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This transceiver still has the best direct conversion receiver I have ever seen for HF operation. *February 2009*

40-meter transceiver for low-power operation

Design and construction details for a QRP CW transceiver operating in the 40-meter band

Have you seen the many articles that have been published on building simple receivers? Or how about the many QRP transmitter articles? How about a deluxe QRP transceiver that has a superior receiver and a healthy 1-watt transmitter, both of which are VFO controlled? Read on.

The excitement of operating QRP accounts for the recent number of articles on the subject, but I feel we've not seen a good transceiver that allows portable, mobile, or fixed operation. So I came up with the rig presented here. I feel sure you'll be amazed by its performance.

The project had some problems getting off the ground. Every direct-conversion (DC) receiver I tried ended up in the scrap bin because it hummed, had tunable hum, overloaded easily, or had microphonics and/or all the above. Then I discovered the design presented here, which has none of these problems.

receiver

This direct-conversion receiver features:

1. Wide dynamic range (resistance to overload)
2. Excellent a-m signal rejection
3. No hum, tunable hum, or microphonics
4. VFO that operates at one-half the desired received frequency

The receiver (see **fig. 1**) has a grounded gate fet rf amplifier, Q101, which is used to bring the typical 40-meter-band noise floor (on a quiet day) above the receiver internal noise floor. This action provides approximately 1.5-microvolt input level for a 10-dB (S + N)/N. The rf stage is electrostatically and electromagnetically isolated from the VFO by T101 and T102 to prevent rf/VFO interaction. T102 provides rf VFO signals to a pair of detectors, each of which a complete detector: CR101, CR102, and CR103, CR104, which operate differentially.

Detector characteristics. The operation of this detector is the single most important feature of the entire transceiver.* From previous descriptions of this detector, I have developed the detector in this rig, which solves the problem of VFO and rf intermodulation and provides translation voltage gain.

The intrinsic characteristics of this detector provide the features stated earlier, because the VFO operates at *one-half* the received frequency; therefore, a-m DSB signals contain a modulation envelope that cancels in each diode pair.

*This detector, which is sometimes referred to as a harmonic detector, has been described in an unbalanced configuration by others.

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This operation is better understood if you consider that the diodes act as rf switches. When the VFO signal approaches its peak amplitude, positive or negative, it turns on a diode. Therefore, one diode in each pair turns on at every peak of the VFO signal. So to obtain an audio beat note, the incoming rf frequency must be twice that of the VFO. The mathematical expression that represents this detector takes on the form of a cubical parabola, which also verifies its inability to detect a-m signals (for which a square-law function is used).

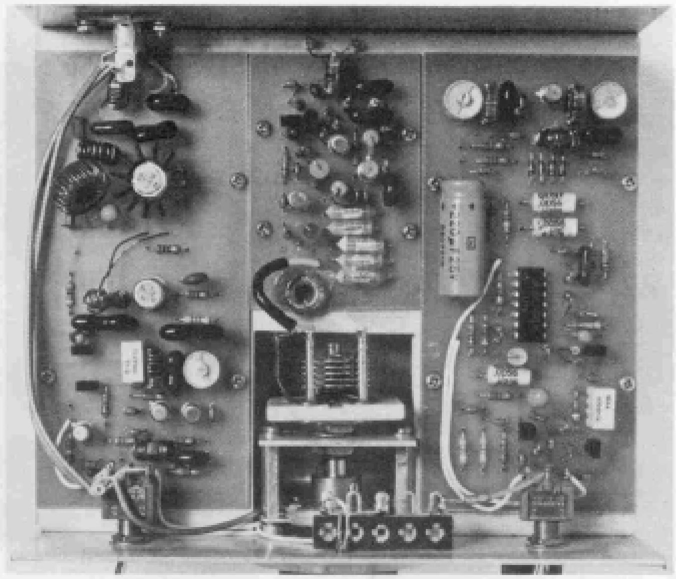
a-m signal rejection. So why such a big deal about a-m signal rejection? No one can hear your signal under an a-m foreign broadcast station, right? You might be surprised — but the big deal is that this feature 1) eliminates tunable hum, 2) reduces static level, and 3) improves microphonic rejection. These parameters benefit from the a-m rejection because all have DSB a-m components that normally go *right through* a product detector. Out-of-band signal rejection is improved because intermodulation is very low in the rf amplifier, VFO, and detector output circuit.

