spot in the HF spectrum using a crystal oscillator and mixer. Then put enough attenuators before and after the mixer to obtain a peak SSB output level of around –60 dBm — weak enough to not overload the receiver but strong enough to hear off-channel garbage another 60 or 70 dB below the peak transmitter output. Connect a CD player with some good acoustic folk music — lots of voice, guitar transients, perhaps a mandolin but no drums — to the exciter microphone input. Then connect the frequency converted exciter output directly into the input of a good receiver and tune it in. Don't connect it to an antenna — amateurs are not permitted to transmit music!

Any receiver with selectable sidebands and a manual RF gain control will do. Turn the receiver AGC off and manually reduce the gain so the receiver noise floor is well below the peak signal level. If your receiver is lacking in audio fidelity, run the receiver "line out" into a stereo amplifier. Play the CD through the SSB exciter, through the attenuators and frequency translator, into the receiver, and back into the stereo and out the speakers. It's an acid test, and this exciter sounds pretty good — better than most AM broadcast stations, and even some badly adjusted FM stations. Friends who hear you on the air will say, "Wow, it sounds exactly like you!"

Project: The MkII — An Updated Universal QRP Transmitter

A frequently duplicated project in the now out-of-print book *Solid State Design for the Radio Amateur*[15] was a universal QRP transmitter. This was a simple two-stage, crystal-controlled, single-band circuit with an output of about 1.5 W. The no frills design used manual transmit-receive (TR) switching. It operated on a single frequency with no provision for frequency shift. The simplicity prompted many builders to pick this QRP rig as a first solid state project.

The design simplicity compromised performance. A keyed crystal controlled oscillator often produces chirps, clicks or even delayed starting. The single pi-section output network allowed too much harmonic energy to reach the antenna, and the relatively low output of 1.5 W may seem inadequate to a first time builder.

A THREE-STAGE TRANSMITTER

Wes Hayward, W7ZOI, updated the design to the MKII (**Fig 13.44**). The circuit, shown in **Fig 13.45**, develops an output of 4 W on any single band within the HF spectrum, if provided with 12 V dc. Q1 is a crystal controlled oscillator that functions with either fundamental or overtone mode crystals. It operates at relatively low power to minimize stress to some of the miniature crystals now available. The stage has a measured output at point X of +12 dBm (16 mW) on all bands. This is applied to drive control R17 to set final transmitter output.

A three stage design provides an easy way to obtain very clean keying. Shaped dc is applied to driver Q2 through a keying switch and integrator, Q4.[16] A secondary keying switch, Q5, applies dc to the oscillator Q1. This is a time-sequence scheme in which the oscillator remains on for a short period (about 100 ms) after the key is released. The keyed waveform is shown in **Fig 13.46**.

The semiconductor basis for this transmitter is an inexpensive Panasonic 2SC5739. This part, with typical F_T of 180 MHz, is specified for switching applications, making it ideal as a class C amplifier. The transistor is conveniently housed in a plastic TO-220 package with no exposed metal. This allows it to be bolted to a heat sink with none of the insulating hardware required with many power transistors. A 2 × 4 inch scrap of circuit board served as both a heat sink and as a ground plane for the circuitry.

Another 2SC5739 serves as the driver, Q2. This circuit is a feedback amplifier with RF feedback resistors that double to bias the transistor.[17] Driver output up to 300 mW is available at point Y. Ferrite transformer T2 moves the 200 Ω output impedance seen looking into the Q2 collector to 50 Ω. The maximum output power of this stage can be changed with different R20 values. Higher stage current, obtained with lower R20 values, is needed on the higher bands. The 2SC5739 needs only to be bolted to the circuit board for heat sinking.

The Q3 power amplifier input is matched with transformer T3. The nominal 50 Ω of the driver is transformed to 12 Ω by T3.

The original design started with a simple L network output circuit at the Q3 collector followed by a third-order elliptic low-pass section to enhance harmonic suppression.[18] C5 is a moderately high reactance capacitor at the collector to bypass VHF components. This L network presented a load resistance of 18 Ω to the Q3 collector, the value needed for the desired 4 W output. But this circuit displayed instabilities when either the drive power or the supply voltage was varied. The output amplifier sometimes even showed a divide-by-two characteristic. The original L network was modified with the original inductor replaced with an LC combination, C4 and L1. The new series element has the same reactance at the operating frequency as the original L network inductor. This narrow band modification provided stability on all bands. The components for the various bands are listed in **Table 13.2**.

The inductance values shown in Table 13.2 are those calculated for the networks, but the number of turns is slightly lower than the calculated value. After the inductors were wound, they were measured with a digital LC meter.[19] Turns were compressed to obtain the desired L value. Eliminate this step if an instrument is not available.

