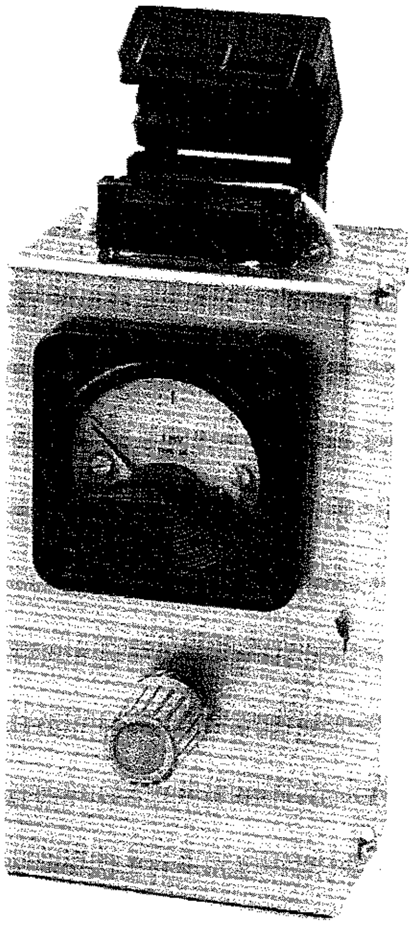
By Steve L. Sparks, N5SV

An RF Current Probe for Amateur Use

You can build this simple, inexpensive gadget in a few hours!



Recently I had a need to make some relative RF current measurements. Not having anything immediately available, I quickly assembled this simple, yet capable instrument. It's not only easy to build, but inexpensive, too.

The probe schematic is shown in Figure 1. With the component values shown, my unit has a half-scale-reading sensitivity of 0.2 mA (10 mW) into 50 Ω at frequencies from 1.8 to 30 MHz. By using a more-sensitive meter—such as a 50 µA unit—you can improve the probe's sensitivity.

Construction

The size of the enclosure you use is primarily dependent on the size of the meter. For ease of use, I suggest keeping the box size no larger than something you can comfortably hold in one hand. The enclosure I use measures 4.25×2.5×1.5 inches (HWD).

Secure the snap-open core to the top of the enclosure using epoxy or another strong adhesive. Before applying the adhesive to the box and core, rough up the attachment area to provide better bonding. Drill a hole through the enclosure on each side of the core to pass the ends of L1. To create the single turn required for L1, run a length of #14 wire through the core (in one end and out the other) and connect its ends to the full-wave diode bridge; see the accompanying photographs. Note that the entire circuit is floating and is not attached (grounded) to the enclosure.

The value of the **SENSITIVITY** pot, R1, isn't critical and can range from 100 to 500 Ω. I used a 10-turn, 100 Ω wire-wound unit.

Uses

There's not much to using the current probe: You simply snap the core around the conductor you're checking and adjust the **SENSITIVITY** control for a usable reading. You can use the probe to check RF current distribution in antenna elements, open-wire feed lines, guy wires and other conductors.

If you're bitten by RF in the shack, you can use the current probe to help you resonate the station's ground wire. Snap the probe around the ground wire, connect a variable capacitor—a broadcast-band type can be used—between the ground wire and your equipment connection and transmit using just enough power to obtain an indication on the probe's meter. Then, tune the variable capacitor for maximum meter deflection. It will likely take some experimentation to find the correct value of capacitance to series-resonate the ground wire. As your operating frequency changes, you'll need to readjust the capacitor accordingly. I used the resonant-ground procedure at a friend's house in Iowa. It cured the problem of RF getting into his computer while on the air.

Contact Steve at 2701 High Country Blvd, Round Rock, TX 78664; **slsparks@ix.netcom.com**.

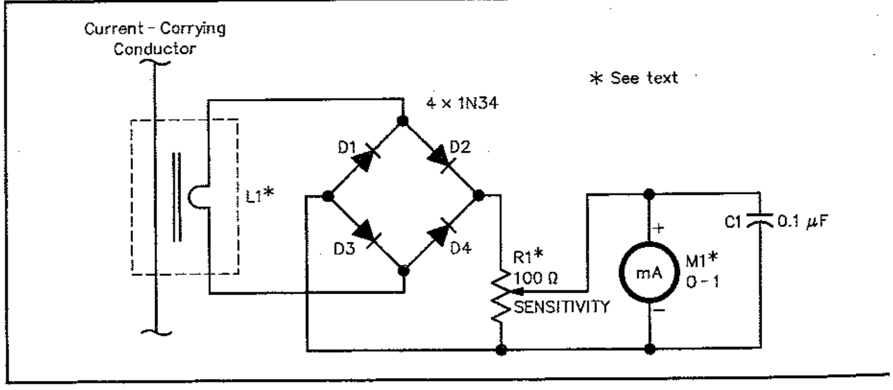


Figure 1—Schematic of the RF current probe. Unless otherwise specified, resistors are 1/4 W, 5% tolerance carbon-composition or film units. Part numbers in parentheses are RadioShack. Equivalent parts can be substituted.

C1—0.1 µF disc ceramic (RS 272-135).
D1-D4, incl—1N34 germanium diode (RS 276-1123); do *not* use silicon diodes.
L1—Single turn of #14 wire through a snap-on ferrite choke (RS 273-105); see text.
M1—0-1 mA or greater sensitivity; (an RS 22-410 can be used without the series multiplying resistor supplied as it's a 0-1 mA movement meter.)
R1—Panel-mount pot, 100 to 500 Ω; 10-turn pot used here.
Misc: Enclosure, knob, hardware, adhesive.

By Steve Hageman

A Synthesized 2-Meter FM Receiver with PC Control

Advanced chip technology and a popular microcontroller combine to make this neat project one *you* can build!

The wireless revolution is certainly making it convenient for amateurs who like to build radios! Every week, a fistful of new, highly integrated receiver chips is introduced. With today's experimenter-friendly distribution channels, it is even relatively easy to get parts. In fact, many manufacturers have Internet sites from which samples can be ordered directly. Perhaps the only downside to this revolution—for "homebrewers," anyway—is that the *size* of the parts keeps shrinking.

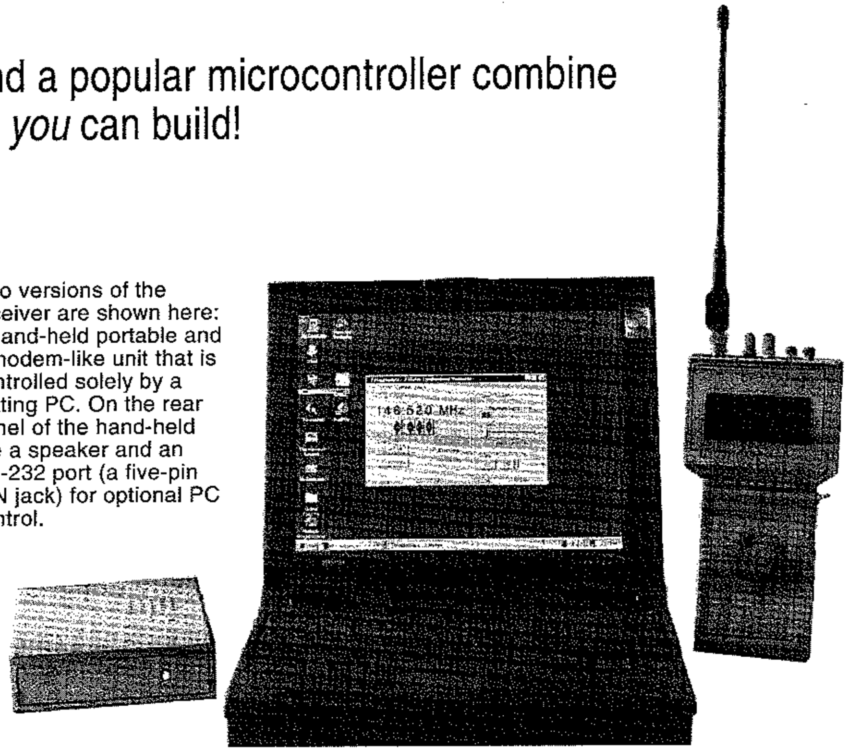
This project describes the construction of a highly integrated 2-meter FM receiver that employs an IC designed for use in commercial cordless phones. The receiver can operate as a portable scanner, or be connected to a *Windows 95/98* platform PC's RS-232 port and operate under PC control.[1]

RF Deck

The heart of any receiver is its RF deck; everything else is support circuitry. This receiver is no exception. Many projects in the past have used a Motorola MC336*x*[2] device. These parts were recently superseded by the more-highly integrated MC13135 family. Truly a receiver on a chip, the MC13135 contains almost all the functions required to get RF energy converted to audio; it even has relatively good large-signal-handling capability.

As can be seen in Figure 1, the support circuitry required for the MC13135 is minimal. The design uses the MC13135 in a dual-conversion configuration with an external first LO and internal, crystal-controlled second LO.

The 50 Ω antenna input is followed by a double-tuned LC filter. This filter is fixed-tuned to cover the entire 2-meter band. C1, C2 and L1 step up the 50 Ω antenna impedance to about 700 Ω to match U1's input impedance. The second filter section, C5 and L2, adds more selectivity. Values for C3 and C4 are chosen to set coupling and hence, filter bandwidth. I use two capacitors in series here for greater bandwidth adjustability when using standard, leaded-capacitor values.


Two versions of the receiver are shown here: a hand-held portable and a modem-like unit that is controlled solely by a mating PC. On the rear panel of the hand-held are a speaker and an RS-232 port (a five-pin DIN jack) for optional PC control.

