

An Optimized QRP Transceiver for 7 MHz

Here is a rig that provides real challenge for the QRP home builder. Nonetheless, this is a classic circuit and a favorite in the QRP community. Even though this project (designed and built by Roy Lewallen, W7EL) was first published in August 1980 *QST*, it is still the best available portable QRP rig in many respects. This presentation has been condensed somewhat from the original and it includes Roy's circuit updates through July 1990.

It is quite a feat to build this circuit into the package shown. The less adventure-some reader can elect to build this rig into a larger package. If you are a beginning home builder or unfamiliar with "ugly" construction techniques, look at *The Ugly Weekender* that precedes this project. That article explains the basics of the "ugly" or "dead bug" construction style and describes a slightly more tame transmitter that could be substituted for the transmit section of this project.

Many QRP rigs have been described in Amateur Radio publications over the years. The distinguishing characteristic of this transceiver is that it was designed and then optimized for high performance. It's relatively easy to build something that works, but it usually requires a great deal more effort to produce something that works really well. That effort has gone into this rig, and the result is a 40-meter CW transceiver with the following characteristics:

- clean keying and smooth, quiet transceiver operation
- stable VFO coverage from 7.0 to 7.15 MHz
- receiver incremental tuning (RIT)
- 1.5 W RF output
- receive current drain less than 20 mA
- high-performance direct-conversion receiver
- small size (1½ × 2½ × 3½ in.)

Some Underlying Philosophy

"High-performance direct-conversion receiver" may seem to be self-contradictory. After all, direct-conversion (DC) receivers are so simple they can't possibly compete with a good superhet, right? Wrong! DC receivers have only one significant disadvantage when compared to superhets: the presence of an audio image which doubles the amount of noise and interference heard.

The only other inherent disadvantage is the inability to generate RF- or IF-derived AGC. The same careful attention to detail and potential problems is required in designing the DC receiver as is required for a top-quality superhet, if comparable performance is to be realized. This last point is frequently overlooked, and that may be one reason why the DC receiver is often seen as a mediocre performer.

All other problems can be overcome with careful design, and even the two inherent disadvantages can be overcome to some extent. For CW, narrow AF filters may be

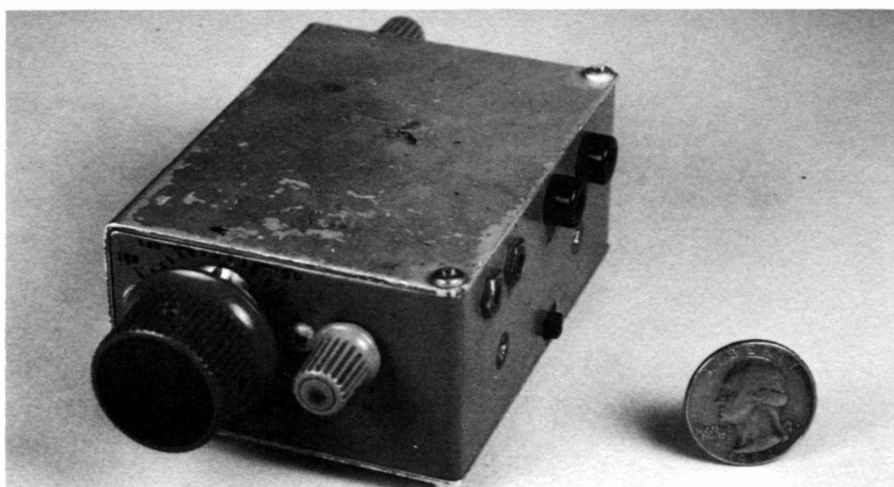


Fig 46—This diminutive QRP transceiver is a joy to operate. It features a high-dynamic-range receiver, smooth break-in operation, RIT and a host of other high-performance features.

used, reducing the image bandwidth along with the desired signal bandwidth. RIT helps also: When an image signal produces the same beat note as the desired signal, adjusting the RIT moves one up in pitch and the other down, thus separating them.