The divide-by-two oscillations mentioned above could be observed with either an oscilloscope or a spectrum analyzer and were one of the more interesting subtleties of this project. The oscilloscope waveform looked like amplitude modulation. In the more extreme cases, every other RF cycle had a different amplitude that showed up as a half frequency component in the spectrum analyzer. The amplitude modulation appeared as unwanted sidebands in the spectrum display for the "moderately robust" instabilities. (Never assume that designing even a casual QRP rig will offer no development excitement!)

The output spectrum of this transmitter was examined with V_{CC} set to 12.0 V and the drive control set for an output of 4 W. The third harmonic output is –58 dBc and the others >70 dB down.

The author breadboarded the oscillator

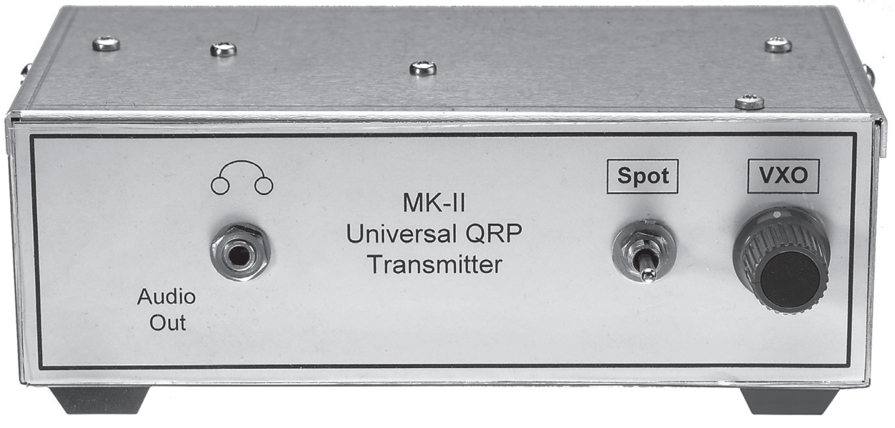
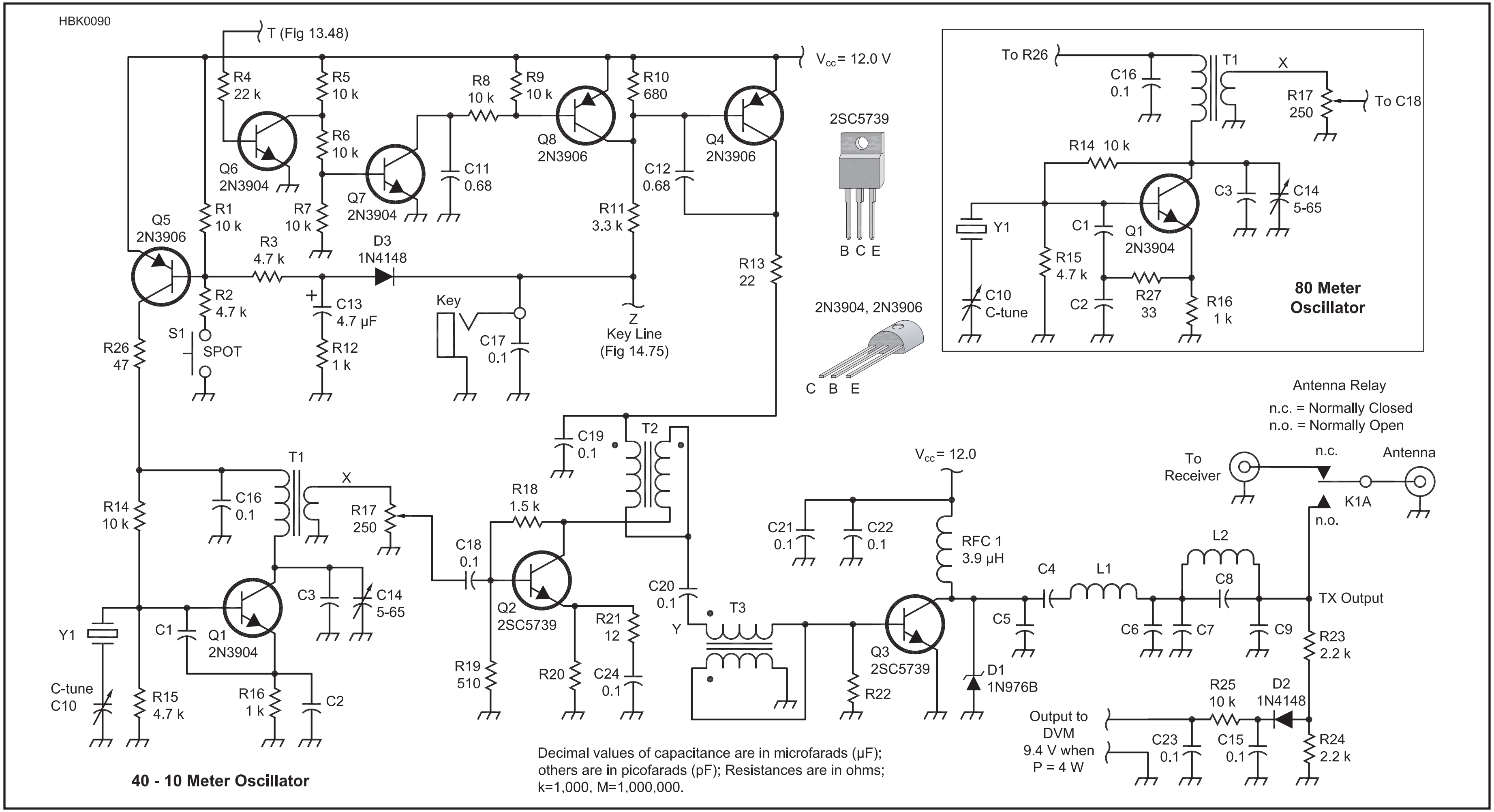


