure should be bypassed as shown in the schematic diagram. If you plan to include a power supply, be sure to

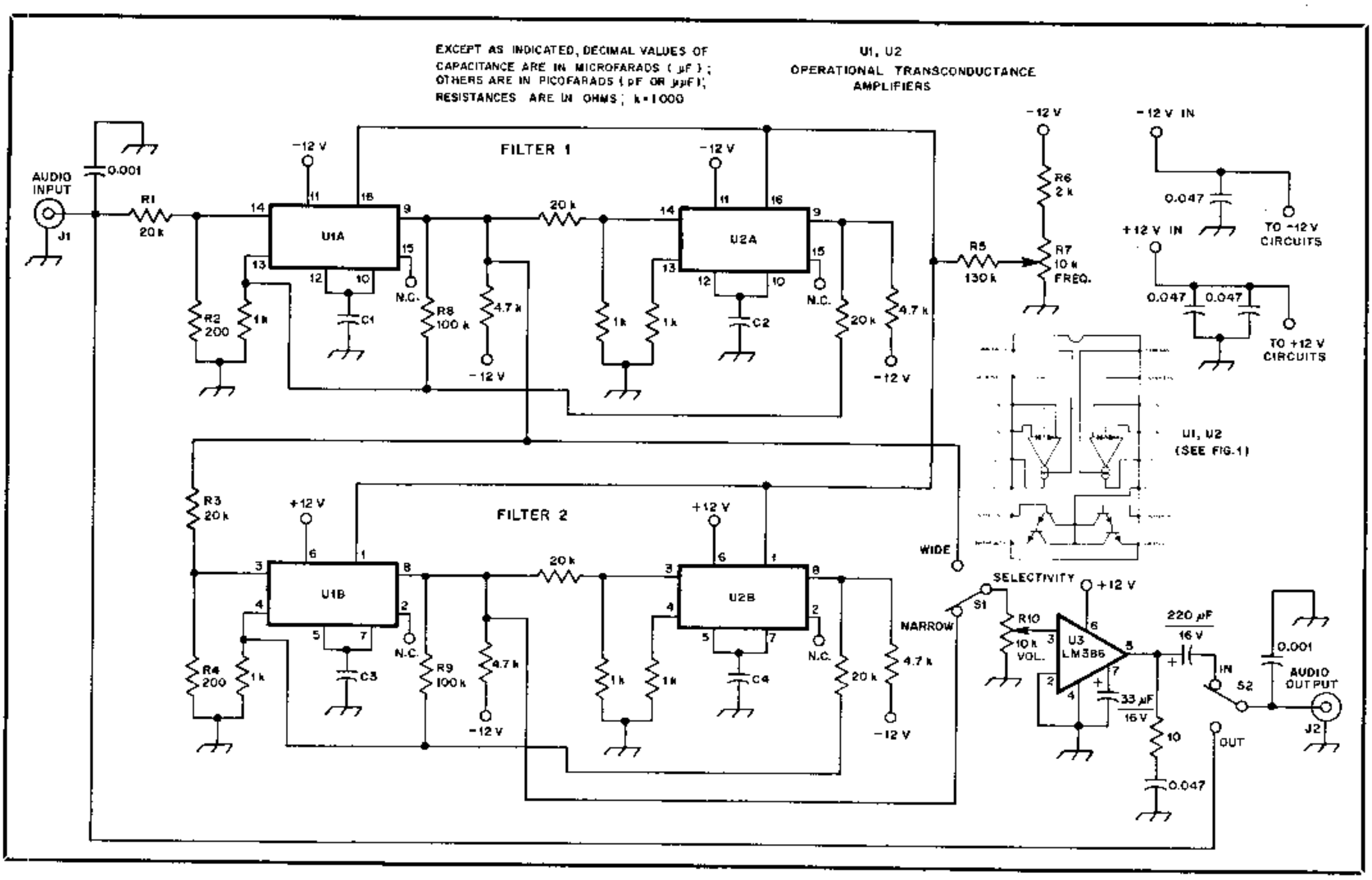

Fig. 3 — Schematic diagram of the tunable cw filter. All fixed-value resistors are 5%-tolerance types.
C1-C4 — 0.001-μF, 5%-tolerance polystyrene or mica capacitor.
R7 — Linear-taper potentiometer.
R10 — Audio-taper potentiometer.