Detector output is dc coupled (since no dc component exists at the detector output) to a differential audio amplifier, U101A, which provides a single-ended output and 46 dB gain. U101B and U101C are 800-Hz filters with a bandwidth of 200 Hz and a gain of 30 dB. The *Q* of these filters is selected to prevent ringing. U101D provides the last 35 dB of receiver gain, picks up the sidetone when transmitting, and drives the headphones.

VFO

The VFO provides an output between 3500 kHz-3590 kHz to transmitter and receiver. On receive the VFO frequency is used directly but on transmit it is doubled. Also in receive the VFO frequency is offset so that a station that returns your call will be shifted in frequency approximately 800 Hz, set by C209, so that it will fall in the audio filter passband.

For a change of pace try operating QRP in the 40-meter Amateur band. What is QRP? It's an operating mode that uses the minimum amount of radio-frequency power that will sustain communications. Some QRP stations use less than 1 watt of input power, sometimes even less than 500 milliwatts. Others use up to, say, 5 or 10 watts. The idea in the QRP world is to see how far you can conduct reliable radio communications with the least amount of radiated power. This article provides construction information on a QRP transceiver that will do a good job on 40 meters with only 1 watt output. The receiver is a notch above most circuits using the direct-conversion process. QRP operation on the Amateur bands today is a real challenge, especially on 40 meters. The circuit and information by WB5DJE will get you started. Good luck and have infinite patience. **Editor.**

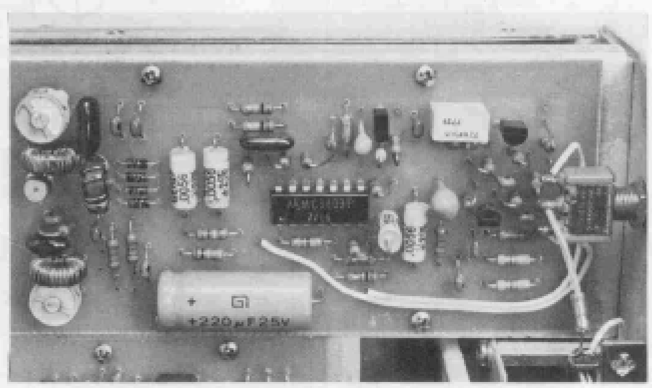


Inside top view of the transceiver, showing three PC boards. The miniature terminal strip secures the dial LED.

Description. The VFO is a Seiler type using a 2N4416 fet followed by an fet buffer and output amplifier. U201 in the VFO is a 5-volt, three-terminal regulator biased to provide +7 Vdc, set by R210. This regulator provides excellent voltage stability far superior to that provided by a zener. The VFO frequency holds within 10 Hz for input supply voltage variations between 15 and 9 Vdc.

The oscillator is very stable, although not temperature compensated, for changes in loading and mechanical vibration. The tank circuit is made of an SF material powdered-iron toroid and polypropylene capacitors. Dipped silver micas will work here but have poorer warmup drift because of the very small rf heating in their dielectrics.

I had an interesting experience with this VFO in the design stages. I started with a Colpitts oscillator,



Top view of the receiver board.