Fig 13.44 — The MKII QRP transmitter includes VXO frequency control, TR switching and a sidetone generator.



Decimal values of capacitance are in microfarads (µF); others are in picofarads (pF); Resistances are in ohms; k=1,000, M=1,000,000.

Fig 13.45 — Schematic diagram and parts list for the RF portion of the MKII transmitter. The oscillator (Q1 and associated components) in the main drawing is for the 40-10 m bands, while a modified version for 80 m is shown in the inset (see text). Fixed resistors are ¼ W, 5% carbon film unless otherwise noted. A kit of component parts is available from Kanga US (www.kangaus.com). TR switching is performed with a relay and additional circuitry (Fig 13.48).

C1-C9 — See Table 13.2, all 50 V ceramic or mica.
C10 — VXO control to provide some frequency adjustment around the crystal frequency. Use what you have in your junk box, although smaller capacitance values provide a wider tuning range. The prototype uses a small 2 to 19 pF trimmer. See text.
C11, 12 — 0.68 µF, 50 V metal film or Mylar.
C13 — 4.7 µF, 25 V electrolytic.
C14 — 5-65 pF, compression or plastic dielectric trimmer.
C15-24 — 0.1 µF, 50 V ceramic.
D1 — 1N976B, 43 V Zener diode.
K1A — See Fig 13.48.
L1, L2 — See Table 13.2.
Q1, Q6, Q7 — 2N3904, NPN silicon small signal transistor.
Q2, Q3 — 2SC5739 NPN silicon switching power transistor.
Q4, Q5, Q8 — 2N3906, PNP silicon small signal transistor.
R17 — 250 Ω, potentiometer (a 500 Ω potentiometer in parallel with 270 Ω fixed resistor can be substituted).
R20, R22 — See Table 13.2, carbon film.
RFC1 — 3.9 µH, 0.5 A molded RF choke. In place of a manufactured product, a T68-2 toroid wound with 26 turns of #22 enameled wire can be used.
T1 — See Table 13.2
T2 — 10 bifilar turns #28 enameled wire on FT-37-43 or FB-43-2401 ferrite toroid core.
T3 — 7 bifilar turns #22 enameled wire on FT-37-43 or FB-43-2401 ferrite toroid core.

Table 13.2
Band Specific Components of the MKII Transmitter

Band MHz	*T1 turns-turns*	*C1 pF*	*C2 pF*	*C3 pF*	*R20 Ω*	*R22 Ω*	*L1 nH, turns wire, core*	*L2 nH, turns wire, core*	*C4 pF*	*C5 pF*	*C6 pF*	*C7 pF*	*C8 pF*	*C9 pF*
3.5	51t-3t #26, T68-2	270	270	82	33	18	3000, 26t #28,T37-2	1750, 20t #28, T37-2	1000	390	1000	1000	300	1000
7	32t-4t #28, T50-6	390	100	82	33	33	1750, 19t #26, T37-2	890, 14t #22, T37-2	470	200	560	470	150	470
10.1	32t-4t #28, T50-6	390	100	0	33	33	1213, 19t #28, T37-6	617, 13t #28, T37-6	330	120	390	330	100	330
14	32t-4t #28, T50-6	390	100	0	33	33	875, 16t #28, T37-6	445, 11t #28, T37-6	220	100	270	220	75	220
18.1	20t-3t #28, T37-6	100	33	0	33	33	680, 14t #28, T37-6	346, 9t #28, T37-6	180	75	220	180	56	180
21	20t-3t #28, T37-6	100	33	0	18	33	583, 12t #28, T37-6	297, 9t #28, T37-6	150	62	180	150	50	150
24.9	20t-3t #28, T37-6	33	18	0	18	33	490, 11t #28, T37-6	249, 8t #28, T37-6	133	56	150	133	43	133
28	20t-3t #28, T37-6	33	18	0	18	33	438, 10t #28, T37-6	223, 7t #28, T37-6	120	47	140	120	39	120