As for AGC, this rig does perfectly well without it. This receiver is on a par with all but the best superhet for any type of operation, except perhaps during contests in conjunction with a high-power transmitter. Yet it has but a fraction of the superhet's complexity. Note also that to use a superhet in a transceiver, an additional oscillator and mixer are necessary to convert the VFO to the transmit frequency. In a transceiver using a DC receiver the required shift is only a few hundred hertz, which can be easily accomplished by pulling the VFO.

Since this rig was designed for portable use, current drain was a major consideration. Experience indicates that many solid contacts are possible using simple antennas and operating at night with 1.5 W on 40 meters. This power level is also more than adequate for short-range daytime operation. Power drain is low-enough that the rig will run for about a week of evening operation from one charge on ten NiCd "A" cells (660 mAh).

The VFO

The oscillator (Fig 47) is a good example of the principle that a circuit need not be complex to work well, if properly designed. This simple Hartley circuit exhibits less than 200-Hz warm-up drift, with about half of that within one minute after turn-on. This drift performance is completely repeatable, as shown by the building of many such oscillators. The circuit used here is the result of considerable experimentation directed toward identifying sources of drift in such VFOs. The following guidelines result:

- Build VFOs with point-to-point wiring

over a ground plane of copper foil. Use circuit board, but copper side up—permost.

- Use NP0 ceramic capacitors.
- A gate diode (D2 here) is essential.
- The inductor is best wound on a type-6 powdered-iron toroidal core. It helps to anneal the coil after winding by boiling it in water a short while and letting it cool in free air.

If rapid temperature changes are expected, you may want to temperature compensate the VFO. Do this by replacing part of the fixed capacitance with negative temperature-coefficient (TC) capacitors, such as polystyrene or negative-TC ceramic units.

The VFO buffer, although designed for low current drain, is the major power consumer in the receiver, requiring 10 mA. The key to efficiency in this sort of buffer is to choose the transformer turns ratio to sustain as large a voltage swing at the output stage collector (or drain) as possible. Buffer voltage gain is approximately one half, providing about 2.5 volts P-P output.

The RIT circuit uses a Zener diode as a voltage-variable capacitor. While Zener diodes are inexpensive and readily available, their nominal capacitances may vary a great deal with different manufacturers. The circuit may be empirically adapted to an individual diode by changing the value of the capacitor (here 15 pF) in series with the diode. Select the capacitor value to yield a tuning range of about 1300 Hz with a diode reverse-bias variation of about 9 to 4 volts. When the RIT control is adjusted to the center of its range, the frequency shift should equal the center frequency of the receive audio filter (about 650 Hz). During transmit, or when the ZERO button is depressed, the shift is removed, causing the transmit frequency to be the same as that of a received signal peaked at the audio-filter center and tuned to the correct side of zero beat.

Fig 47—The circuit of the optimized QRP transceiver. Resistors are 1/4 or 1/8 W, 5%. When winding the inductors that use BLN-43-2402 cores, the wire should be passed once through both holes of the core for each "turn" specified. See the illustration. Wire two sizes smaller than shown may be used for all inductors except L1 (for frequency stability). Type 73 ferrite may be used where type 72 is specified.

C1—1 μ F, 3-V non-polarized ceramic.
D1—Zener, 15-V, 400-mW, 1N965 or equiv.
D2, D3, D5-D13—Silicon general-purpose/switching diode; 1N914, 1N4152 or equiv.
D4—Zener, 33-V, 400-mW, 1N973 or equiv.
D14—Zener, 10-V, 400-mW, 1N961 or equiv.
L1—Approximately 3 μ H; 26 turns of no. 26 enam wire on a T-44-6 core. Tap at seven turns from ground end.
L2—Approximately 10 μ H, 43 turns of no. 28 enam wire on a T-50-2 core.
L3, L4—1 μ H; 19 turns of no. 26 enam wire on a T-37-6 core.
L5—9.4 μ H; 58 turns of no. 34 enam wire on a T-37-6 core.
Q1, Q11—Silicon N-channel JFET, 300 mW, 2N4416.
Q2, Q3, Q10—General purpose, silicon NPN, 310-mW, 2N3904.
Q4—General purpose, silicon NPN, 1.8 W, 2N2222.
Q5—RF power, silicon NPN, 7 W, 2N3553 or 2N5859.
Q6, Q7—General purpose, silicon PNP, 310 mW, 2N3906.
Q8—General purpose, NPN, 310 mW, 2N4124 or 2N3565.
Q9—General purpose, silicon NPN, 310 mW, 2N4124 or 2N3904.
RFC1—100- μ H subminiature choke, wound on a 1/4-watt-resistor-sized ferrite form. Dc resistance is approximately 8 Ω .
T1—Primary 10 turns, secondary 2 turns of no. 34 enam wire on a BLN-43-2402 core or 15 turn primary, 3 turn secondary on an FT-37-72 core.
T2—Primary 39 turns (approximately 6.7 μ H), secondary 5 turns of no. 30 enam wire on a T-44-6 core.
T3, T4—5 trifilar turns of no. 34 enam wire on a BLN-43-2402 binocular core or 5 trifilar turns of no. 26 enam wire on an FT-37-72 core.
U1—op amp, LM301.
U2, U3—Dual op amp, LM358N (one section unused).