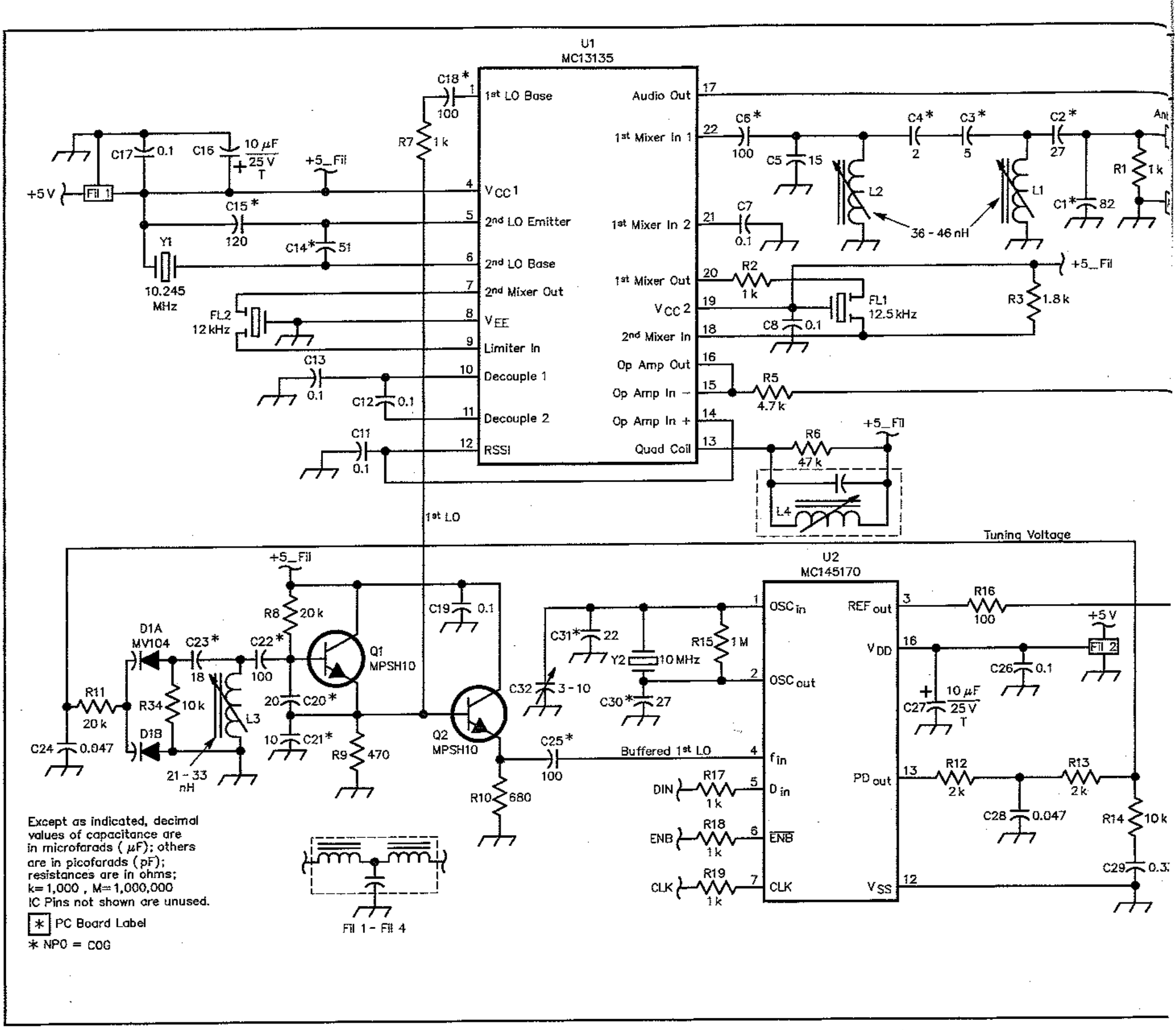
U1's first mixer is a classic active Gilbert cell. These mixers have a low third-order intercept. This limits the receiver's large-signal-handling performance. On the plus side, an active mixer provides conversion gain, so no amplifier is needed after the mixer. Also, the mixer's sensitivity to output-matching problems is lower than that of a double-balanced diode configuration. Gilbert cells also operate with a very low LO input power. Because of this, physical layout is much less sensitive to spurious-signal pickup.

Choosing an LO frequency is a tradeoff. The first IF—10.7 MHz—is picked to make parts procurement easy. A 21.4 MHz first IF would have improved image rejection, but crystal filters for that IF are not easy to come by in small quantities. With the first IF at 10.7 MHz, the first image frequency is around 165-169 MHz. This image frequency does not present much of a problem as the 165-169 MHz band is between the common pager frequencies.

U1 has an internal transistor that can be used as the first LO, but the transistor's operation is limited above 100 MHz, so a discrete transistor (Q1) is used instead. Q1 is configured as a Colpitts oscillator with C20 and C21 setting the feedback. C22 provides a dc block to L4. C23 limits D1's tuning range. When building a VCO, it is desirable—because of noise on the tuning-voltage line—to limit the tuning range as much as possible. Because the usable, linear-tuning range of the PLL is fixed at 1 to 4 V (set by the power supply voltage), the VCO is adjusted to just cover the LO frequency range required. Decreasing the VCO tuning sensitivity improves the VCO noise performance.

The first LO VCO is tuned to the operating frequency plus 10.7 MHz for high-side injection to the mixer. This produces a constant first IF of 10.7 MHz. The output of the first mixer (U1 pin 19) is impedance-matched to the 10.7 MHz, two-pole crystal

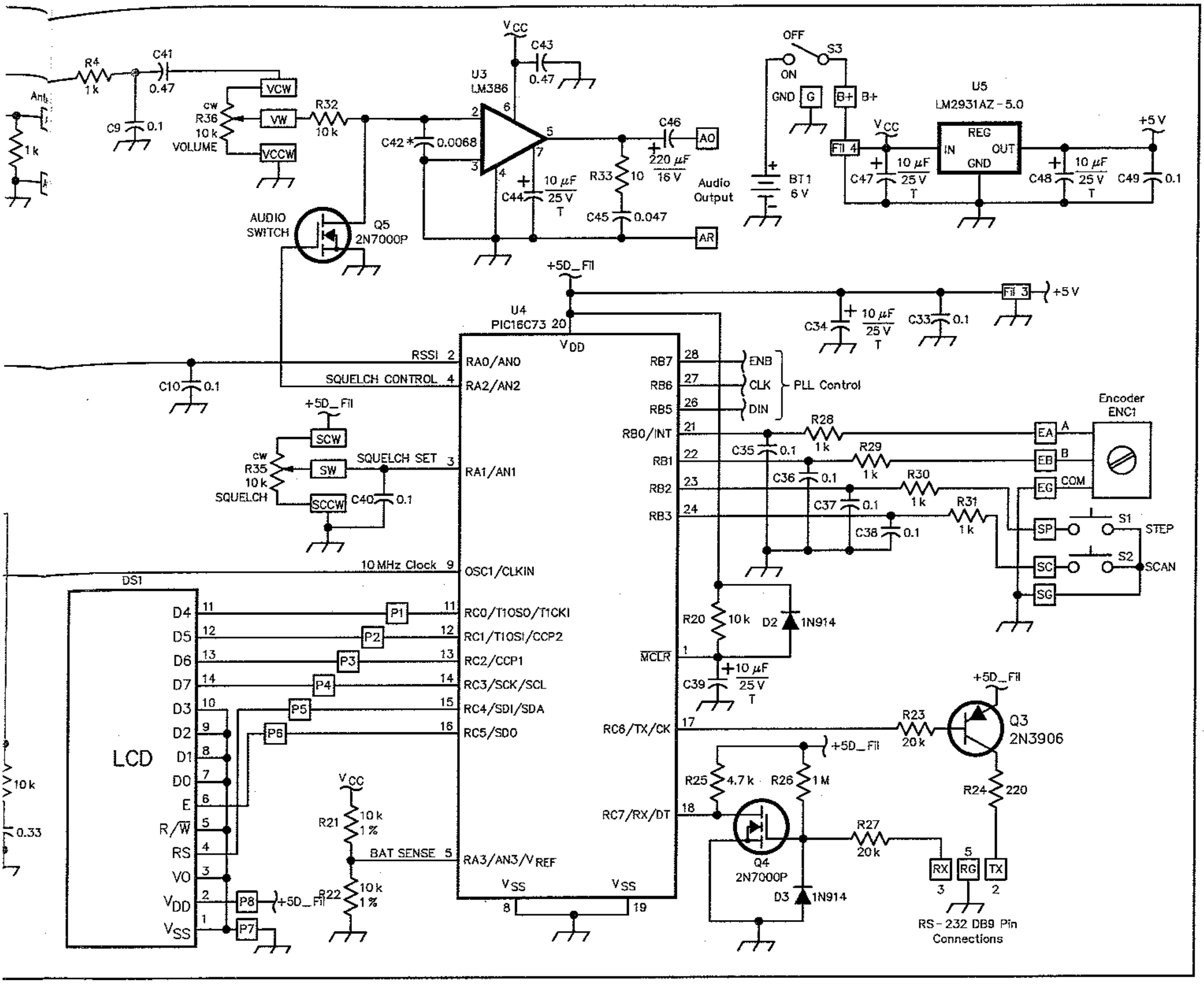
[1] Notes appear on page 40.



Except as indicated, decimal values of capacitance are in microfarads (µF); others are in picofarads (pF); resistances are in ohms; k=1,000 , M=1,000,000
IC Pins not shown are unused.
☐* PC Board Label
* NPO = COG

Figure 1—Schematic of the synthesized 2-meter FM receiver. Each receiver section is associated with one IC—that's how integrated receiver design has become. A PIC microcontroller takes care of the user-interface functions and programs the PLL for the chosen frequency. The only control that is not programmable is **VOLUME**. Unless otherwise specified, resistors are 1/4 W, 5% tolerance carbon-composition or film units. Equivalent parts can be substituted. Parts are available from these suppliers and others: Digi-Key Corp, 701 Brooks Ave S, Thief River Falls, MN 56701-0677; tel 800-344-4539, 218-681-6674, fax 218-681-3380; **http://www.digikey.com**; Mouser Electronics, 2401 Hwy 287 N, Mansfield, TX 76062; tel 800-346-6873, 817-483-4422, fax 817-483-0931; **sales@mouser.com**; **http://www.mouser.com**; Newark Electronics, 4801 N Ravenswood Ave, Chicago, IL 60640-4496; tel 800-463-9275; 312-784-5100; fax 312-907-5217; **http://www.newark.com**.

BT1—Five 550 mAh AAA NiMH cells (RadioShack 23-527)
C1—82 pF, 100 V, NP0, ceramic (Mouser 141-100N5-082J)
C2, C30—27 pF, 100 V, NP0, ceramic (Mouser 141-100N5-027J)
C3—5 pF, 100 V, NP0, ceramic (Mouser 141-100N5-005J)
C4—2 pF, 100 V, NP0, ceramic (Mouser 141-100N5-002J)
C5—15 pF, 100 V, NP0, ceramic (Mouser 141-100N5-015J)
C6—100 pF, 100 V, NP0, ceramic (Mouser 141-100N5-101J)
C7-C13, C17, C19, C26, C33, C35-C38, C40, C49—0.1 µF, 100 V, X7R, ceramic (Mouser 581-UEZ104K1)
C14—51 pF, 100 V, NP0, ceramic (Mouser 141-100N5-051J)
C15—120 pF, 50 V, NP0, ceramic (Mouser 140-CD50S2-121J)
C16, C27, C34, C39, C44, C47, C48—10 µF, 25 V tantalum (Digi-Key P2049-ND [Panasonic ECS-F1EE106K])
C18, C22, C25—100 pF, 100 V, NP0, ceramic (Mouser 141-100N5-101J)
C20—20 pF, 100 V, NP0, ceramic (Mouser 141-100N5-020J)
C21—10 pF, 100 V, NP0, ceramic (Mouser 141-100N5-010J)
C23—18 pF, 100 V, NP0, ceramic (Mouser 141-100N5-018J)
C24, C28, C45—0.047 µF, 100 V, X7R, ceramic (Mouser 581-UEZ473K1)
C29—0.33 µF, 100 V, X7R, ceramic (Mouser 581-UEZ334K2)
C31—22 pF, 100 V, NP0 (Mouser 141-100N5-022J)
C32—3-10 pF (Digi-Key SG10016-ND [Sprague GKG10016])
C41, C43—0.47 µF, 50 V, Z5U, ceramic (Mouser 581-UDW474M1)
C42—6800 pF, 100 V, NP0, ceramic (Mouser 581-UEC682J2)
C46—220 µF, 16 V aluminum electrolytic (Digi-Key P5232-ND [Panasonic ECE-A1CGE221])
D1—MV104 dual Varactor diode (Newark MV104)
D2-D3—1N914, 1N4148 (Digi-Key 1N4148MSCT-ND)
DS1—16-character, 2-line LCD (Digi-Key 73-1045-ND [Optrex DMC-16207N-B])
ENC1—Encoder (Digi-Key P80685-ND EVQ-VEMF0124B [Panasonic])
FIL1-FIL4—Panasonic EMI filter (Digi-Key P9809CT-ND)
FL1—12.5 kHz, 2-pole 10.7 MHz crystal filter (Digi-Key X701-ND)
FL2—12 kHz, 455 kHz ceramic filter (Digi-Key TK2334-ND)
L1, L2—36-46 nH SMT coil (Digi-Key TKS2715CT-ND)



