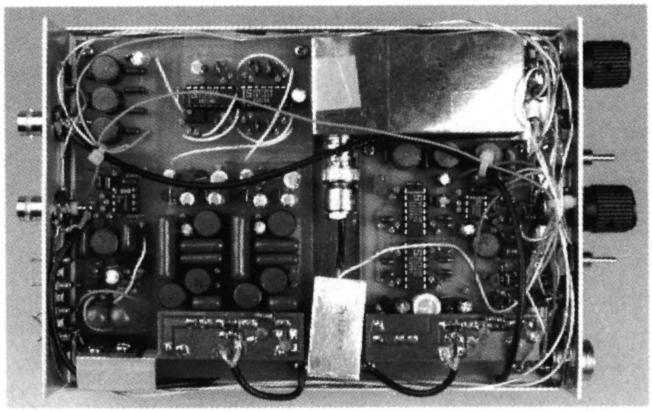
Single-Conversion Microwave SSB/CW Transceivers

No-tune transverters have made it easy to get on the UHF/SHF bands—as long as you have a commercial 2-meter transceiver you can dedicate to that application. Here's how to put two other recent *QST* projects, the R2 direct-conversion receiver and T2 transmitter, to work with a transverter as an inexpensive and lightweight, high-performance, all-home-brew station.



(photos by Kirk Kleinschmidt, NTØZ)

By Rick Campbell, KK7B
Department of Electrical Engineering
Michigan Technological University
Houghton, MI 49931

In January, I described a high performance SSB/CW receiver called R2,[1] and last month I presented a companion multimode transmitter, T2.[2] These two modules can be used to build high-performance, direct-conversion (D-C) transceivers for *any band* below 500 MHz.

One of my favorite activities is weak-signal microwave work on mountaintops using small, portable SSB/CW systems. Using the R2 and T2 boards as a tunable IF for a no-tune microwave transverter, I can build high-performance microwave SSB/CW transceivers that are smaller and use less battery power than systems using commercial multimode 2-meter transceivers and transverters. This article describes some of the design philosophy behind single-conversion microwave systems, and presents a complete 1296-MHz transceiver and an IF system using a choice of two VFO circuits and the R2 and T2 boards.

Basic Design Considerations

Fig 1 is the block diagram of the SSB/CW transceiver. The transceiver has an SSB/CW generator and IF receiver, a pair of mixers and a local oscillator (LO) to perform the IF-to-RF frequency conversion, and RF amplifiers to set the receiver noise figure and increase the transmitter power. The same arrangement can be used for signal frequencies from a few kilohertz to hundreds of gigahertz.

The choice of intermediate frequency (IF) is determined by the selectivity of the RF filtering and the available IF-filtering components. An IF of about 10% of the signal frequency permits good image rejection with a reasonable number of noncritical RF tuned circuits. Conventional SSB/CW superhets for microwaves need to use several frequency conversions to reach a narrow-bandwidth crystal filter operating near 10 MHz. Each frequency conversion adds system complexity, spurious responses, and internally generated receiver signals ("birdies").

We can eliminate the need for crystal filters by using the R2 and T2 boards to build a tunable IF. Since both R2 and T2 work fine at 1/10 the frequency of any microwave band below 6 GHz, we can build single-conversion microwave transceivers that cost less and have fewer spurious responses and outputs than a traditional scheme.

Block Diagram

A complete microwave transceiver using a no-tune transverter board[3] and the R2 and T2 boards is shown in Fig 2. Fig 3 shows the first prototype of this system, and Fig 4 shows IF2, a 144-MHz transceiver intended for direct connection to a no-tune transverter. It's relatively easy to build a transceiver with these boards, because the two share no functions other than the LO. In fact, the interconnections between the boards are almost identical to the cables that interconnect a Collins S line and 62S-1 transverter for VHF-transceive operation!

Each board needs a +12-volt supply at the points marked **+**. Since the T2 board includes transmit-receive switching and R2 has a muting circuit, both boards are normally powered continuously. R2 requires an external speaker, volume control and filter, options for which were discussed in my January 1993 and August 1992 *QST* articles.[4]

T2 has microphone connections, a push-to-talk (PTT) solder pad marked **P** on the circuit board, and a solder pad marked **K** for key. **P** is grounded for transmitting SSB or CW. To disable audio modulation when transmitting CW, the audio preamp output marked **A** is shorted to ground. A grounded solder pad is etched next to **A** for conve-