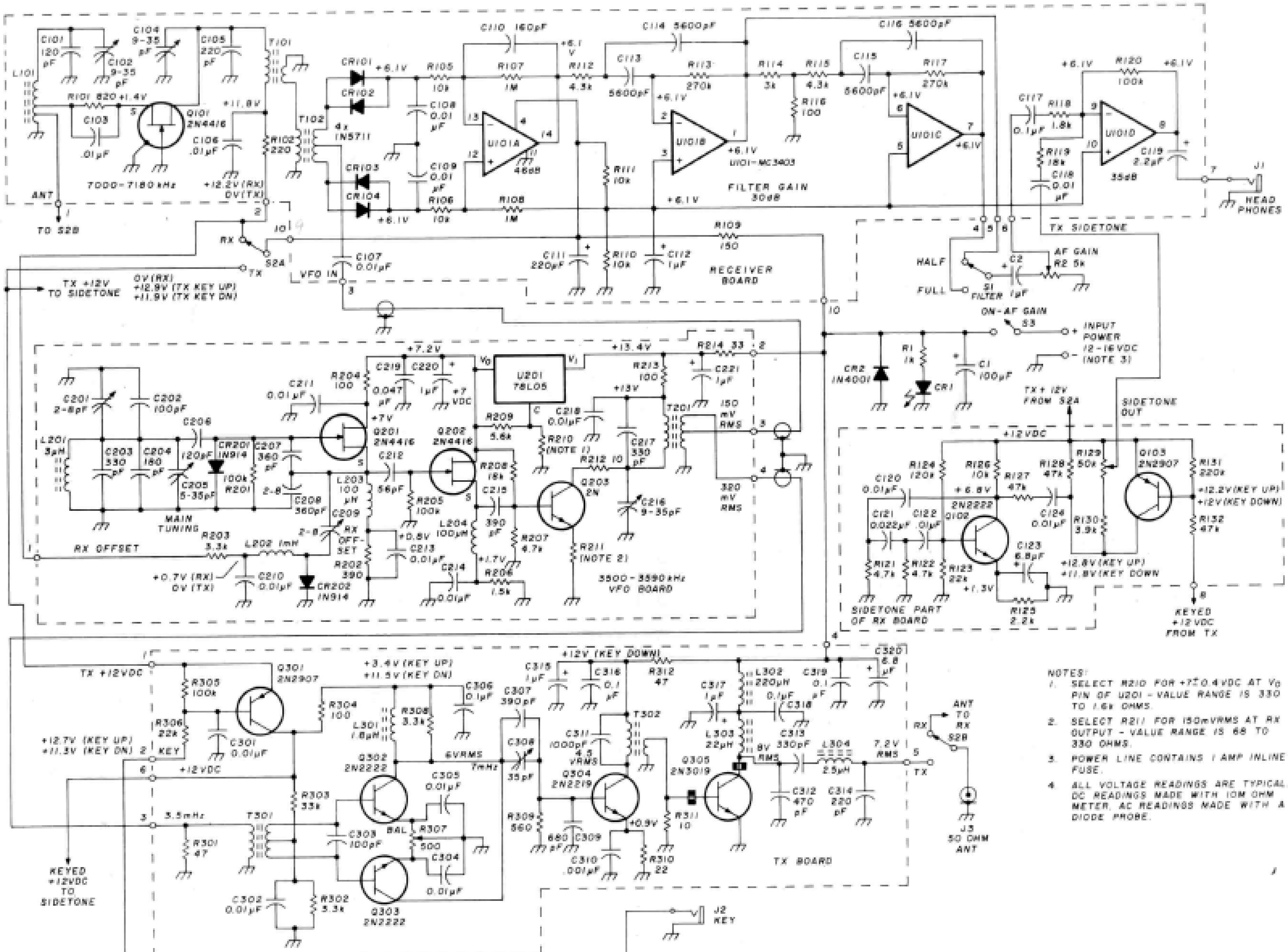
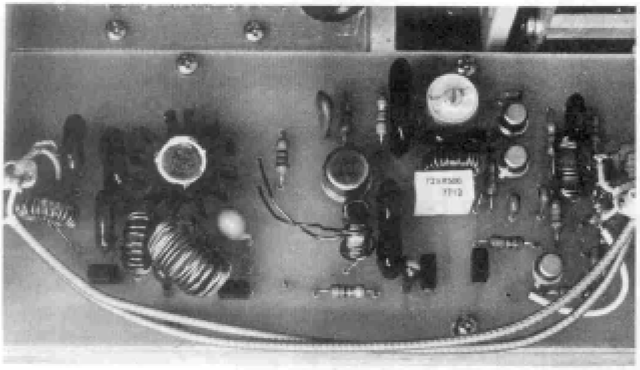


fig. 1. Schematic of the QRP transceiver. The receiver has some novel features not found in most direct-conversion circuits. The VFO is a Seiler type that provides an output between 3500-3590 kHz. On receive the VFO frequency is used directly; on transmit it's doubled. The transmitter provides 1 watt output and uses transistor keying. As an added operating aid, a sidetone circuit is also included.