L3—21-33 nH SMT coil (Digi-Key TKS2714CT-ND)
L4—Toko quadrature coil (Digi-Key TK1302-ND [RMC2A6597HM])
LS1—Panasonic EAS-45P104S (Digi-Key P10176-ND)
Q1, Q2—MPSH10 RF NPN (Newark MPSH10)
Q3—2N3906 general-purpose PNP (Newark 2N3906)
Q4, Q5—2N7000P, N-channel MOSFET (Digi-Key 2N7000P-ND)
R35, R36—10 kΩ, single-turn pot (Digi-Key RV6N10KC-ND)
S1, S2—SPST NO momentary contact; snap-action only (Digi-Key CKN4010-ND)
U1—MC13135P dual-conversion, narrowband receiver (Newark MC13135P)
U2—MC145170P PLL (Newark MC145170P)
U3—LM386N-1 (or -3, -4) audio amplifier (Digi-Key LM386-1ND)
U4—PIC16C73A/JW-20 (*programmed* PIC; see text and Note 1)
U5—LM2931AZ-5.0 low-dropout voltage regulator (Digi-Key LM2931AZ-5.0-ND)
Y1—10.245 MHz, 30 pF parallel mode, HC25/U (International Crystal Mfg Co, PO Box 26330, 10 N Lee, Oklahoma City, OK 73126-0330; tel 800-725-1426, 405-236-3741, fax 800-322-9426.
Y2—10.000 MHz, 20 pF (Mouser 73-XT49S1000-20 parallel mode)
Misc: Enclosure—Pac-Tec K-TT (Mouser 616-72821), hardware.

filter, FL1, by R2 and R3. The two-pole crystal filter specified has a 3 dB bandwidth of ±4 kHz and a stopband of 20 dB at ±18 kHz.

The second mixer uses a 10.245 MHz LO to convert the 10.7 MHz first IF to 455 kHz. FL2, the second IF filter, is a low-cost 12-kHz bandwidth unit that provides more selectivity and limits the noise bandwidth to the input of the limiting amplifiers. A narrower filter could be used here, but a 12 kHz unit allows for frequency drift in the second LO and provides more than adequate stop-band performance. (The MC13135 is so well thought-out that its impedances match those required by the second IF ceramic filter without any external components!) At the output of the second IF filter, the total gain of U1, after filter losses, is about 12 dB. At this point, the receiver's total noise figure is about 10 dB. This level of performance is sufficient for microvolt sensitivity.

The only shortcoming of these integrated receivers is the relatively low third-order intercept of the first mixer (−17 dBm). This manifests itself as a limiting factor in the receiver's overall spurious-free dynamic range. Spurious-free dynamic range (SFDR) can be defined as the ratio of the minimum detectable signal (MDS) to the signal level that produces third-order products that are equal to the MDS. In this receiver, the SFDR is about 60 dB. That may sound small, but in absolute voltages, the ratio is 1000:1. So for a 1 µV MDS, the largest spurious-free signal that can be processed is 1 mV (all in RMS volts). Larger signals than the theoretical SFDR predicts can be present at the input and a

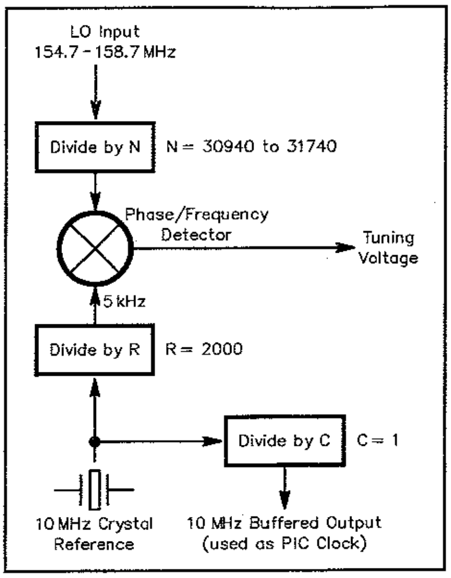


Figure 2—The PLL (U2 of Figure 1) has three counters that are programmed by the PIC. The R and C counters are programmed to the proper operational values at power-on. The R counter divides the 10-MHz reference by 2000 to get a 5-kHz internal signal that sets the receiver's minimum tuning-step size. Only the N counter needs to be changed to tune the receiver during operation.

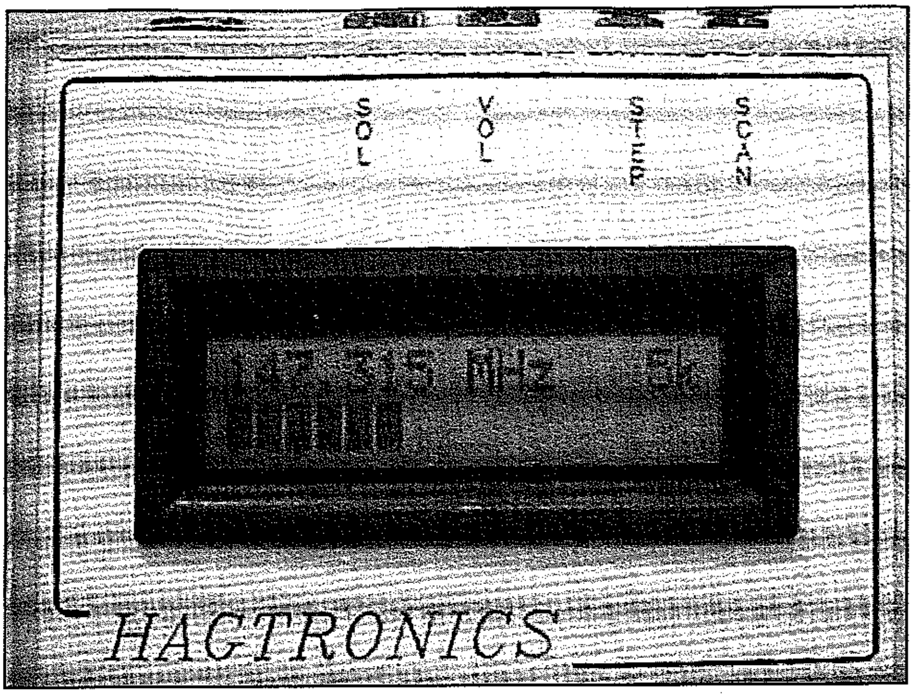
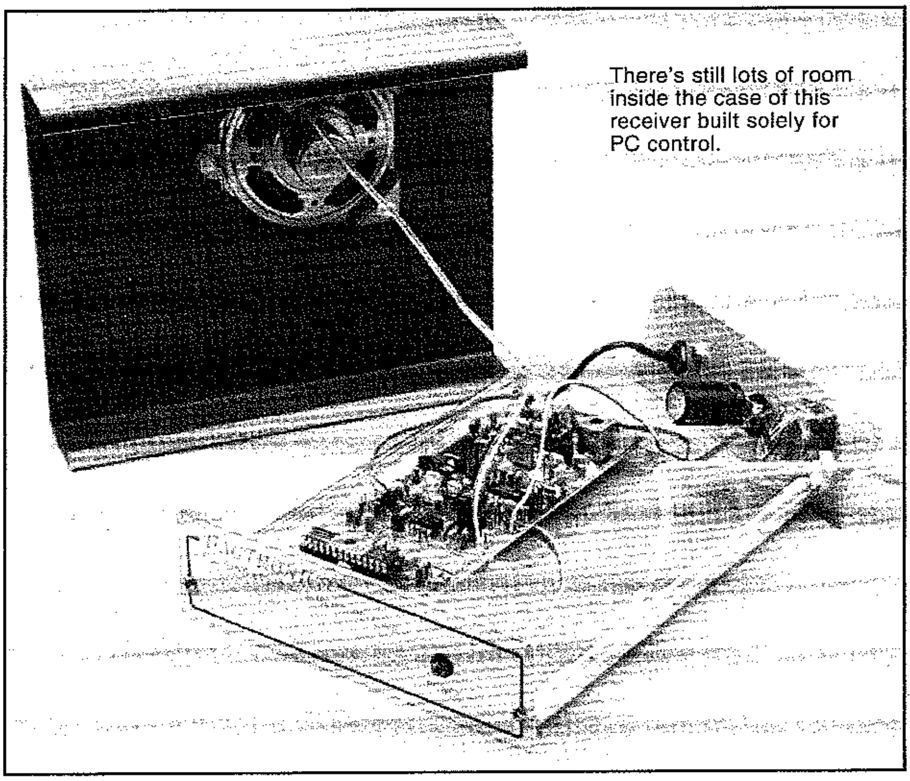


Figure 3—On the top line of the LCD, the frequency and tuning-step size are shown. The second line is a bar-graph signal-strength meter. During scanning and RS-232 operation with a PC, messages appear in the display to show the current mode. When the battery gets low, **BAT** flashes on the lower portion of the display.



There's still lots of room inside the case of this receiver built solely for PC control.

readable signal heard, but the distortion products decrease the signal-to-noise ratio.

After the second-mixer IF filter, U1 has 110 dB of gain in the limiting amplifiers. This much gain usually presents an excellent opportunity for regenerative feedback and oscillation in the amplifiers. The MC13135 prevents some of these problems by rolling off the bandwidth of the limiting amplifier above 2 MHz. Use of a PC-board ground plane helps to keep the MC13135 oscillation-free.

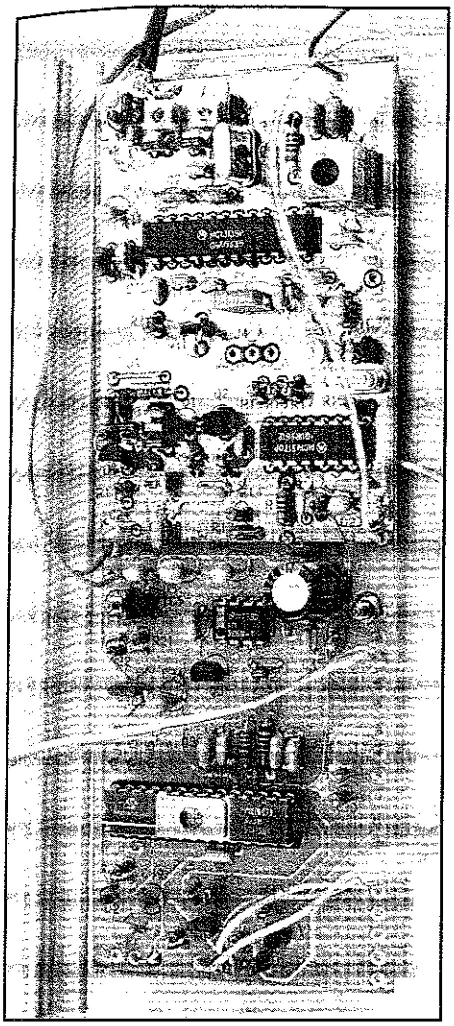
The limiting amplifier produces a voltage proportional to the logarithm of the RF-input signal. This is identified as the *received-signal-strength indicator*, or RSSI. The RSSI signal is buffered by an uncommitted amplifier in the MC13135 (pins 14, 15 and 16) and fed to one of the A/D channels in the PIC microprocessor, U4. This RSSI signal is then used for squelch and a signal-strength indicator on the LCD.