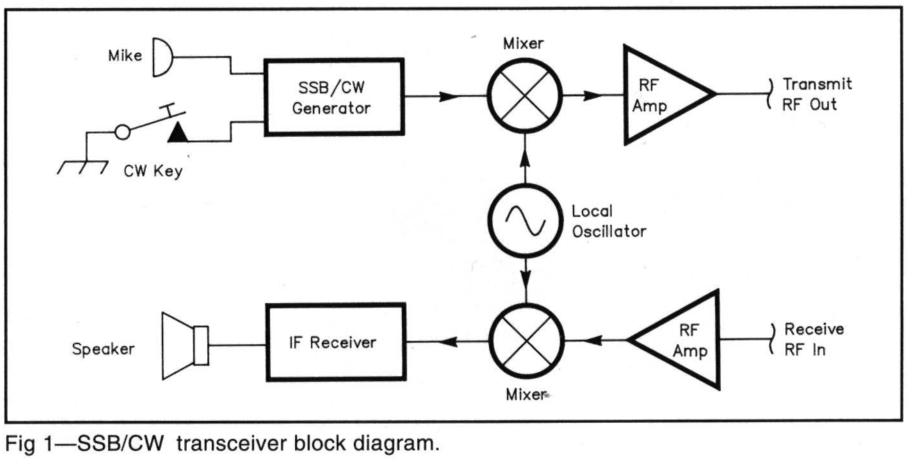


Fig 1—SSB/CW transceiver block diagram.

[1]Notes appear on page 34.

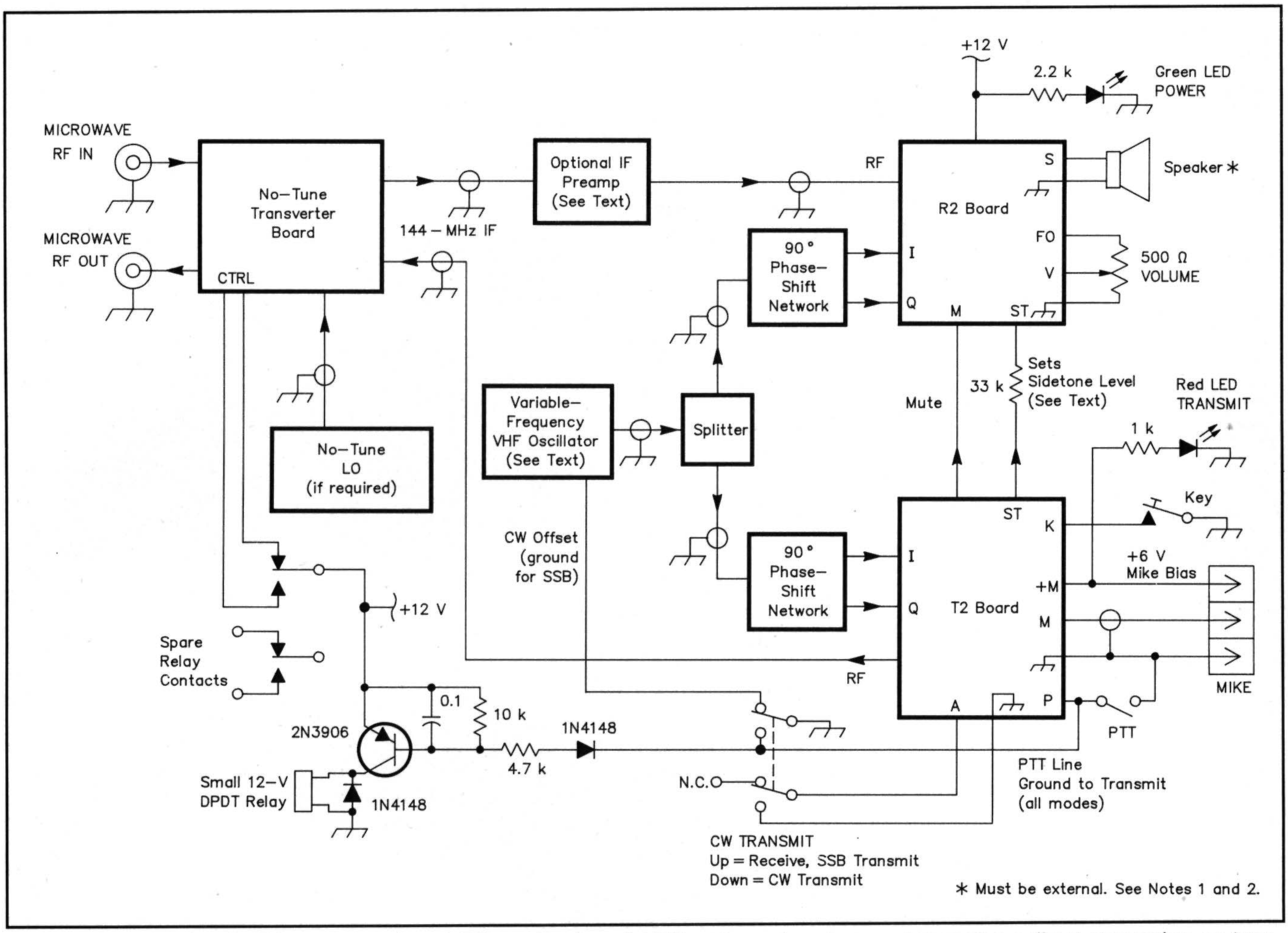


Fig 2—Interconnecting the T2 transmitter board, R2 receiver board, VFO and a no-tune transverter creates a direct-conversion, no-tune microwave transceiver. All of the no-tune transverters except the 903-MHz version use external local oscillators. Set the resistance value in the **ST** line to an appropriate level for your listening environment; 33 kΩ works well for relatively quiet locations. The volume connection (**FO** on the R2 board) *must* be terminated in 500 Ω (see Note 1).

nience in doing this. I use a DPDT **CW TRANSMIT** switch on my radios that simultaneously grounds the audio-preamp output, grounds the PTT line and offsets the local oscillator from zero beat.