Close-up view of the transmitter board.

which seemed to work very well. However, when I keyed the transmitter it shifted about 650 Hz. After working on shielding and buffering, and still stuck with a 300-Hz shift, I threw it out and designed the Seiler, which, without any shielding, shifts only about 25 Hz when the transmitter is keyed and sounds as if it is crystal controlled.

Tank inductor L201 is mounted with a coating of polystyrene Q-dope to secure the turns and the inductor to the board. This prevents VFO frequency shift when the rig is vibrated.

table 1. Coil and transformer winding data for the low-power 40-meter CW transceiver.

L101	3.5 μH (33 turns no. 28 [0.3 mm] on T37-6 toroid core; tapped at 1 turn for antenna; tapped at 3 turns for Q101 source)
L201	3 μH (30 turns no. 28 [0.3 mm] on T37-6 toroid core). Adjust number of turns and spacing to set center frequency and tuning range; coat with *Q-dope* when final adjustments are completed.
L301	1.8 μH (23 turns no. 26 [0.4 mm] on T37-6 toroid core)
L302	220 μH (64 turns no. 30 [0.25 mm] on FT50-1 ferrite toroid)
L303	22 μH (20 turns no. 24 [0.5 mm] on FT37-1 ferrite toroid)
L304	2.5 μH (27 turns no. 26 [0.4 mm] on T37-6 toroid core)
T101	2.2 μH primary (25 turns no. 28 [0.3 mm] on T37-6 toroid core; secondary is 6 turns no. 26 [0.4 mm])
T102	1.3 μH (5 trifilar wound turns no. 26 [0.4 mm] on FT37-1 ferrite toroid)
T201	6.4 μH primary (48 turns no. 28 [0.3 mm] on T37-6 toroid core; secondary is 6 turns no. 26 [0.4 mm], tapped at 3 turns for the receiver)
T301	1.3 μH (5 trifilar wound turns no. 26 [0.4 mm] FT37-1 ferrite toroid)
T302	0.53 μH primary (13 turns no. 26 [0.4 mm] on T37-6 toroid core; secondary is 4 turns no. 24 [0.5 mm])

Notes T37-6 powdered iron toroid core (SF material) has 3/8 inch (10 mm) outside diameter, is rated at 30 μH per 100 turns.

FT50-1 ferrite toroid (Q1 material) has ½ inch (25 mm) outside diameter, is rated at 510 μH per 100 turns.

FT37-1 ferrite toroid (Q1 material) has 3/8 inch (10 mm) outside diameter, is rated at 425 μH per 100 turns.

Dial calibration. Before the coil is coated, the VFO tuning range should be set to calibrate the dial, with C201 set at mid position, by adjusting the number of L201 turns and spacing. Once this is set, calibration can be made by adjusting C201, for which a hole is provided in the bottom cover.

I selected a tuning range of 7000-7180 kHz (3500 kHz-3590 kHz VFO frequency) so that my dial would provide 10 kHz per 10 degrees of rotation. This isn't quite right, because the change is not perfectly linear; but the dial can be laid out with a protractor without having to mark it on the tuning capacitor, and the error will be only a few kHz. Just make sure it's correct at 7025 kHz above, which isn't that critical.