FM signals are handled by a quadrature demodulator in U1. The 90° phase shift required for demodulation is provided by L3, a commercially made quadrature coil.

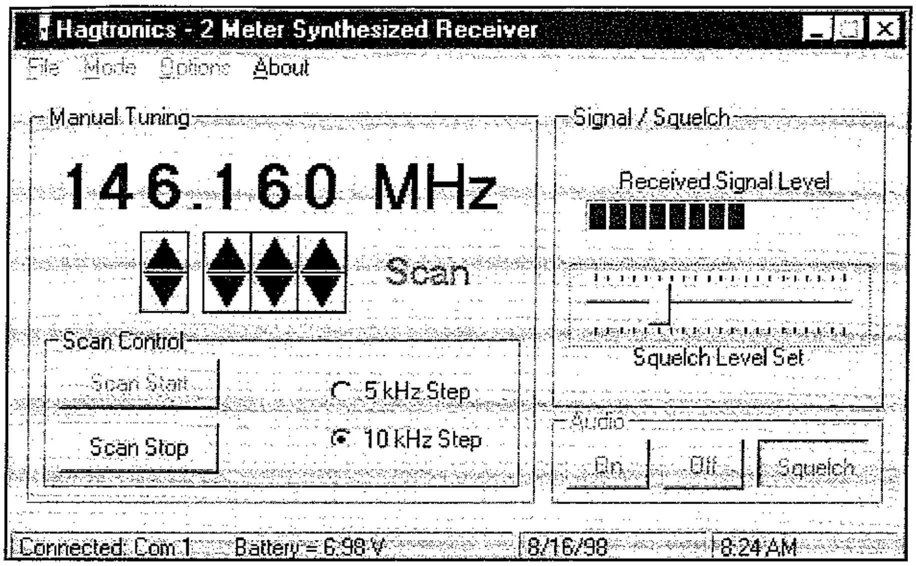
PLL Circuit

U2 is a Motorola MC145170, a fully programmable PLL that is controlled by the PIC (U4). The PLL gives the receiver the ability to be "digital." The LCD can show the exact frequency to which the receiver is tuned without actually counting the LO frequency (see Figure 2). This is accomplished in U2 by dividing the 10 MHz crystal-reference clock to 5 kHz with U2's R counter (divide by 2000). This 5-kHz reference frequency then sets the receiver's minimum channel spacing. From 144 to 148 MHz, there are 801 such channel steps. The PIC keeps track of the channel to which the receiver should be tuned and programs U2's main counter (the N counter) accordingly. When the N counter varies from 30,940 to 31,740, the first LO tunes from 154.7 to 158.7 MHz.

U2 also has a buffered output that is routed to the PIC for use as its clock (through the C counter). Because the PIC is performing RS-232 communications, it



Here's a close-up of the boards in the modem-like receiver.



146.160 MHz

○ 5 kHz Step

● 10 kHz Step

Connected: Com 1 Battery = 6.98 V 8/16/98 8:24 AM

Figure 4—Under PC control, all receiver functions can be controlled via RS-232 commands. Shown here is the manual tuning portion of the PC control program. From this display, the entire receiver can be controlled and the entire 2-meter band scanned. In Memory mode, up to 10 specific user-programmed memory channels can be sequentially scanned. All receiver set-up parameters—such as how long the receiver delays on a scanned signal—can be set for individual users.

must have a stable clock source also, but the frequency accuracy required by the PIC for successful RS-232 operation is about 60 times less than the RF portion needs.

The PLL feedback loop is stabilized by the loop filter composed of R12, R13, R14, C28, C29 and C24. R12, R13, R14 and C29 add the main pole and zero to the PLL transfer function. These are the most important components in stabilizing the loop. C28 and C24 help filter any reference feedthrough and prevent it from modulating the VCO. C28 and C24 also destabilize the loop by adding more poles to the overall transfer function. These components were taken into account during the design of the loop to ensure stability.

The PIC

The user interface is managed by a Microchip Technology[3] PIC 16C73 microprocessor, U4. The PIC provides a very comprehensive set of features for the radio with minimum parts count. This PIC contains two 8 bit I/O ports, an internal four-channel, 8-bit A/D converter and RS-232 UART, all in a 28 pin package.

The radio operates in two basic modes: When the radio is turned on, it checks to see if a PC is connected to the RS-232 port. If not, the radio goes into *stand-alone mode.* In this mode, the radio operates like a portable receiver and all the knobs, switches and LCD are active. If U4 senses a PC connected to the RS-232 port at power-up, it enters *RS-232 mode.* In this mode, U4 *ignores* the radio's knobs and buttons and waits for RS-232 commands to control the receiver functions.

In stand-alone mode, U4 loops continually, looking for any input in the tuning knob encoder, switches, RSSI value and squelch setting. If it senses any change at these inputs, it takes the appropriate action. The receiver provides these functions:

- Volume level (not PIC controlled)
- Squelch level—the PIC compares the level set here with the RSSI value from the receiver and determines whether the audio should be on or off.
- Tuning-step size in 5, 10, 100 kHz and 1 MHz increments, along with a means to lock the frequency to the current setting.
- Scan button—places the receiver in a scan mode in which it steps through the entire band and delays on any active signal.
- Tune encoder that allows an analog frequency-tuning input via a front-panel knob.

DS1 shows the currently tuned frequency in megahertz, and the currently selected tuning step size. In addition, the second line of DS1 acts as a bar-graph signal-strength meter (see Figure 3).

PC Control Program

I've written a program (see Note 1) that allows total control of the receiver by a PC. The PIC responds to RS-232 commands by setting receiver hardware as needed and sending receiver status information back to the PC. The PC program has three major modes:

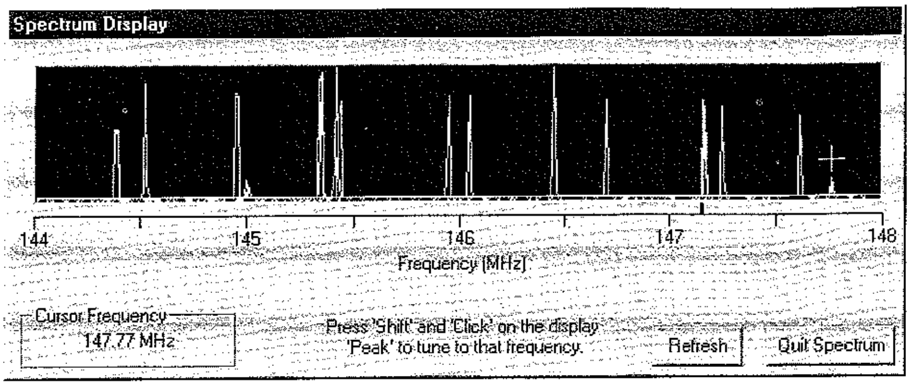
First is the *manual/scan* mode (Figure 4). In this mode, the receiver can be tuned to any frequency in the 2-meter band. Also, a straight band scan can be performed. Another mode allowed by the program is a *memory scan.* In this mode, you load up to 10 frequencies into the computer's memory and the PC scans *only those frequencies.*

Perhaps the most interesting of the receiver's modes is that of *spectrum display* (Figure 5). In this mode, the PC continually sweeps the 2-meter band in 10-kHz steps and displays the RSSI value at each point. This generates a relative signal-strength versus frequency plot. A cursor allows you to determine actual frequencies, and by double-clicking on a peak, the receiver tunes to that frequency.

Usually when one composes a program, all sorts of constants get hard-coded. The constants contain display-scaling factors and things like the delay duration after a signal stops before scanning resumes. These decisions can make the radio inconvenient for other people to use who might have different preferences. I added an options screen to this program that lets *you* override all my preconceived constants! Every time the program starts, these preferences are reloaded from disk.

Options and Construction

The receiver can be built for manual and PC control, or for PC-only control. If PC-only operation is desired, several parts may be omitted: the LCD—it is not used in RS-232 mode; the tuning encoder, **SCAN** and **STEP** switches are not used, and neither is the **SQUELCH** pot. The radio then works



Press 'Shift' and 'Click' on the display 'Peak' to tune to that frequency.

Figure 5—Perhaps the most interesting mode is that of spectrum display. Here the receiver is continuously tuned across the band in 10 kHz steps. The display operates in a storage-oscilloscope fashion so it shows all the signals the receiver has heard. The heights of the signal blips indicate their relative signal strengths. The small cross at the right-hand side of the screen is the PC's mouse pointer acting as a cursor. The exact frequency beneath the cross (mouse) is shown in the lower-left corner of the display. This is useful in determining the true frequency of any signals displayed.

only under PC control. The single remaining adjustment is the **VOLUME** control.

Building the radio is straightforward using a FAR Circuits[4] PC board. The PC board is designed for through-hole versions of U1 and U2. If these are unavailable, buy surface-mount devices and use Aries SMT-to-DIP adapter sockets (see the parts list). This provides maximum flexibility in constructing the receiver.

Several jumpers are used on the PC board. Use special care with one particular jumper: The one from R16 at U2 to U4 is the 10-MHz clock line for the PIC. This jumper has an associated ground trace on the PC board that it is designed to have a jumper wire placed *on top* of it. By placing the jumper on the trace, we make a kind of "poor man's coaxial cable." This helps to keep the clock signal clean and prevents 10-MHz harmonic radiation to the RF deck. The jumper can be made from a short length of wire-wrap wire. Tack the wire along the ground trace every ½-inch or so with Super Glue or a similar adhesive.

L1, L2 and L4 are Toko surface-mount types. These inductors are positioned on the PC board, with one end soldered to the ground plane, the other end soldered to the pad on the top of the board.

Enclosure

You can house the portable receiver in any suitable enclosure, but it is designed to fit into a professional-looking Pac-Tec,[5] hand-held enclosure shown in the accompanying photo. All the pots, speaker, battery, display and RS-232/battery-charging connector can be shoehorned into the case without too much trouble. For the PC-only controlled version of the receiver, I used an aluminum case from my junk box that gives the unit an almost modem-like appearance.

There is just enough room in the Pac-Tec enclosure to contain five NiMH AAA cells. These cells (see parts list) have a rating of 550 mAh and can power the receiver for 5 to 10 hours, depending mainly on the volume level used. The five cells provide a nominal 6 V and can be recharged in the receiver using any convenient dc "wall wart" supply. I recycled a 12 V, 200 mA dc wall wart and use a 36 Ω, 2 W resistor in series with its output to limit the charging current. On my portable receiver, a five-pin DIN receptacle on the rear panel is used to supply charging power to the batteries and make the RS-232 connection when needed. I mounted the current-limiting resistor in the mating DIN plug.