Only two wires connect the R2 and T2 boards: mute and sidetone. To mute the receiver during transmit, connect a wire from the unmarked solder pad to the right of **P** on the T2 board to the solder pad marked **M** on the R2 board. The sidetone generator is on the T2 board, with an output marked **ST**. The sidetone input on the receiver board is also marked **ST**. Directly connecting these two points results in a very loud sidetone! For a more comfortable sidetone level, experiment with series resistor values between about 10 kΩ and 100 kΩ. I settled on 33 kΩ for portable operation in quiet locations. Of course, a 100-kΩ sidetone-level pot is an acceptable alternative.

Each board requires a pair of quadrature LO signals, as discussed in the R2 and T2 articles. The first transceiver I built used a

Fig 3—The first no-tune, single-conversion 1296-MHz transceiver that follows the block diagram of Fig 2.

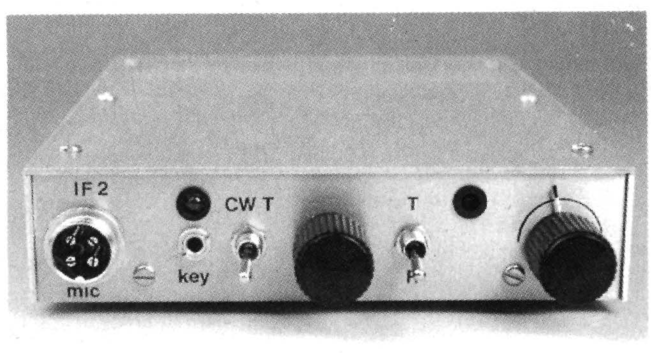
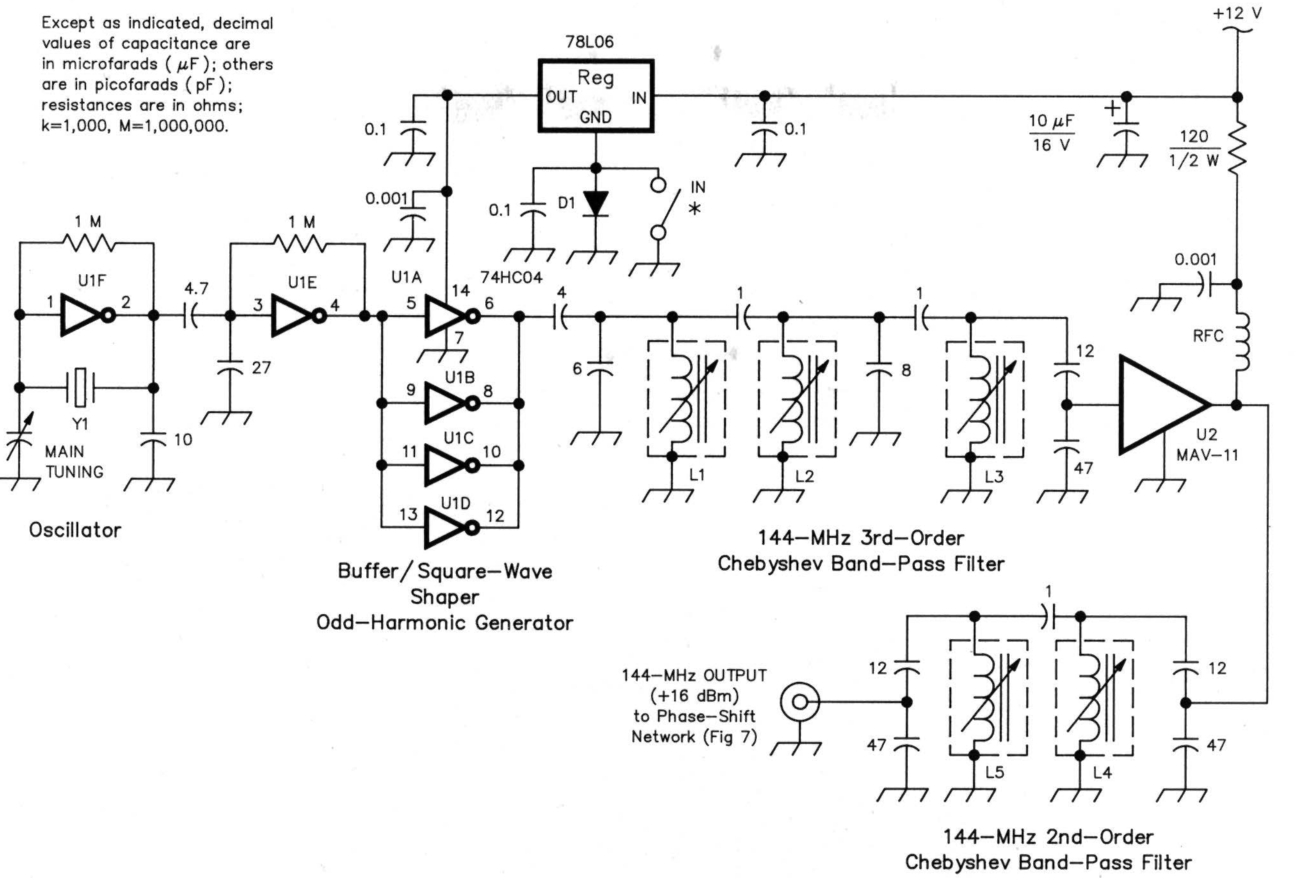