You can calculate or measure the actual change if you want a more accurate calibration across the entire band. Also you can increase the range if you desire. A handy equation for this is:

$$L = \frac{(1 - \frac{\omega_o}{\omega_1})^2}{(\omega_o)^2 (\Delta C)} \quad (1)$$

where L = inductance (henries)

$\omega_o = 2\pi f_o$, f_o being the lowest frequency of interest (Hz)

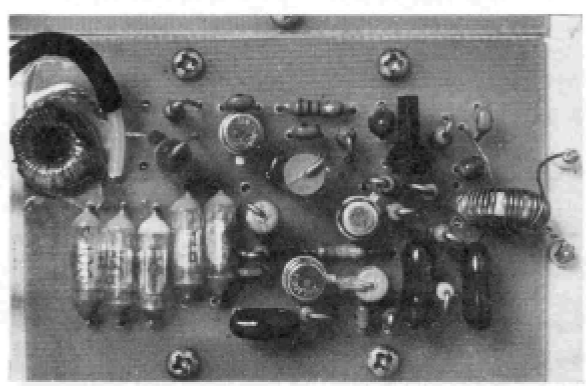
$\omega_1 = 2\pi f_1$, f_1 being the highest frequency of interest (Hz)

ΔC = change in capacitance available (farads)

Once the value of L is found, the total capacitance required for resonance is:

$$C_o = \frac{\frac{1}{(\omega_o)^2}}{L} \quad and\ C1 = C_o - \Delta C \quad (2)$$

where $C1$ is the amount of fixed capacitance required and includes the oscillator capacitive loading.



The VFO board. Note coax connection to variable capacitor.

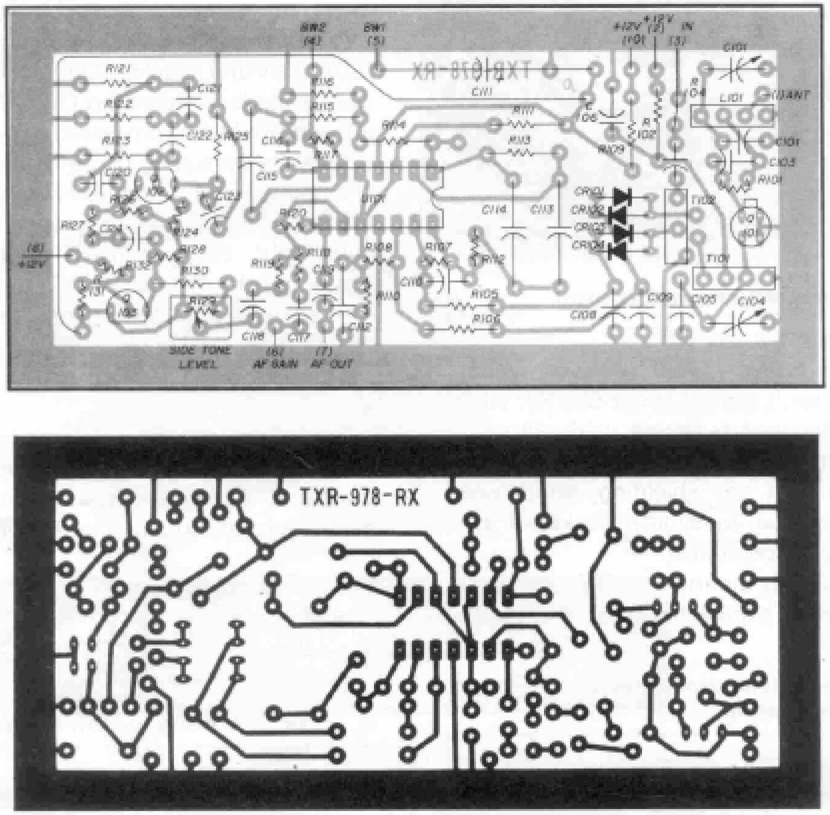


fig. 2. *Above*, receiver-board parts layout. *Below*, receiver board, foil side.