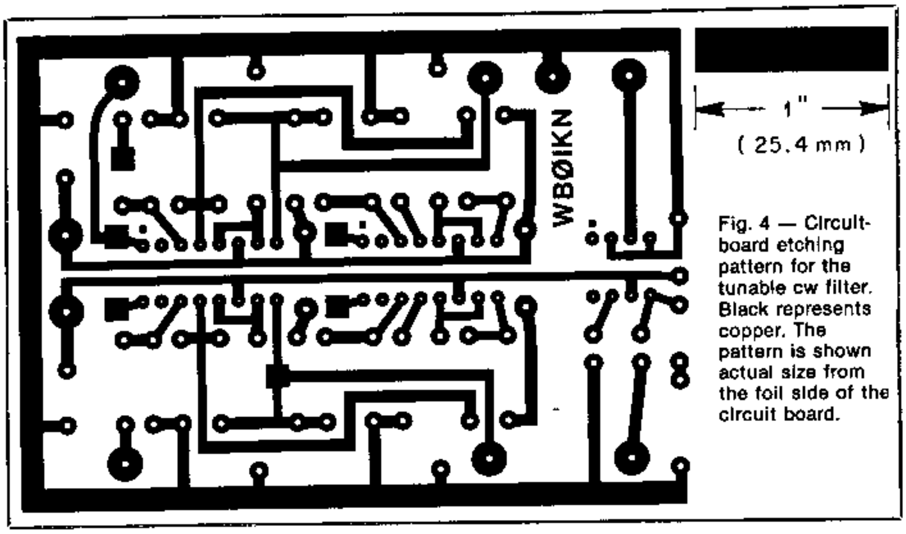

Fig. 4 — Circuit-board etching pattern for the tunable cw filter. Black represents copper. The pattern is shown actual size from the foil side of the circuit board.

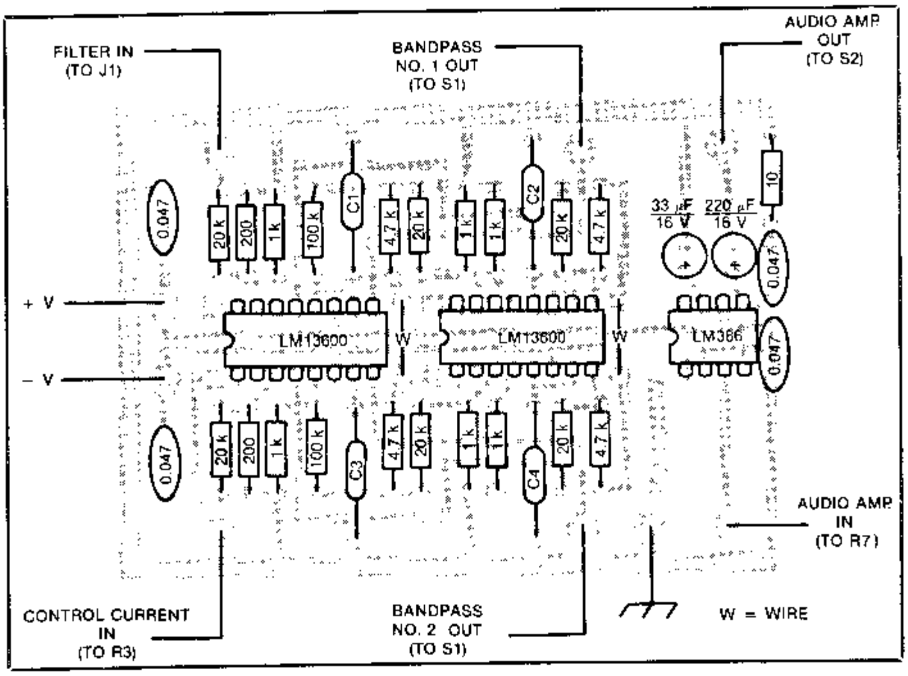

Fig. 5 — Parts-placement guide for the tunable cw filter. Parts are placed on the nonfoil side of the board; the shaded area represents an X-ray view of the copper pattern.