Fig 4—IF2, a D-C transceiver with an integral VXO (Fig 5). This $1\frac{1}{4} \times 5\frac{1}{4} \times 7\frac{1}{2}$-inch transceiver can be directly connected to a no-tune microwave transverter to create a single-conversion microwave transceiver.



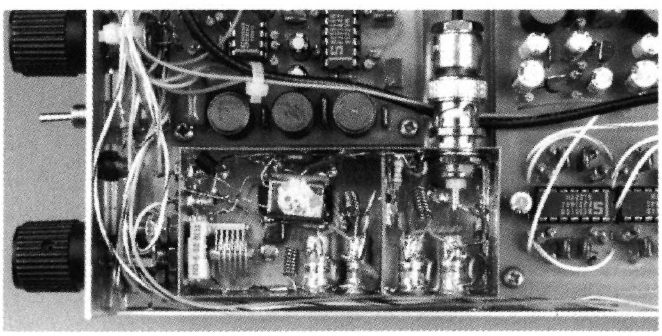


Fig 5—This simple VXO circuit has a tuning range of ±25 kHz. All capacitors less than 50 pF are NPØ. When D1's anode is not grounded via switch or relay contacts, a 1-kHz frequency offset is imposed for CW operation. The photo shows the prototype VXO circuit built into the IF2 transceiver of Fig 4. The output network in this prototype differs slightly from the schematic (it uses glass trimmer capacitors for tuning; fixed, hand-wound inductors; and gimmick coupling capacitors, for example).

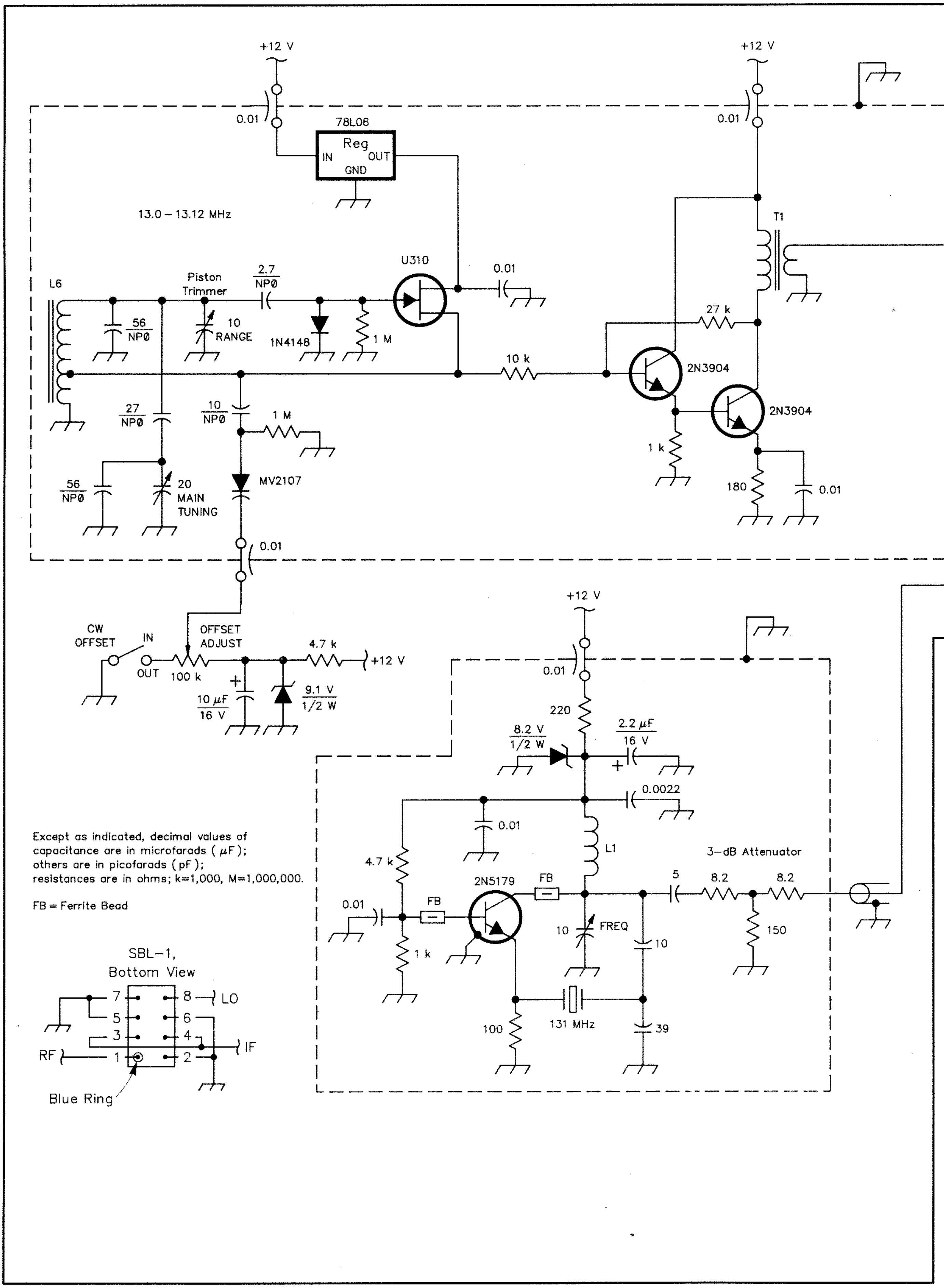
D1—Schottky diode (HP 5082-2835 or equivalent).
L1-L5—108-nH shielded variable inductor (Toko MC122 or equivalent).
RFC—8 turns #24 enameled wire closewound, ⅛ inch ID.
U1—74HC04.
U2—MAV-11 or MSA-1104 MMIC.
Y1—10-pF parallel-resonant crystal.
For 144.2-MHz center frequency, use 20.6-MHz crystal; for 144.1-MHz output, use 20.5857-MHz crystal.