Tune-Up

Receiver setup is relatively simple. First, tune the receiver to 148.000 MHz and set the PLL voltage by adjusting L4 until the voltage at R14 is about 3 V. Next, set the receiver to 144.000 MHz; the voltage at R14 should be around 1.5 V. Tune the receiver to a known station frequency (such as a local club's repeater frequency) and set the 10 MHz reference by adjusting C32 for the best signal.

The FM-demodulator adjustment (L3) should be fairly close to ideal as it comes from the supplier. You can optimize the audio quality by listening to a strong signal and adjusting L3 *slightly. Do not turn L3 more than one-half a turn either way* or you may get on the other side of the demodulation **S** curve, which will *reduce* the audio level and quality!

The input filter is the most difficult adjustment. If you have access to a network analyzer, use it. But I'm betting most people won't, so here is the manual procedure. Pretune the filter first: Set L1 so that the tuning slug is three-quarters of the way to the bottom of the core. Set L2 so that one-quarter of the slug is above the top of the core. Next, tune to a station at about midband. The signal source can be a signal generator, a dip meter (and frequency counter) or another transmitter at some distance from the receiver. To prevent misadjustment due to overloading, make sure that the LCD signal meter is at half scale or less during L1 and L2 tuning. Adjust L1 for a signal peak. Then adjust L2 for the best signal levels at 144 and 148 MHz. You may need to adjust L1 slightly to optimize the bandwidth, then readjust L2. Basically, L1 sets the filter's center frequency and L2 adjusts the bandwidth.

Future Directions

The next logical step in the development of this receiver platform is the addition of a transmitter to make a full-featured transceiver. Very little would need to be changed in the receiver. The PIC has enough memory for many more features than are implemented here (such as split-frequency operation). The PLL could be switched to the transmit frequency and a diode TR switch added to the antenna circuit to steer the signals as required for transmit and receive. The latest transmitter ICs developed for cell-phones cost about $15 in small quantities, and even though they are designed to operate at 900 MHz, many of them work acceptably well in the 2-meter band.

Notes

[1] Minimum program requirements are a PC operating under *Windows 95/98*, and a 16550 UART-driven RS-232 serial port. You can obtain the 2-meter FM receiver PC control program along with the object and source code contained in *HAG2MRX.ZIP* available from **http://www.arrl.org/files/**. Or, send author Steve Hageman a self-addressed, stamped diskette mailer and three (3) formatted, 1.44 MB floppy disks. Also available from author Steve Hageman is a *programmed* 16C73 PIC: $30 US, check only. Foreign orders add $5 US for shipping and handling; South American orders add $10 US for shipping and handling. You are encouraged to visit Steve's Web site **http://www.sonic.net/~shageman/**.

[2] Motorola Inc, Phoenix, AZ; **http://www.motorola.com**. A list and links to Motorola component distributors can be found at **http://mot-sps.com/sales/sales_web.html/**. Among them is Newark Electronics, 4801 N Ravenswood Ave, Chicago, IL 60640-4496; tel 800-463-9275, 312-784-5100, fax 312-907-5217; **http://www.newark.com**.

[3] Microchip Technology Inc, 2355 W Chandler Blvd, Chandler, AZ 85224-6199; tel 602-786-7200, fax 602-899-9210; **http://microchip.com**.

[4] PC boards for this project are available from FAR Circuits, 18N640 Field Ct, Dundee, IL 60118-9269; tel 847-836-9148 (voice and fax). Price: $9.75 plus $1.50 shipping for up to four boards. Visa and MasterCard accepted with a $3 service charge.

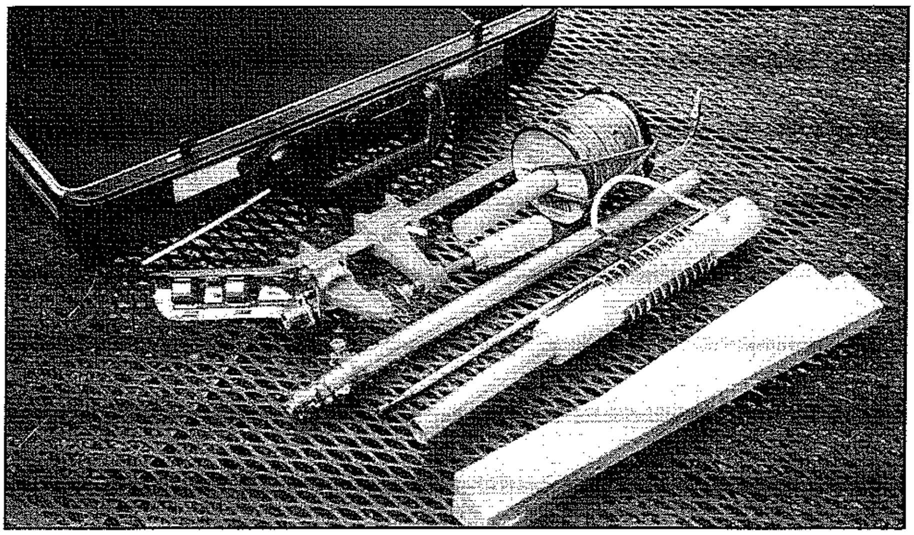
[5] Pac-Tec, One LaFranca Way, Concordville, PA 19331; tel 610-361-4200, fax 610-361-4201; **http://www.pactecenclosures.com**.

Steve Hageman, a confirmed "analog-a-holic" has been involved in electronics since the fifth grade. Always interested in the magic of grabbing signals out of the ether, he is currently employed by Hewlett-Packard Company, where he develops RF semiconductor test equipment. You can reach Steve at 9532 Camelot Dr, Windsor, CA 95492; **shageman@sonic.net**.

By Robert H. Johns, W3JIP

A Briefcase-Portable HF/VHF Antenna

Here's a smaller version of the portable antenna for 80 through 2 meters that appears in the August 1998 issue. It includes a novel way to build a multitapped coil.



This antenna will pack in your luggage—even in a briefcase if need be. The components are 14 inches in length. This antenna uses the same mounting clamp and flagpole bracket that were described in my earlier article. Please refer to that article for construction details.[1] The aluminum-tubing element has been broken up into small units, however, and a smaller-diameter loading coil is used. You can still set up the antenna to match the space available: the upper half of this dipole can be anything from about 1½ to 11 feet long, and the coil adjusted to bring the antenna into resonance.

This smaller version of the portable antenna sacrifices some efficiency because its coil diameter is smaller, and also some ruggedness, since the lighter whip element won't take as much banging around. Still, it works well and can mount anywhere.

Construction

The tubing element is made from telescoping 14-inch lengths of ¾, ⅝, ½ and ⅜-inch (OD) aluminum tubes having 0.058-inch wall thickness. Hardware departments sometimes stock tubing with slightly thinner walls that works here, also. Each tube is slotted and tightened around the next-smaller tube with hose clamps. The rest of the element is a 6-foot-long telescoping whip (RadioShack 270-1408) that fits into the ⅜-inch aluminum tube after you drill out its inside diameter with a 9/32-inch bit. Drill about ¾ of an inch into this aluminum tube before cutting slots in it.

There is nothing special about the 14-inch segment length. Increase it if you want a longer vertical element. The wooden legs that make a tripod for the tubing element also are 14 inches long. You can buy carpenter's clamps shorter than the 18-inch one shown in the first article, or cut the longer one with a hacksaw. I cut mine and put a ⅝-inch rubber tip at the cut end.

The coil is wound on a 9-inch length of one-inch Schedule-80[2] plastic pipe. The actual diameter of this pipe is 1.3 inches. The coils in the photo were wound on polypropylene[3] pipe, which is an excellent insulator. It could also be on PVC pipe unless you will be using high power. (At 100 W, PVC works well, but at kilowatt levels it can melt and burn!) In order to fit the ¾-inch-OD aluminum tubing of the antenna, a 1½-inch-long sleeve of ⅞-inch-diameter, 0.058-inch-wall aluminum tubing is glued inside each end of the

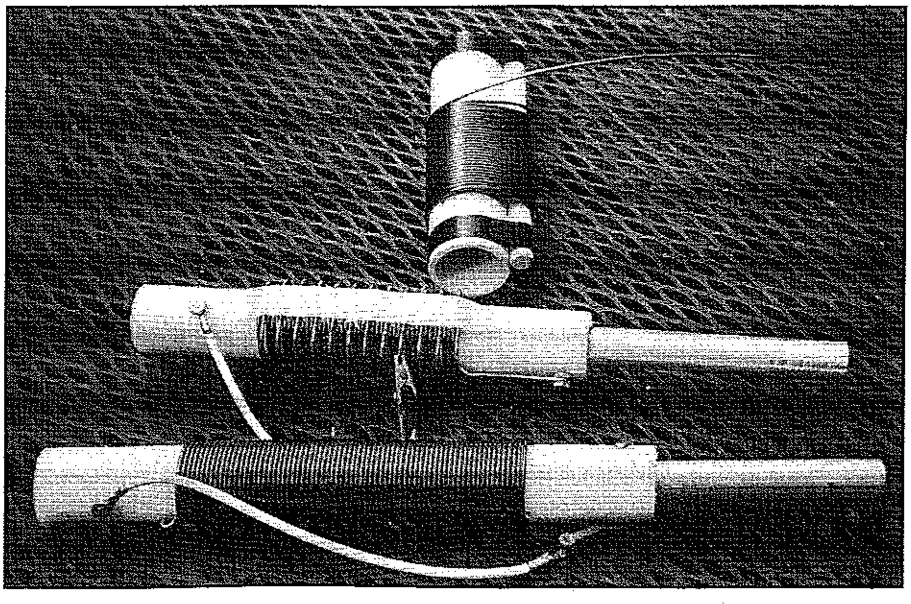


Figure 1—The 40 and 80-meter coils are only about 1.5 inches in diameter. To make many taps in the 40-meter coil, it is wound on an oversize form with a "bump" along its length (at rear). When the coil is removed and transferred to the correct form, the bends in the wire stick out to become taps.

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[1] Notes appear on page 43.

Schedule-80 pipe with epoxy. The epoxy takes up the loose play between the plastic pipe and the aluminum sleeve. The 3/4-inch tubing of the antenna is a good fit into these sleeves. A 6-inch length of 3/4-inch-OD aluminum tubing is bolted into one end so that it extends five inches out. This goes into the flagpole bracket.

You may use the same spool of wire for the lower half of the antenna that was described in the original version. If that 4.5-inch diameter spool from Home Depot is too large for your luggage, smaller spools of wire are available at RadioShack, as in the photos. You could also cut down the diameter of the rims of the larger spool. This antenna wire is connected to the flange of the coax connector with a clip lead. This separates the spool from the clamp, making the antenna easier to pack.

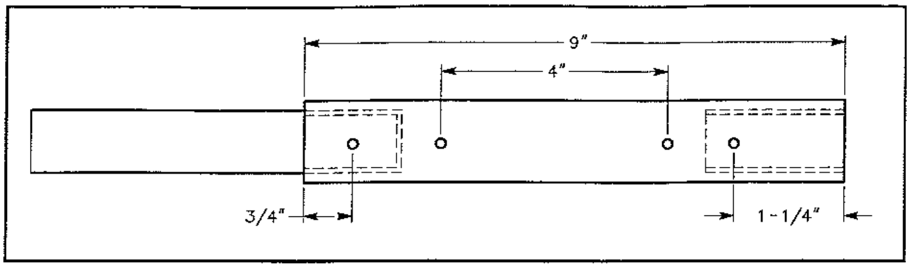


Figure 2—Coil-form hole locations. The 40-meter form is shown; the 80-meter form is similar except that it is 11 inches long and the holes for the coil are 6.3 inches apart.