The Transmitter

The transmitter is a fairly efficient (75%) class C design. The Zener diode (D4) was added to protect the output transistor after it was twice destroyed by inadvertently transmitting with the antenna disconnected. Some caution is necessary when using a Zener diode at the output-stage collector, as many Zener diodes have a large shunt capacitance. When adding the diode, the collector capacitance must be reduced by an amount approximately equal to the capacitance of the diode when it is reverse biased by the collector supply voltage. In this transmitter, the total capacitance at the collector should equal approximately 450 pF, including the fixed capacitor, the 51-pF receiver pick-off capacitor, the Zener diode and the transistor (about 10 pF). If the capacitance of the diode can't be measured, make the 385-pF fixed capacitor variable and adjust it for best transmitter efficiency.

The value of L2 is not critical, as long as it's not much smaller than the 10 μ H shown. Conventional solenoid RF chokes work fine, but toroids help reduce mutual coupling in a tightly packed rig.

In some versions of the transceiver, the VFO is pulled off frequency during receive-transmit TR switching. This occurs because some transmit RF is coupled into the VFO tank circuit.

The frequency can be measured with a frequency counter or a stable receiver. Connect a counter to the secondary of T1 or listen to the VFO on the receiver (connect a short wire to T1 if needed). Without transmitting, push the ZERO (spot) button. At one end of the RIT range, the VFO frequency should not change. Leave the RIT setting there and transmit. Any frequency shift results from unwanted RF coupling into the VFO.

RF may couple via radiation or conduction. Build the VFO inside a shielded box (inside the rig) to minimize radiation problems. A full ground plane in the VFO compartment helps, and locate the VFO tank-component (L1 and the 510-pF capacitor are the most important) ground connections at the same point to minimize conduction problems. This assures that the components are not part of an RF ground loop.

If the input power is less than 2 W (output less than 1.5 W), low VFO output (less than 4 V P-P) is the probable cause. VFO output is low when the pinch-off voltage of the FET (Q1) is less than 3.5 V. Most, but not all, 2N4416s are adequate. (Do not substitute MPF-102s, many of which have inadequate pinch-off voltages.)

The Receiver

More time has been spent improving the receiver than any other part of the rig. The end result is no more complex than the first version, but the improvement has been great, again showing that complexity and performance don't equate.

The receiver signal is taken through the 51-pF capacitor from the transmitter output filter. When transmitting, the diodes protect the receiver and cause the 51-pF capacitor to become part of the transmitter output network. When receiving, the capacitor and L5 make up a fairly low-Q series-resonant network to reduce signal attenuation by maintaining an approximately 50-ohm source impedance to the mixer. The additional filtering it provides is helpful also. A conventional and doubly balanced mixer is used.

A diplexer follows the mixer. It provides a wide-band 50- Ω termination for both RF and AF, while preventing RF energy from reaching the AF amplifier and preventing AF energy from being wasted in the RF termination. The RF termination is a 0.1- μ F capacitor and a 51- Ω resistor; RFC1 and the 0.47- μ F capacitor form a low-pass filter which prevents any residual RF from reaching Q9, thus greatly enhancing immunity

to AM interference. Q9 presents an input impedance of approximately 50 Ω for maximum power transfer.