single 90° LO phase shifter with a splitter on each output port to drive the I and Q ports of the R2 and T2 boards. I found that I could adjust the phase-shift network for good opposite sideband suppression from *either* the transmitter or the receiver, but not both! A better approach is to split the LO output first, then use separate phase-shift networks for transmit and receive. This allows independent adjustment of the receiver and transmitter for best opposite-sideband suppression.

Local Oscillators

The superhet system in Fig 2 uses single conversion with a crystal-controlled front end and a tunable IF. To make the IF tunable, we need a tunable LO. It's easy to build a stable VFO for frequencies as low as 5 or 10 MHz, but not quite as easy at VHF. Several approaches to VHF VFOs that are stable enough for SSB and CW have been used in custom and commercial equipment over the years. The simplest approach is a variable crystal oscillator (VXO), and the simplest VHF VXO I've seen appeared on the back of my napkin at lunch a few months ago. The most recent iteration is shown in Fig 5. This oscillator has a 50-kHz range at 144 MHz, reasonable stability, and spurs that are suppressed more than 72 dB. I obtained a CW offset of about 1 kHz by raising the 74HC04 supply from 6.0 to 6.4 volts by switching a Schottky diode in series with the 6-volt, three-terminal regulator's ground lead. This is about the minimum-parts-count CW-offset circuit I've seen, and it emphasizes the need for voltage regulation on crystal oscillators followed by frequency multipliers!

Another tunable VHF local oscillator, a *premixed* VFO, is shown in Fig 6. This circuit achieves oscillator and image spurious levels about 45 dB below the desired output, when properly shielded. A premixed VFO is simply a high-frequency VFO followed by a low-level transverter. *The ARRL Handbook* shows several examples of VFOs and transverters that can be combined to provide a stable, tunable LO for VHF. If the VFO frequency is less than about 10% of the


+12 V
0.01
78L06
Reg
IN
OUT
GND
+12 V
0.01
13.0 – 13.12 MHz
T1
U310
0.01
L6
Piston
Trimmer
2.7
NPØ
56
NPØ
10
RANGE
1N4148
1 M
27 k
10 k
2N3904
2N3904
27
NPØ
10
NPØ
1 M
1 k
56
NPØ
20
MAIN
TUNING
MV2107
180
0.01
0.01
CW
OFFSET
IN
OUT
OFFSET
ADJUST
100 k
4.7 k
+12 V
10 μF
16 V
9.1 V
1/2 W
+12 V
0.01
220
8.2 V
1/2 W
2.2 μF
16 V
0.0022
0.01
L1
3–dB Attenuator
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.
FB = Ferrite Bead
4.7 k
2N5179
FB
FB
5
8.2
8.2
0.01
10
FREQ
10
150
1 k
SBL–1,
Bottom View
7
8
LO
5
6
3
4
IF
RF
1
2
Blue Ring
100
131 MHz
39