Loading Coil

There are 45 turns of #12 magnet wire in the coil and 33 taps for connecting to it with the copper alligator clip. (See Figure 1.) How to make so many taps? It takes some extra effort, but is not difficult. The coil is wound on a length of 1 1/4-inch PVC pipe, which is actually 1.66 inches in diameter. A lengthwise ridge that is added to this form makes many bends in the wire as it is wrapped around the pipe. When the coil is removed, placed on the 1.3-inch-diameter tube and tightened, the bends stick out from the coil circumference at regular intervals. A little scraping finishes the tap points. Taps occur every one-and-a-third turn, but they line up with each other every fourth turn, making nice rows. The taps are far enough apart so they don't interfere with connections made to nearby taps. Here are the details:

The ridge on the larger form is made with a 1/2-inch wooden dowel. Simply tape it, lengthwise, on the winding form, as in Figure 1. After 35 turns are wound on the large form, pull out the dowel. This releases the wire to unwind and come free of the form. After transferring it to the smaller diameter form, pass one end of the wire through a set of diametric holes in the form (see Figure 2) with a four-inch lead that will connect to the 6-inch aluminum tube. Rotate the coil to tighten it around the smaller form and lay the turns against one another. This will take some gentle handling. After several passes of rotating and tightening, the winding should be snug and close-wound. Tighten the turns until the bends line up in straight rows. The other end of the coil wire passes through holes in both walls of the form. Cut off all but about one-half inch, scrape the lead clean and bend it into a loop (a connection point for this end of the coil). The coil can be made more rugged by gluing the turns together with epoxy. I made three lines of glue between the rows of taps.

The taps must be scraped to remove the wire insulation. In addition, each one should be coated with solder to provide a corrosion-free surface for the alligator clip to grip. This "tinning" operation will also reveal any streaks of insulation that weren't removed, since the solder won't stick there.

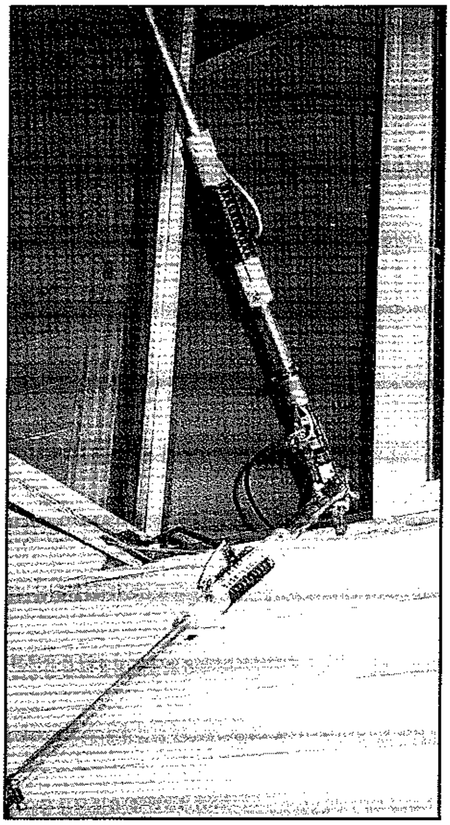


Figure 3—A briefcase portable made from two tubing elements forming a **V**.

In this coil, the tap wire with the alligator clip attached is bolted to the sleeve at the open end of the coil form. Drill and tap through the polypropylene form and the 7/8-inch aluminum sleeve for #6-32 brass screws. They make the electrical connection from the tap wire to the sleeve.

Instead of counting turns to locate the connection for a particular band, I count taps. These are much easier to work with. In the photos, you can see a strip of white vinyl electrical tape between two rows of taps. The tap numbers are written on each edge of the tape: 1,2...4,5...7,8, etc. The missing numbers belong to taps on the opposite side of the coil.

80 Meters

I made a briefcase-sized coil for 80 meters on a one-inch Schedule 80 polypropylene-pipe coil form, see Figure 1. This coil has 72 turns of #12 magnet wire wound directly on the final form. See Figure 2 for the coil-form hole locations. For 80-meter operation, the coil is placed between the flagpole bracket and the 40-meter coil, that is, both coils are used. For continuous coverage, the 80-meter coil is tapped 24 and 41 turns from the end with the aluminum tube. These taps are made before final tightening of the wire on the form. To make a tap, pry a turn outward and bend the wire. The vertical half of the antenna must be fully extended for 80-meter operation. There is no extra inductance in the coil to compensate for a shorter whip.

Operation

I have not traveled with this briefcase portable, but have tried it in several places around the house and yard. It behaves just as does its big brother.

For *Really* Tight Spaces

If you don't have space for $\lambda/4$ of wire, it is possible to use two tubing elements, as shown in Figure 3. Two flagpole brackets are mounted on a bar clamp with the same insulator and ground clamp hardware that is used for a single bracket, see Figure 4. The resulting **V** antenna may be mounted on a deck rail or window sill with the elements in a vertical plane or on a flat surface—such as a table—for horizontally polarized waves. The tripod orients one element vertically and one horizontally.

To separate the two halves of the antenna, one of the elements must be insulated from its support. This is done by replacing the aluminum tube at one flagpole bracket with a 3/4-inch Plexiglas rod. (W1VT recommends polycarbon rod. It's UV resistant and much stronger than Plexiglas. You can buy it in small quantities from Small Parts Inc, 13980 NW 58th Ct, PO Box 4650, Miami Lakes, FL 33014-0650; tel 305-557-7955 Customer Service; 305-558-1255 Catalog requests; fax 800-423-9009; **smlparts@smallparts.com**; URL **http://www.smallparts.com**.) A two-inch length of 7/8-inch-OD, 0.058-inch-wall aluminum tubing fits over the plastic rod, where it is bolted in place to form a socket for the 3/4-inch tubing of the antenna element

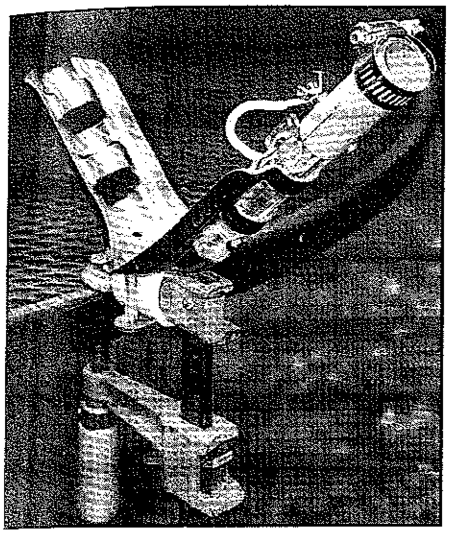


Figure 4—Two flagpole brackets are attached to one bar clamp. One of them must have some of its mounting plate cut away to fit "inside" the other.

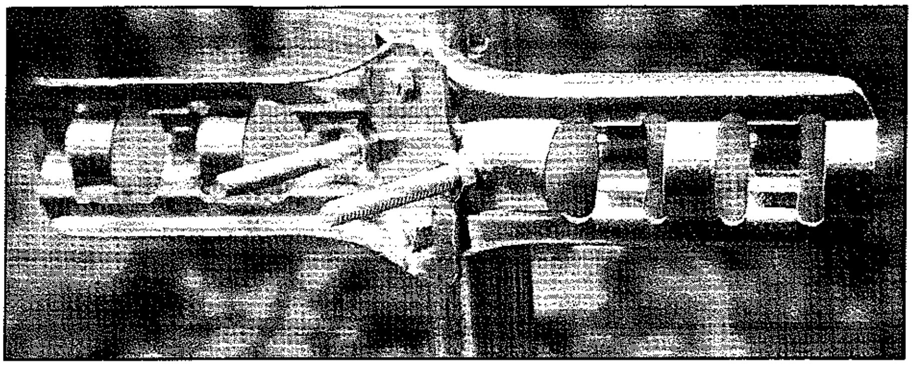


Figure 5—Two tubing elements will also form a dipole when their brackets are bolted together. A **U** bolt mounts them on a mast.

or loading coil. A coax connector is bolted to this bracket and a wire from its center terminal runs to the $^7/_8$-inch tube, which makes the electrical connection to the element.

Straight Dipole Mounting

Two flagpole brackets may be bolted together to place the elements in a straight line with a **U** bolt attaching them to a mast, as in Figure 5. This arrangement also requires an insulated mounting for one of the elements, the Plexiglas rod in Figure 4.

Bigger is Better

If you want a larger antenna, it is easy to add extra length between the flagpole bracket and the coil. Fifteen-inch segments of $^3/_4$-inch and $^7/_8$-inch aluminum (0.058-inch wall) tubing can be telescoped together, with the $^3/_4$ tubing going into the flagpole bracket, and the $^7/_8$ tubing receiving the coil. More length increases efficiency. I have added four such segments that lengthen the tubing element to more than 16 feet. The clamp, bracket and tubing stand up well.

The longer element is not as convenient, however, since the coils may be out of reach for adjustments unless you remove the element from its bracket.

Notes

[1] Robert Johns, W3JIP, "Build a Portable Antenna," *QST*, Aug 1998, pp 44-46.

[2] Schedule 80 pipe has a thicker wall than the Schedule 40 pipe that is stocked in hardware, electrical, and plumbing departments. Schedule 80 PVC is available from some large plumbing distributors. Search by telephone to find a local distributor that carries it.

[3] Polypropylene pipe is available from Plastic Piping Systems, 2841 Egypt Rd, Audubon, PA 19403; tel 610-666-7155. One inch Schedule 80 pipe is $2.55 per foot, with a minimum order of 20 feet.

Bob Johns is a semi-retired physics teacher. First licensed in 1952, he builds and experiments with coils, traps and antennas. He can be reached at Box 662, Bryn Athyn, PA 19009; **ksjohns@mindspring.com.**

W1AW SCHEDULE

Pacific	Mtn	Cent	East	Mon	Tue	Wed	Thu	Fri
6 AM	7 AM	8 AM	9 AM		Fast Code	Slow Code	Fast Code	Slow Code
7 AM-1 PM	8 AM-2 PM	9 AM-3 PM	10 AM-4 PM	Visiting Operator Time				
1 PM	2 PM	3 PM	4 PM	Fast Code	Slow Code	Fast Code	Slow Code	Fast Code
2 PM	3 PM	4 PM	5 PM	Code Bulletin				
3 PM	4 PM	5 PM	6 PM	Teleprinter Bulletin				
4 PM	5 PM	6 PM	7 PM	Slow Code	Fast Code	Slow Code	Fast Code	Slow Code
5 PM	6 PM	7 PM	8 PM	Code Bulletin				
6 PM	7 PM	8 PM	9 PM	Teleprinter Bulletin				
6^{45} PM	7^{45} PM	8^{45} PM	9^{45} PM	Voice Bulletin				
7 PM	8 PM	9 PM	10 PM	Fast Code	Slow Code	Fast Code	Slow Code	Fast Code
8 PM	9 PM	10 PM	11 PM	Code Bulletin				

W1AW's schedule is at the same local time throughout the year. The schedule according to your local time will change if your local time does not have seasonal adjustments that are made at the same time as North American time changes between standard time and daylight time. From the first Sunday in April to the last Sunday in October, UTC = Eastern Time + 4 hours. For the rest of the year, UTC = Eastern Time + 5 hours.