Output amplifier Q203 is operated class A into T201, which provides VFO energy to receiver and transmitter continuously. T201 is tuned with C216 to peak the VFO output in the center of the band. It operates with a *Q* that prevents excessive level variation across the band. The VFO output level should be 150 mV rms at the receive output. At this level the detector is optimized for Schottky diodes (for which germanium could be used), and the transmitter doubler is designed to operate at the level provided by the second output of 320 mV rms. (These readings were made with a diode probe.) R211 in Q301 emitter is selected to provide these levels. I prefer this method of level adjustment over dividing the VFO externally because it provides a lower noise floor.

transmitter

The transmitter is straightforward using transistor keying, a frequency doubler, a driver, and a power amplifier. The keying is accomplished by Q301, which turns on when the key is closed. However, Q301 has only +12 Vdc available when in the transmit mode to prevent keying the transmitter without an antenna. Also note that Q301 keys the +12 Vdc to only the frequency doubler stage, because the driver and PA operate class C and don't require keying of the dc supply.

Q302 and Q303 are connected as a push-push doubler with 180-degree base feed accomplished by trifilar-wound T301. R307 in the emitter circuits allows the 3500 kHz fundamental to be balanced out, so that the output waveform contains very little fundamental component. The doubler output is capacitively tapped down to provide the base drive for the driver Q304.

C308 tunes the doubler output and should be peaked in the center of the band. The doubler adjustments should be made carefully to ensure it's stable and operating properly. Do not peak R307 and C308 for maximum amplitude alone, but adjust them for a stable 7090-kHz output that contains a minimum amount of 3545-kHz energy.

Driver Q304 operates class C with some self bias, which should not be changed. The bias selected pro-

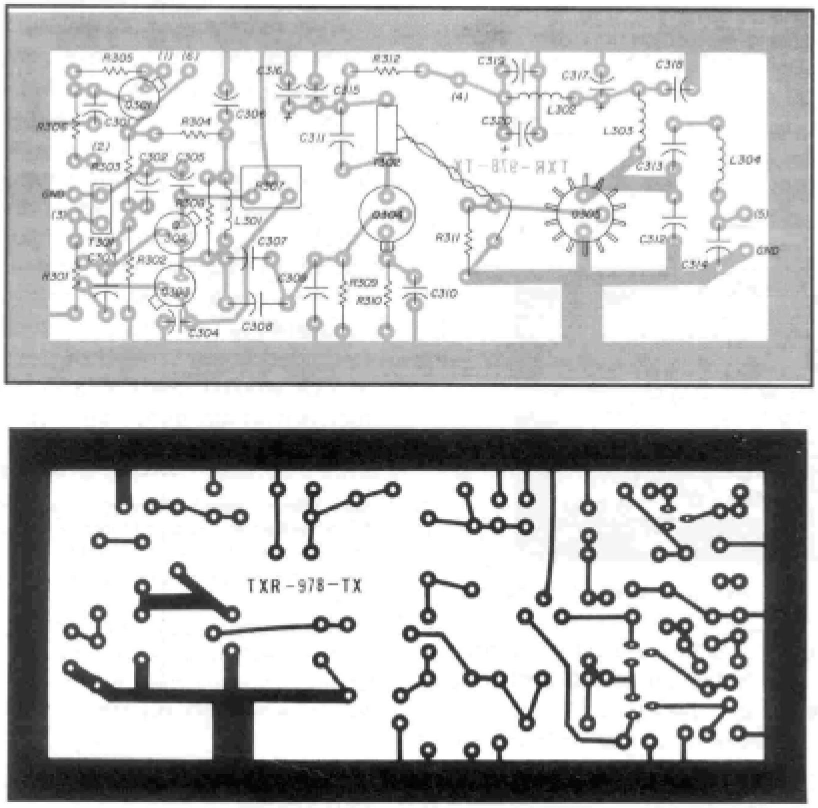


fig. 3. *Above*, transmitter-board parts layout. *Below*, transmitter board, foil side.

vides a clean optimum output for the drive level in use. T302 is tuned by C311 and provides a low-impedance drive to power amplifier Q305.

The power amplifier is a 2N3019, for which other 5-watt, 1 ampere transistors could be used. However, if the 2N3019 is not used, select one with an f_T of about 100 MHz. If the f_T is much higher, such as in a 2N3866, the possibilities of VHF components on the output are very great (TVI).