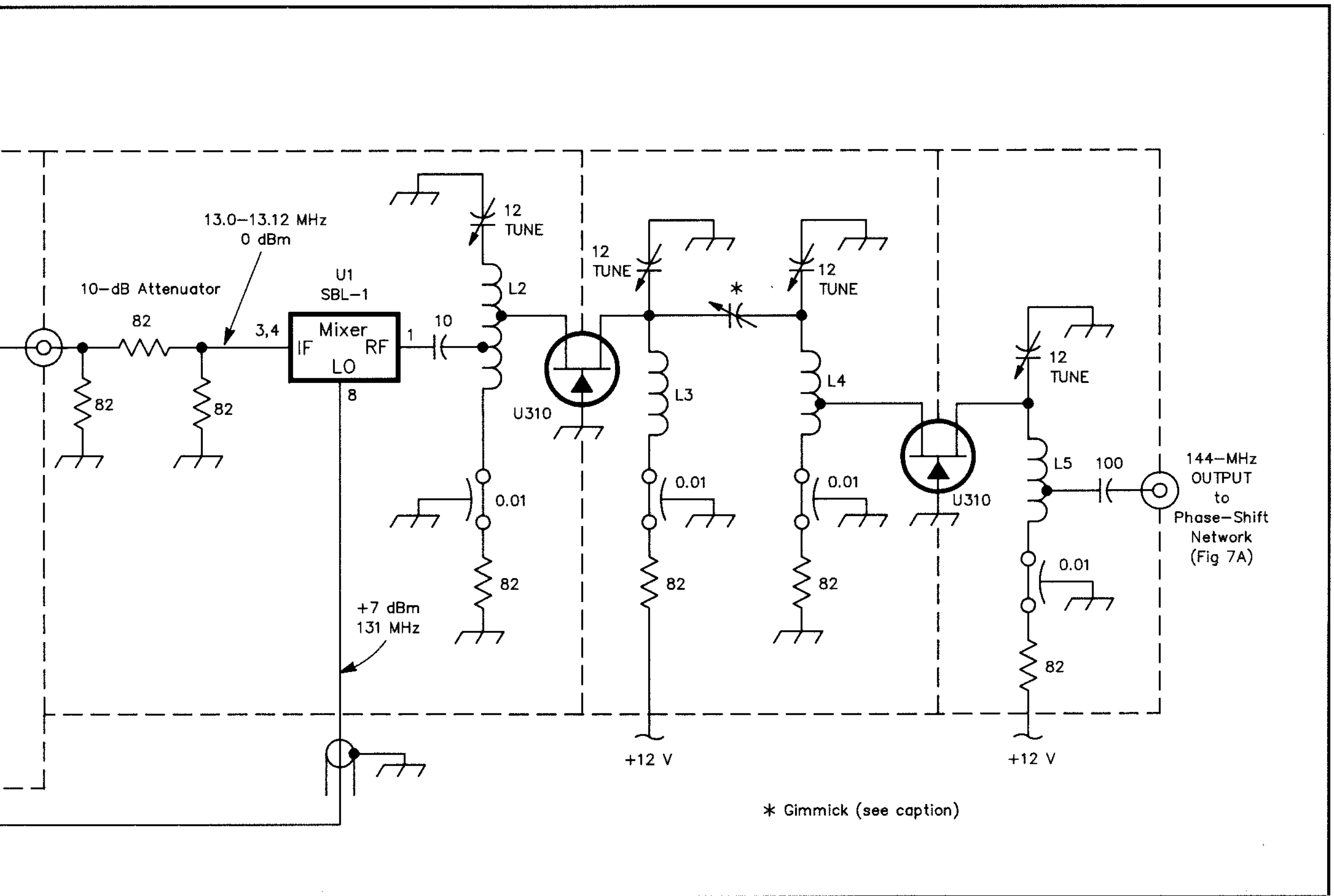


Fig 6—The premixed VFO circuit. The **CW OFFSET** switch is opened to enable the offset. This function can be handled by a relay contact or the front-panel **CW TRANSMIT** switch. The *gimmick* capacitor that provides interstage coupling consists of a ½-inch-long tightly twisted pair of #24 insulated wires.

L1—5 turns #24 enameled wire, ⅛-inch ID, ⅛ inch long.
L2—8 turns #24 bare wire, ¼ inch ID, ⅜ inch long. Tap input 2 turns from ground end; tap U310 source 3 turns from ground end.
L3—8 turns #24 bare wire, ¼ inch ID, ⅜ inch long.
L4—8 turns #24 bare wire, ¼ inch ID, ⅜ inch long. Tap U310 source 3 turns from ground end.
L5—8 turns #24 bare wire, ¼ inch ID, ⅜ inch long. Tap output 2 turns from ground end.
L6—24 turns #24 enameled wire on a T-37-6 core, tapped at 6 turns from ground end. For best stability, boil L6 in water for 2 minutes after winding it.
T1—Core: FT-37-43. Primary: 15 turns #22 enameled wire; secondary, 3 turns #22 enameled wire.

desired output frequency, then the transverter needs very good selectivity to remove the image and oscillator spurs. Helical filters, often used in VHF receiver front ends, can be used to obtain the necessary selectivity.