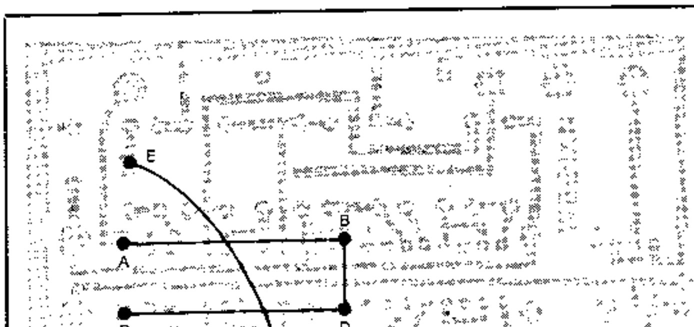

Fig. 6 — Jumper-placement diagram for the tunable cw filter. Jumpers are placed on the foil side of the board; the shaded area represents the copper pattern.

allow sufficient room and provide for air circulation: The transconductance stages will drift with temperature changes.

The layout and dress of interconnections is not critical, although some basic precautions should be observed. Be sure to keep all inputs and outputs as far apart as possible, particularly those associated with the amplifier circuit. Pay special attention to the possibility of ground loops. It is advisable to use a "star ground" technique wherever possible, returning all ground connections to a common point on the chassis. This will help to keep hum from creeping into the audio.[6]

Operation

To install the filter, connect the input jack to the loudspeaker or headphone jack on your receiver using a patch cord. Connect the filter to a regulated power supply capable of providing +12 V at 250 mA and −12 V at 100 mA (I use a pair of rechargeable batteries to eliminate any chance of hum in the audio amplifier). Then connect a loudspeaker or headphones to the output jack and apply power to the filter. Flip the IN/OUT switch to OUT (direct audio) and tune in a cw signal on your receiver. Now flip the IN/OUT switch to IN and the SELECTIVITY switch to wide and tune the filter frequency control until the desired signal is peaked. Adjust the VOLUME control to equalize the direct and filtered amplitudes, and then try the NARROW selectivity position. You will notice that off-center signals are reduced significantly, with no increase in ringing on the desired signal. You may now peak any signal within the receiver passband without changing the receive frequency, simply by tuning the audio filter.

This filter has brought new life to my aging Drake R4B receiver. Not only does it provide a significant improvement in selectivity, but it removes hiss (wideband noise) and hum from the audio (much needed). Whether your receiver is a vintage tube-type, or is state-of-the-art, this filter will help you dig out the weak ones.

First licensed in 1969 as WB2IQF, Richard A. Nelson joined the ARRL that same year. Richard has worked as an audio recording engineer, and as chief engineer and station manager of KCMK-FM, Glenwood Springs, Colorado. He is the founder of Analog Technology, Fort Collins, Colorado, manufacturers of Amateur Radio and professional audio products. Currently, Richard is majoring in engineering physics at Colorado State University in Fort Collins. His Amateur Radio interests include receive and transmit signal processing, and contesting. Other hobby interests include microcomputers, sports cars, building and playing electronic music synthesizers, and collecting gemstones.

Notes

[1]Bloom, "Active Filters," *QST*, July, 1980, p. 17.
[2]Berlin, "The State Variable Filter," *QST*, April 1978, p. 14.
[3]"LM13600/LM13600A/LM11600A Dual Operational Transconductance Amplifier with Linearizing Diodes and Buffers," National Semiconductor, July 1978.
[4]Grabowski, "PC Board Standards Can Speed Experiments," *QEX* (ARRL), May 1982.
[5]mm = in. × 25.4
[6]The author will answer your questions about this article; please include a business-size s.a.s.e. when you write.