♦ Morse code transmissions:

Frequencies are 1.818, 3.5815, 7.0475, 14.0475, 18.0975, 21.0675, 28.0675 and 147.555 MHz.

Slow Code = practice sent at 5, 7$^1/_2$, 10, 13 and 15 wpm.

Fast Code = practice sent at 35, 30, 25, 20, 15, 13 and 10 wpm.

Code practice text is from the pages of *QST*. The source is given at the beginning of each practice session and alternate speeds within each session. For example, "Text is from July 1992 *QST*, pages 9 and 81," indicates that the plain text is from the article on page 9 and mixed number/letter groups are from page 81.

Code bulletins are sent at 18 wpm.

W1AW qualifying runs are sent on the same frequencies as the Morse code transmissions. West Coast qualifying runs are transmitted on approximately 3.590 MHz by W6OWP, with K6YR as an alternate. At the beginning of each code practice session, the schedule for the next qualifying run is presented. Underline one minute of the highest speed you copied, certify that your copy was made without aid, and send it to ARRL for grading. Please include your name, call sign (if any) and complete mailing address. Send a 9×12-inch SASE for a certificate, or a business-size SASE for an endorsement.

♦ Teleprinter transmissions:

Frequencies are 3.625, 7.095, 14.095, 18.1025, 21.095, 28.095 and 147.555 MHz.

Bulletins are sent at 45.45-baud Baudot and 100-baud AMTOR, FEC Mode B. 110-baud ASCII will be sent only as time allows.

On Tuesdays and Fridays at 6:30 PM Eastern Time, Keplerian elements for many amateur satellites are sent on the regular teleprinter frequencies.

♦ Voice transmissions:

Frequencies are 1.855, 3.99, 7.29, 14.29, 18.16, 21.39, 28.59 and 147.555 MHz.

♦ Miscellanea:

On Fridays, UTC, a DX bulletin replaces the regular bulletins.

W1AW is open to visitors from 10 AM until 4 PM on Monday through Friday. FCC licensed amateurs may operate the station during that time. Be sure to bring your current FCC amateur license or a photocopy.

In a communication emergency, monitor W1AW for special bulletins as follows: voice on the hour, teleprinter at 15 minutes past the hour, and CW on the half hour.

Headquarters and W1AW are closed on New Year's Day, President's Day, Good Friday, Memorial Day, Independence Day, Labor Day, Thanksgiving and the following Friday, and Christmas Day.

Table 1
CWAZ 50-Ω Low-Pass Filters

Designed for second-harmonic attenuation in amateur bands below 30 MHz.

Band (m)	Start Frequency (MHz)	C1,7 (pF)	C3,5 (pF)	C4 (pF)	L2,6 (µH)	L4 (µH)	F4 (MHz)
—	1.00	2986	4556	680.1	9.377	8.516	2.091
		1659	2531	378			3.76
160	1.80	1450 + 220	2100 + 470		5.21	4.73	
		1500 + 150	2200 + 330	330 + 47			3.78
		853	1302	194			7.32
80	3.50		1150 + 150		2.68	2.43	
		470 + 390	1200 + 100	150 + 47			7.27
40	7.00	427	651	97.2	1.34	1.22	14.6
		330 + 100	330 + 330	100			14.4
30	10.1	296	451	67.3	0.928	0.843	21.1
		150 + 150	470	68			21.0
20	14.0	213	325	48.6	0.670	0.608	29.3
		220	330	47			29.8
17	18.068	165	252	37.6	0.519	0.471	37.8
		82 + 82	100 + 150	39			37.1
15	21.0	142	217	32.4	0.447	0.406	43.9
		150	220	33			43.5
12	24.89	120	183	27.3	0.377	0.342	52.0
		120	180	27			52.4
10	28.0	107	163	24.3	0.335	0.304	58.5
		100	82 + 82	27			55.6

NOTE:
The CWAZ low-pass filters are designed for a single amateur band to provide more than 50 dB attenuation to the second harmonic of the fundamental frequency and to the higher harmonics. All component values for any particular band are calculated by dividing the 1-MHz values in the first row (included for reference only) by the start frequency of the selected band. The upper capacitor values in each row show the calculated design values obtained by dividing the 1-MHz capacitor values by the amateur-band start frequency in megahertz. The lower standard-capacitor values are suggested as a convenient way to realize the design values. The middle capacitor values in the 160- and 80-meter-band designs are suggested values when the high-value capacitors (greater than 1000 pF) are on the low side of their tolerance range. The design F4 frequency (see upper value in the F4 column) is calculated by multiplying the 1-MHz F4 value by the start frequency of the band. The lower number in the F4 column is the F4 frequency based on the suggested lower capacitor value and the listed L4 value.

as a means of describing this LPF design advancement for the benefit of the Amateur Radio fraternity.

A New Type of Low-Pass Filter

This article introduces a new eight-element LPF having a topology similar to that of the seven-element Chebyshev LPF, with two exceptions: The center inductor is resonated at the second harmonic in the filter stop band, and the component values are adjusted to maintain a more than acceptable RL across the amateur passband. To distinguish this new low-pass filter from the familiar SVC Chebyshev LPF, I propose that this new filter be named the "Chebyshev with Added Zero" LPF or a "CWAZ" LPF design. With this designation, you should understand that these LPFs are *output filters for single-band transmitters.* They provide optimum second and higher harmonic attenuation while maintaining a suitable level of return loss over the amateur band for which they're designed.

Figure 1 shows a schematic diagram of a CWAZ LPF design. Table 1 lists suggested capacitor and inductor values for all amateur bands from 160 through 10 meters. These tabulated values were derived from the normalized values provided to me by Jim Tonne for use in this article. If you want to confirm my tabulated values or calculate the CWAZ values for different bands, simply divide the first-row C and L values (for 1 MHz) by the start frequency of the desired band. For example, C1, 7 for the 160-meter design is equal to 2986/1.80 = 1659 pF. The other component values for the 160-meter LPF are calculated in a similar manner.

CWAZ Versus Seventh-Order SVC Chebyshev

The easiest way to demonstrate the superiority of a CWAZ LPF over the Chebyshev LPF is to compare the RL and insertion-loss responses of these two designs. As an example of a Chebyshev design, we will use the 20-meter SVC LPF design used by NN1G for filtering the output of his 20-meter QRP SSB transceiver.

Figure 2 shows the computer-calculated return- and insertion-loss responses of a seven-element Chebyshev SVC LPF commonly used for attenuating the harmonics of a 20-meter RF amplifier. The plotted responses were made using Jim Tonne's *ELSIE* filter design and analysis software. This DOS-based program is available from Trinity Software (Ref 7). The component values, obtained from the LPF schematic diagram shown in Figure 1 on page 30 of NN1G's *QST* article, were used by *ELSIE* in plotting the Chebyshev SVC LPF responses. A sketch of the filter topology with component values is included in Figure 2.

Figure 3 shows the computer-calculated return- and insertion-loss responses of a CWAZ LPF intended to replace the seven-element 20-meter Chebyshev SVC LPF. The stop-band attenuation of the CWAZ LPF in the second-harmonic band is more than 60 dB and is substantially greater than that of the Chebyshev LPF. Also, the pass-band RL of the CWAZ LPF is quite satisfactory, at more than 25 dB. The disadvantages of the CWAZ design are that an extra capacitor is needed across L4, and several of the designs listed in Table 1 require paralleled capacitors to realize the design values. Nevertheless, I believe these disadvantages are minor in comparison to the increased second-harmonic stop-band attenuation that is possible with a CWAZ design.

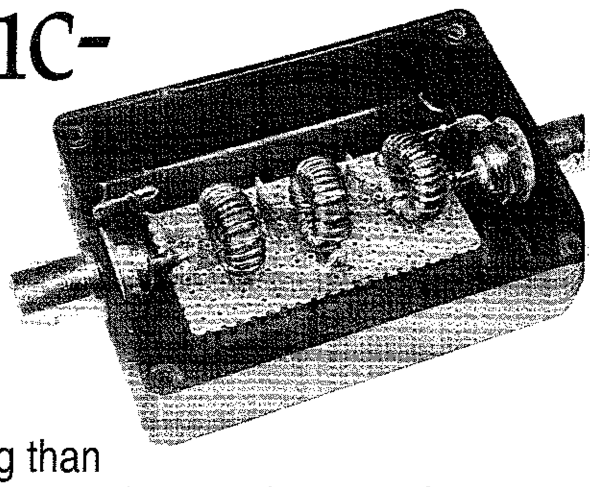
LC Filter-Design Demo Software is Available

Those involved in passive LC filter design on an amateur and semiprofessional basis may experience the capabilities of *ELSIE* through a demo disk that is available from Jim Tonne. I use *ELSIE* V 1.11 with a 386SX CPU operating at 20 MHz. Although the plotting response of this computer is slow, I can evaluate the return- and insertion-loss responses of a design in less than 10 seconds, by using the minimum number of data points for preliminary plots. V 1.11 requires less than 1 Mb of hard disk space, while a more recent V 1.23 requires about 1.1 Mb. *ELSIE* requires a hard disk.

The *ELSIE* demo disk is restricted to LC filters of the third-order or less, but one can still explore all the capabilities of *ELSIE* in the design and analysis of filters. For ex-

By Ed Wetherhold, W3NQN

Second-Harmonic-Optimized Low-Pass Filters



Sometimes we need a little more output filtering than traditional designs offer. Look at a new filter that can give you that extra boost.

Above: A QRP 20-meter CWAZ low-pass filter installed on a piece of perf board in a small (1×2⅞×2-inch, HWD) plastic box available from Farnell (Ref 4), order #645-680, $1.56 each. The toroidal cores are Micrometals (Ref 5) T50-17. The capacitors shown are Philips 683 series, low-k, 100 V dc, with a 2% tolerance. Some of those shown have a 0.2-inch lead spacing, which is no longer available from Farnell. For new construction, use Philips 680, low-K series having 0.1-inch lead spacing. The Philips 680 series is good for all QRP filtering because of its 2% tolerance.

Introduction

The FCC requires transmitter spurious outputs below 30 MHz to be attenuated by 40 dB or more for power levels between 5 and 500 W (Ref 1). Radio amateurs usually attempt to satisfy this requirement by placing a seven-element standard-value capacitor (SVC) low-pass filter (LPF) after the final amplifier. This procedure was demonstrated by Dave Benson, NN1G, in his *QST* article discussing a 3-W PEP QRP SSB transceiver for 20 or 75 meters (see Ref 2). The seven-element Chebyshev LPF is adequate for Benson's application because spurious signals must be attenuated by only 30 dB at power levels less than 5 W.

For power levels greater than 5 W, the typical second-harmonic attenuation (40-dB) of a seven-element Chebyshev LPF is marginal. An additional 10 dB of attenuation is needed to assure compliance with the FCC requirement (Ref 3).

If the standard seven-element Chebyshev SVC LPF could be slightly modified to obtain an additional 10 dB of stop-band loss at the second-harmonic frequency without significantly decreasing its passband return loss (RL), the problem would be solved. The minimum passband RL of Benson's 20-meter LPF is about 21 dB, and this minimum RL level is suitable to use as a guide for an acceptable return loss after the filter design modifications have been completed.