Receiver Audio

Because the receiver audio gain exceeds 100 dB, great care must be taken to prevent feedback or amplification of power-supply hum. This receiver uses an active decoupling circuit (consisting of Q8 and associated parts) to avoid these problems in the input stage, where the sensitivity is greatest.

An active audio filter follows the AF preamp. The filter has a peaked low-pass response with a Q of five—low enough to keep ringing unnoticeable. It is simple, noncritical and adequate for general operating. The peak frequency is about 650 Hz, which corresponds to the transmit-receive frequency offset with the RIT control centered. An LM301 op amp was used because of its low noise and relatively low current drain. A TL071 or TL072 should give comparable performance, and one section of an LM358 may be used with a 2-dB increase in noise figure.

The last two stages are conventional AF amplifier stages. Their frequency response rolls off below 150 Hz and above 1500 Hz.

Builders may want to add a low-impedance audio output. This may be done by reducing the gain of U2B (change the 270-pF capacitor to 0.0056 μ F and the 390-k Ω resistor to 20 k Ω) and routing the U2B output to an LM386 amplifier circuit.

A low-impedance audio output increases a D-C receiver's tendency to oscillate (squeal) because output-return signals feedback to early audio stages through circuit ground. The tendency can be reduced through careful grounding techniques (see the double-starred components in Fig 47), or isolate the low-impedance return path from circuit ground (insulate the output jack mounting from circuit ground and connect the output return directly to the ground terminal of the output amplifier).

You can use low-impedance headphones and avoid feedback problems by using a small audio transformer between the HI-Z PHONES output and the phones. This provides the needed impedance transformation while isolating low-impedance ground currents from the transceiver. Any transformer with an input impedance of 1000 Ω or more and an output impedance from 8 to 16 Ω should work fine (one example is Radio Shack no. 273-1380, 1000 Ω : 8 Ω).

Unwanted audio may also feedback through the VFO and mixer stages. Such feedback can be reduced by operating the VFO at half of the output frequency and feeding the mixer through a doubler stage. Schematics and discussions of a suitable low-impedance output stage and a VFO-doubler arrangement are available as "Optimized Options" from the Tech Dept secretary at ARRL HQ for an SASE.

U3 is a sidetone oscillator. The injection level is set by the 100-k Ω resistor at pin 6

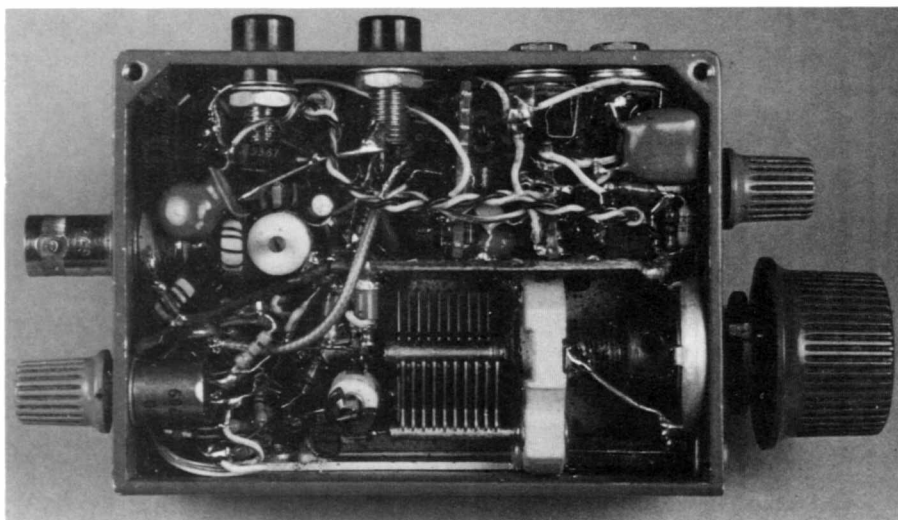


Fig 48—High component density is necessary to squeeze all the circuitry of the transceiver into such a small package. Point-to-point wiring is used. The transmitter circuitry is at the upper left in the photo. The output transistor, which is bolted to the case, is hidden below the top layer of components.

of U2B. The level may be varied to suit individual taste by changing the resistor value.