Another option for a stable variable VHF LO is a frequency synthesizer using a PLL, DDS or some other combination of letters. I have built a few of each type, but they were more complicated and didn't work as well as my VXOs and premixed VFOs, so I stopped playing with them for a while.

Whatever VFO type you choose, use lots of shielding. Commercial radios never have enough shielding, because it's expensive to manufacture and causes problems on the assembly line. Mount your VFO or VXO in a rigid, RF-tight box, and premix circuitry in a separate RF-tight box. Then enclose the whole radio in another RF-tight enclosure. Proper shielding eliminates many of the problems we have learned to tolerate in commercial radios, and once these bugs are gone, it's hard to go back to store-bought gear. Shielding is cheap in a custom radio, so use lots!

The VFO drives a splitter and phase-shift network (Fig 7). This circuit routes the VFO drive to the T2 and R2 boards, as well as handling phase-shifting for the I and Q ports on each board.

Interconnecting T2 and R2 with a No-Tune Transverter Board

The R2 and T2 boards interface directly with the receive and transmit IF ports of the no-tune transverters. The 1296-MHz transceiver in the title photograph follows the block diagram in Fig 2, without the optional IF preamplifier. The R2 noise figure is about 17 dB without the amplifier stage, so it may be useful to add a single MMIC amplifier stage if the transverter gain is low. The R2 receiver can hear signals at reduced sensitivity at odd harmonics of the VFO frequency, so the R2 input needs a simple low-pass filter. Since the 1296-MHz no-tune transverter board includes plenty of RF gain and a low-pass coupler at the mixer output, a piece of RG-174 can be connected directly from the transverter's receive-IF port to the R2's RF input.

The transmitter board contains an MMIC and low-pass filter, so a direct connection works with any of the no-tune transverters.

The no-tune transverters require a continuous 12-volt supply for the LO and multiplier circuitry, and switched 12-volt supplies for transmit and receive. I use the relay circuit in Fig 2, with a spare set of contacts available for hard-switching an external preamplifier and power amplifier.

Fig 8 shows the measured output spectrum of the 1296-MHz transceiver with the premixed VFO. It's a little cleaner than the no-tune 1296-MHz transverter driven by an ICOM IC-202, and *much* cleaner than the transverter slightly overdriven by a badly

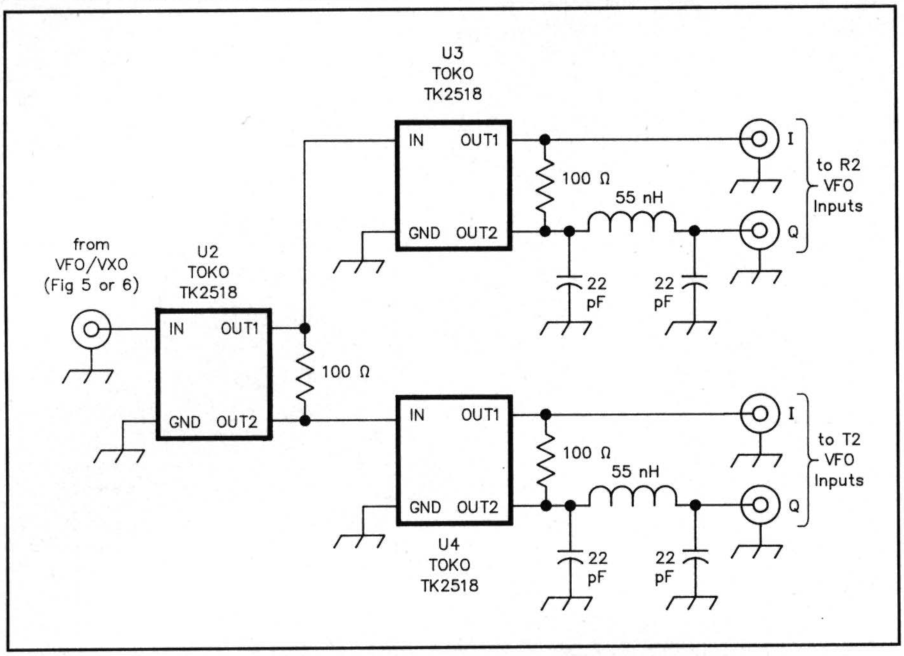
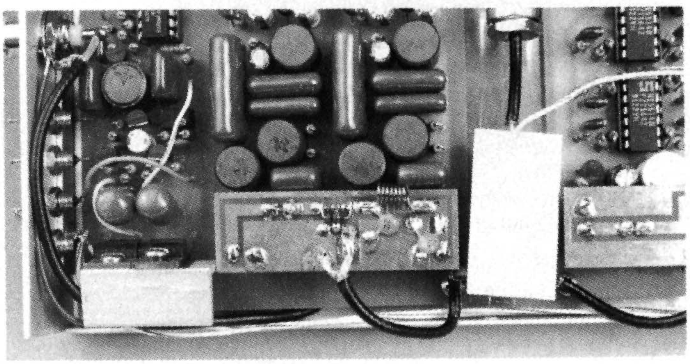