We can easily increase the 20-meter SVC LPF second-harmonic attenuation at 28 MHz by adding a capacitor across the center inductor to form a resonant circuit. If this is done, however, the 20-meter passband RL decreases to an unacceptable level, less than 12.5 dB. We need a way to add the resonant circuit, while maintaining an acceptable RL level over the 20-meter passband.

The typical LPF used by Benson (and the Chebyshev SVC designs listed in *The ARRL Handbook*) all have maximum SWR (equivalent to a minimum RL level) specifications that extend from the filter ripple-cutoff frequency down to dc. For the usual Amateur Radio application, however, we need an acceptable minimum RL only over the amateur band for which the LPF is designed. If the passband RL below the amateur band (where it is not needed) could be exchanged to improve the RL only in the passband—while simultaneously increasing the stop-band loss at the second-harmonic frequency—it would be practical to resonate the center inductor at the second harmonic. Our problem would be solved.

This problem of significantly increasing the second-harmonic attenuation of the seven-element Chebyshev LPF while maintaining an acceptable RL over the amateur passband has been solved by Jim Tonne, WB6BLD. With Jim's approval and encouragement, I am using this article

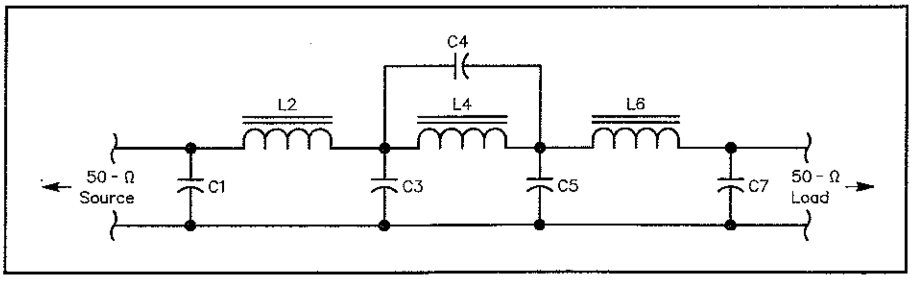


Figure 1—Schematic diagram of a CWAZ low-pass filter designed for maximum second-harmonic attenuation. See Table 1 for component values of CWAZ 50-Ω designs. L4 and C4 are tuned to resonate at the F4 frequency given in Table 1. For an output power of 10 W into a 50-Ω load, the RMS output voltage is $\sqrt{10 \times 50} = 22.4\text{ V}$. Consequently, a 100 V dc capacitor derated to 60 V (for RF filtering) is adequate for use in these LPFs if the load SWR is less than 2.5:1. For QRP filtering, use Philips 680 low K (high Q), 100 V dc ceramic capacitors, mainly for their close tolerance (2%). This capacitor is available from Farnell/Newark in values up to 330 pF and is listed on page 62 of the March/September 1998 Farnell catalog (Ref 4). For QRP filtering, the Micrometals T37, T44 or T50 cores of materials –2 (red), –6 (yellow) or –17 (blue/yellow) are suitable (Ref 5). These cores are available in small quantities from Amidon (Ref 6).

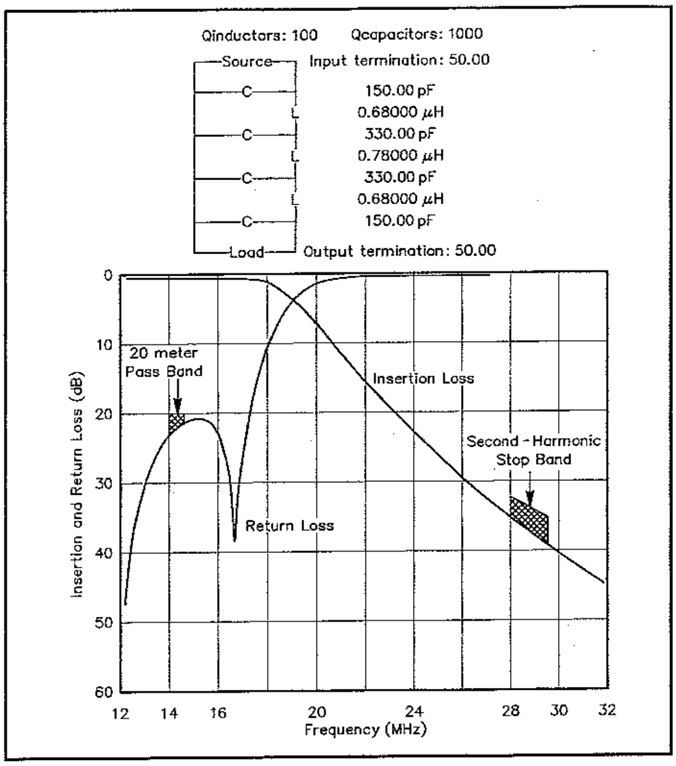


Figure 2—The plots show the *ELSIE* computer-calculated return- and insertion-loss responses of the seventh-order Chebyshev SVC low-pass filter used in the April 1997 *QST* article to attenuate second-harmonic signals. The 20-meter passband RL is about 21 dB, and the insertion loss over the second-harmonic frequency band ranges from 35 to 39 dB. A listing of the component values is included.

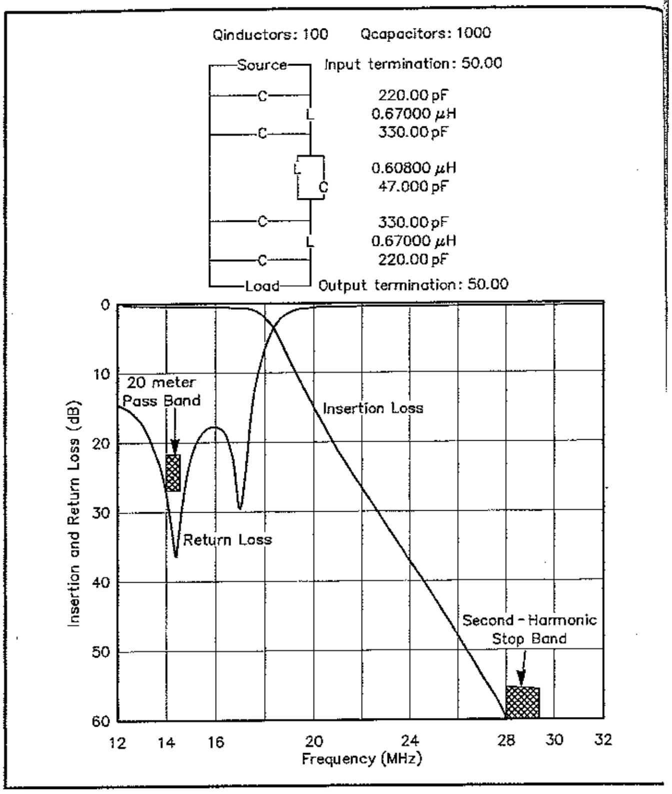


Figure 3—The plots show the *ELSIE* computer-calculated return- and insertion-loss responses of the eight-element low-pass filter using the CWAZ capacitor and inductor values listed in Table 1 for the 20-meter low-pass filter. Notice that the calculated attenuation to second-harmonic signals is greater than 60 dB, while RL over the 20-meter passband is greater than 25 dB.

ample, you can use the tune option to adjust the component values of a Cauer third-order band-pass filter until the transmission zeroes fall in the centers of the adjacent ham bands for optimum RF selectivity. This would be impractical with tables of normalized values, but *ELSIE* can evaluate many different designs in a relatively short time.

If you are seriously interested in passive LC filter design and analysis, but cannot afford the high-priced software used by professional filter designers, contact Jim Tonne at Trinity Software (see Ref 7) about the *ELSIE* demo disk.

Summary

The seven-element SVC Chebyshev low-pass filter is commonly used to attenuate the second and higher harmonics of QRP RF transmitters to comply with FCC requirements. Using *ELSIE,* I've demonstrated that the second-harmonic attenuation provided by a seven-element Chebyshev SVC low-pass filter is marginal. I introduced a new filter that provides maximum attenuation at the second-harmonic frequency while simultaneously maintaining an acceptable return loss in the filter pass band. This is accomplished by forming a resonant circuit (the center inductor and capacitor) and using special values of inductance and capacitance to restore the passband return loss. A table of precalculated 50-Ω CWAZ LPF designs is presented for all the amateur bands. I evaluated an example 20-meter CWAZ LPF design to demonstrate how the harmonic attenuation is improved over that of a standard Chebyshev LPF while still maintaining an acceptable pass-band return loss.

Whether or not these new CWAZ LPFs will eventually supersede the more familiar seven-element Chebyshev SVC LPFs remains to be seen. I encourage you to try these new CWAZ designs and report your experience with them.

References

1. Dean Straw, N6BV, Ed., *1998 ARRL Handbook for Radio Amateurs,* 75th Ed, (Newington: ARRL, 1997) Figure 29.3, p 29.7. (Because of WRC-97, new, more-stringent emission standards will take effect over the next few years. For details see Technical Correspondence (*QST*, Jun 1998, pp 61-62) and Larry E. Price, W4RA, and Paul Rinaldo, W4RI, "WRC-97—An Amateur Radio Perspective," *QST*, Feb 1998, pp 31-34.—*Ed.*)
2. Dave Benson, NN1G, "A Single-Board QRP SSB Transceiver for 20 or 75 Meters," *QST*, Apr 1997, p 29.
3. These filters are most useful with single-band, single device transmitters. Common medium-power multiband transceivers use push-pull power amplifiers because such amplifiers inherently suppress the second harmonic. This suppression then permits the use of octave-related low-pass filters (eg, 2, 4, 8, 16 and 32 MHz) rather than a separate filter for each band.—*Ed.*
4. *Farnell Electronic Components Catalog,* copyright 1998 by Newark Electronics, Chicago, IL 60640; tel 800-718-1997, fax 800-718-1998; **http://www.farnell.com**.
5. Iron-powder cores catalog RF Applications Issue F, Sep 1996. Micrometals, 5615 E La Palma Ave, Anaheim, CA 92807; tel 800 356-5977; **http://www.micrometals.com**.
6. Amidon Associates, Inc, 240 Briggs Ave Costa Mesa, CA 92626; tel 800-898-1883 fax 714-850-1163.
7. Trinity Software, 7801 Rice Dr, Rowlett, T 75088, (Jim Tonne, President); tel 972-475 7132.

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

Ed obtained his Amateur Radio license i 1947, while serving in the Air Force as a radi mechanic instructor at Scott AFB, in Illinois. Fo the past 22 years, he has been a technical adviso to the ARRL on passive LC filters. Ed's man articles on simplified filter design have been published in the electronics trade and Amateur Radio journals, such as Interference Technolog Engineers' Master *(ITEM),* QST, QEX, CQ *an* Practical Wireless, *and in professional EM journals. The* 1998 ARRL Handbook *contain Ed's SVC filter design tables and an explanatio of how to design passive LC filters.*

While not working on filters, Ed is active as tournament tennis player and is ranked Numbe 1 in the Men's 70 doubles in the USTA's Middl Atlantic section. You can contact Ed at 142 Catlyn Pl, Annapolis, MD 21401-4208; tel 41 268-0916, fax 410-268-4779.