Some component-value selection can be made in the output-matching circuit if desired. The values shown were slightly changed from the calculated values by using a spectrum analyzer to optimize the 7000-kHz-to-harmonic-energy content. The values shown provided 1 watt at 7000 kHz with the second harmonic down 40 dB, the third down 50 dB, and other harmonics down 60 dB or better. The VHF harmonics were down better than 90 dB.

When in the transmit mode, power is also applied to the sidetone, which is keyed by Q301. R129 provides an independent adjustment level for the sidetone regardless of the af gain setting.

construction

The QRP transceiver uses PC-board construction.* Parts layouts for the receiver, transmitter, and VFO boards are shown in **figs. 2** through **4** respectively. Coil data are given in **table 1**.

General notes. I have built an enclosure for my rig so that I could have the size I wanted and accessibility to both top and bottom of the circuit boards. Other types of enclosures can be used without any problems since the board interconnects are not very critical. I do suggest that 50-ohm cable be used to connect the VFO to the receiver and transmitter as well as to connect the antenna circuitry. The audio circuitry is low impedance and shouldn't require shielded cable.

As you can see from the pictures, I did not shield the VFO. I found that on 40 meters it was not necessary. However, on higher frequency bands it would be a good idea.

*Many components for this transceiver are available from Radiokit, Box 429, Hollis, New Hampshire 03049.

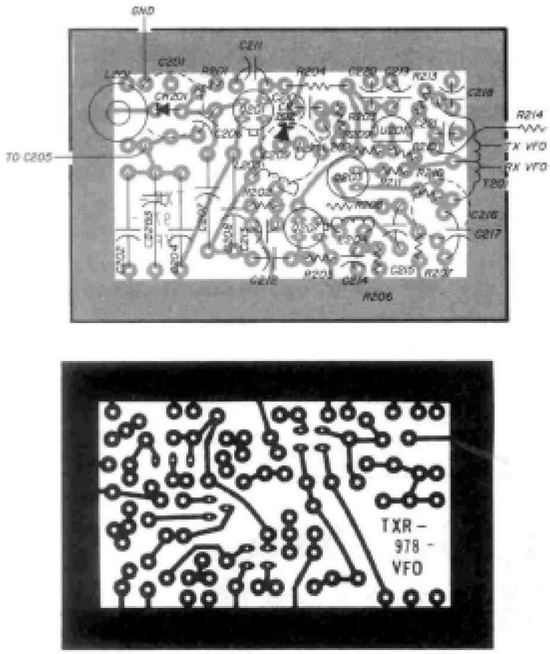


fig. 4. *Above*, VFO-board parts layout. *Below*, VFO foil side.

Making the VFO dial. I made the dial by cutting a piece of Plexiglas into a perfect 2-inch (50-mm) circle by pushing a file against the rotating disk.

I then cut a thin sheet of mylar onto which I lettered the markings with dry transfers. I then sprayed an adhesive onto the front of the Mylar and attached it to the *back* of the Plexiglas. This prevents fingernails from damaging the dial markings. To make the pointer, I cut a slit with a saw blade into a thin aluminum plate, which fits behind the dial, and I back-lighted the slit with a green LED. The dial mounts with two screws onto the Jackson Drive (a ball bearing 6:1 reduction drive).

Note that the transceiver is made up of three circuit boards. This allows you to choose the type of packaging that suits your needs — or your can build just the receiver or transmitter if you wish.

I think you will find this project to be well worth while if you have the QRP bug or think you might get it. I've worked coast-to-coast with this rig on 40 meters with very good signal reports.

bibliography

Cohn, Marvin, James E. Degenbord, and Burton A. Newman, "Harmonic Mixing with an Anti-Paralleled Diode Pair," *IEEE Transactions on Microwave Theory and Techniques,* Vol. MTT-23, No. 8, August, 1975.

Hawker, Pat, "Low-Cost Satellite Receiving Techniques," Wireless World, January, 1979.

Automation and Remote Control, (USSR), April, 1958, 355 *et seq.*

IRE Transactions on Instrumentation, December, 1960, pages 349-355.

IEEE Transactions MTT, March, 1975.

IEEE Transactions, MITT, May, 1976.

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