Fig 7—The power splitter and phase-shift network at A drive the R2 and T2 boards with either the VXO (Fig 5) or the premixed VFO (Fig 6). Phase delay in each phase-shift network is optimized by squeezing or spreading the turns of the two 55-nH inductors. Each inductor consists of 7 turns of #22 enameled wire spacewound on a 0.113-inch-ID form (#33 drill). "Piggyback" phase-shift networks are used in IF2 (Fig 4); a photo of the R2 board's network is shown below.



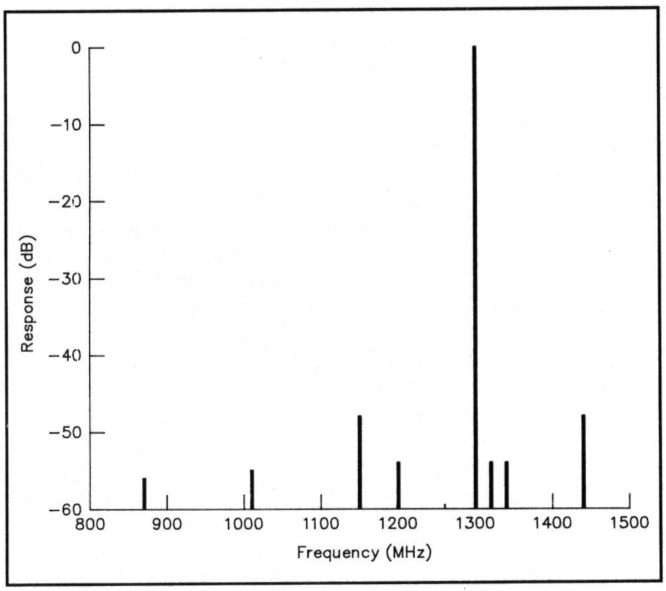


Fig 8—Measured output spectrum of the prototype no-tune 1296-MHz transceiver of Fig 3.

aligned FT-290R. The home-brew setup has higher transmit spurious levels than an ICOM IC-1271, but it also sounds better on both transmit and receive, and it has no birdies over the receiver's entire tuning range.

On transmit, the carrier and opposite-sideband suppression are comparable to VHF multimode radios, and the audio quality is far superior. On receive, the combination of high fidelity, low-distortion audio, decent opposite-sideband suppression, and no AGC is a real eye-opener. Loud, clear signals 40 dB above the noise simply disappear on the other side of zero beat. Weak signals at the noise level may be heard without the distractions of audio distortion and an AGC system that resets the gain on every noise peak.

The radio in the small aluminum box (Fig 4) shown in the photos is the 144-MHz IF for a 903.1-MHz SSB/CW system. It contains only an R2 board, T2 board, VXO and phase shift networks—simple! The no-tune 903 transverter is mounted at the antenna. Separate coax lines connect the transmit and receive IF to the T2 and R2 boards.

I didn't put RIT in either of these radios because I don't use RIT in portable microwave work. Battery-powered microwave radios on cold, windy hilltops tend to be pretty drifty, and it's better to follow other stations around the band than to try operating "random split." For radios with larger front panels, it's easy to add your favorite features.

Conclusions

This article describes one of my favorite applications for the R2 and T2 boards. The January *QST* article showed a 40-meter QRP CW transceiver using an R2 board. With the basic transmitter and receiver circuitry contained on a pair of small printed-circuit boards, the possibilities for custom-built radios are limited only by our imaginations.

I would like to thank the many hundreds of readers who have written to me since the R1 article appeared last August, and to apologize for not having enough time to respond to all of you. I am greatly encouraged by your thoughtful comments; it appears that the technical side of Amateur Radio is very healthy. Keep up all the good work—this stuff is fun!

I would also like to thank my family for tolerating all the evenings I've spent at the bench turning ideas into working radios, and all the times the telephone interrupted a bedtime story.

Notes

[1]R. Campbell, "High-Performance, Single-Signal Direct Conversion Receivers," *QST*, Jan 1993, pp 32-40.
[2]R. Campbell, "A Multimode Phasing Exciter," *QST*, Apr 1993, pp 27-31.
[3]No-tune transverter boards and kits for 432 through 5760 MHz are available from Down East Microwave, RR 1 Box 2310, Troy, ME 04987, tel 207-948-3741, fax 207-948-5157. Catalog available.
[4]R. Campbell, "High-Performance Direct-Conversion Receivers," *QST*, Aug 1992, pp 19-28.