Keying and TR Switching

Three events must occur when this kind of transceiver is keyed, and they must occur in the proper sequence if operation is to be clean. They are, in order: (1) receiver mutes, (2) VFO shifts frequency, and (3) transmitter keys. These events must occur in reverse sequence when switching back from transmit to receive. The sidetone oscillator must also be keyed, but its timing isn't as critical.

Attention to this sequence and proper transmitter waveform shaping makes the difference between a poor-sounding rig and a really clean one. Many people have been surprised to learn my power level—because "it doesn't sound like a QRP rig." Only a few parts are required to accomplish this. In addition, it's easier to copy a clean weak signal than a poor one, so good keying and freedom from chirp, clicks and roughness are particularly important for QRP transmitters.

The receiver is muted by Q11 which acts as a series gate. Q9, U1 and U2A are all driven to saturation for a while when the transmitter is keyed—and again when the key is released. Q11 is turned off immediately when the transmitter is keyed, then turned back on after the disturbance is over, about 60 ms after the key is released.

The diodes around U2A prevent the output of U2A from swinging to ground during the disturbance, a condition which turns Q11 on when it should be off. I find the 60-ms delay to be ideal, as it removes distractions between dits and dahs at medium speeds, while it is short enough to provide essentially instantaneous break-in. The disturbance (hence, required delay) could possibly be reduced further by limiting the swing of either or both Q9 and U1 or by biasing the U1 and U2A outputs closer to the positive supply voltage.

Oscillator frequency shift is obtained by changing the bias on the Zener diode (used as a voltage-variable capacitor) in the VFO circuit. Q7 provides the timing; it switches on quickly when the key is closed, but switches off some 5 ms after the transmitter output drops to zero following the release of the key. Shaped keying is provided by Q6 and the associated components. Simultaneous base and collector keying of the driver stage is required to give the desired rise and fall times (a few ms) at the transmitter output. The sidetone oscillator is keyed from the same line.

Construction

Fig 48 shows the interior of the transceiver. It would be very difficult to duplicate the unit exactly, because many hard-to-find miniature components are used. Get a good idea of the placement of controls, connectors and large components

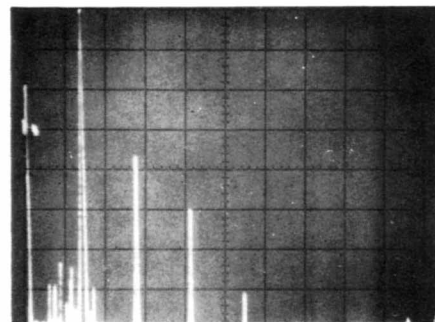


Fig 49—The output spectrum of the optimized QRP transceiver. Vertical divisions are each 10 dB; horizontal divisions are each 5 MHz. The second harmonic is about -37 dBc. The transmitter meets FCC spectral purity requirements for a 5-W transmitter.

before you begin. Since it's difficult to troubleshoot or modify such a rig once built, construct and operate a large breadboard version first.

Build the circuitry on small pieces of perfboard and mount the boards vertically for dense packing. It helps a great deal to mount components on both sides of each board and ignore the convention of placing parts in neat rows. A surprising amount of space was saved by using 1/8-W resistors rather than 1/4-W units. Tantalum electrolytic capacitors also save a great deal of space over their aluminum counterparts. Small parts are nearly always more expensive and less available than their larger counterparts, so each builder must decide if the trade-off is a good one.

Adjustment and Operation

Only three controls require adjustments: (1) Set the VFO trimmer so that the lowest VFO frequency is at the lower band edge. (2) Adjust the drive-level pot for 1.5 W of output power (no major problem will arise if driven at higher or lower levels, but efficiency may drop slightly). (3) Peak the transmitter driver tank circuit at the center of the frequency range. None of these should require attention once set. Fig 49 shows the spectral output of the transceiver.

Operation is simple by design. The only point worth noting is that (as with any direct-conversion receiver) signals must be tuned on the correct side of zero beat so that the transmitter will be on the same frequency. Guest operators usually pick this up in a few minutes, so the SPOT button is seldom used. When the rig is new, however, it's nice to know just where the transmitter will be when the key is pressed.