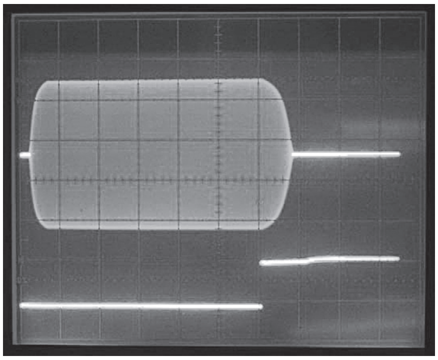


Fig 13.46 — Keyed waveform. The lower trace is the keyer input, which triggered the oscilloscope in this measurement. The horizontal time scale is 5 ms/div.

and buffer section for all HF amateur bands from 3.5 to 28 MHz.[20] The power amplifier circuit has been built at 3.5, 7, 14 and 21 MHz. The crystals, obtained from Kanga US (**www.kangaus.com**), were fundamental mode units through 21 MHz, and third overtone above. The breadboard was built on two scraps of circuit board. Q1 and Q2 were on one with Q2 bolted to the board to serve as a heat sink. The second board had Q3 bolted to it, also serving as a heat sink.

After the breadboarding work was done, the circuits were moved to an available 2 × 3 × 6 inch box, an LMB #138. A new circuit board scrap was used, but most of the circuitry was moved intact from the breadboard. A diode detector was added to aid tune-up. The final RF board is shown in **Fig 13.47**.

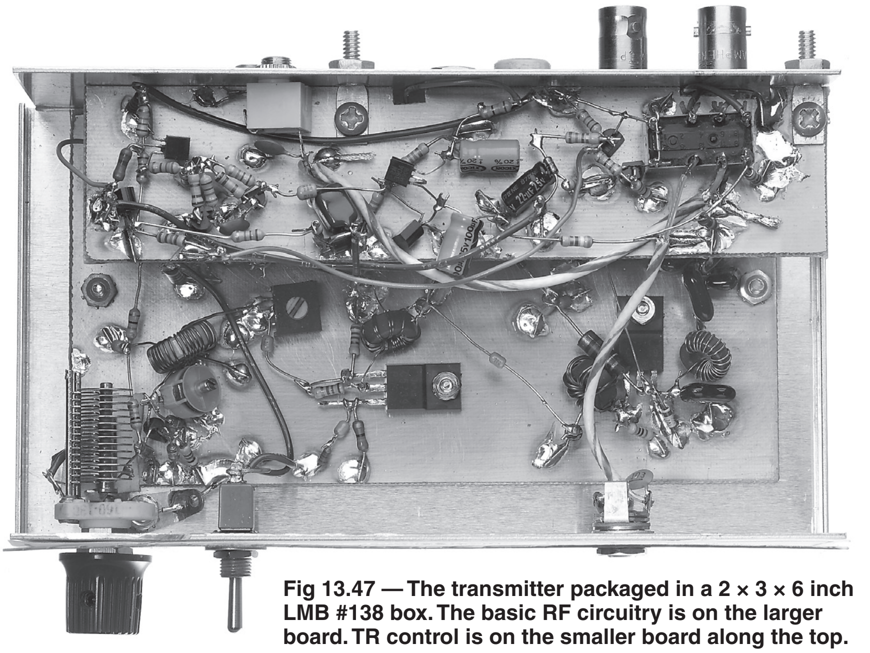


Fig 13.47 — The transmitter packaged in a 2 × 3 × 6 inch LMB #138 box. The basic RF circuitry is on the larger board. TR control is on the smaller board along the top.

CONSTRUCTION NOTES

Since publication in *QST*, some builders have encountered questions or difficulties. This section addresses those difficulties and further information may be found in *QST*.[21]

VXO Capacitor Grounding

The VXO capacitor, C10 of Fig 13.45, is mounted on the front panel of the transmitter rather than the circuit board. Grounding of the capacitor has been reported to be critical. A lead, ideally a short one, should go from the variable capacitor to the ground foil near the oscillator stage, Q1. In one of the transmitters built, the builder had merely attached the variable capacitor to the panel and relied on the ground connection that held the board to the box. This was, unfortunately, close to the power amplifier. The result was that the crystal oscillator would not always come on when the SPOT button was pushed. Adding a cleaner grounding wire solved the problem. The prototype uses a ground lug on the chassis very close to variable capacitor C10 and soldered directly to the PC foil right next to Q1.

Oscillator Changes

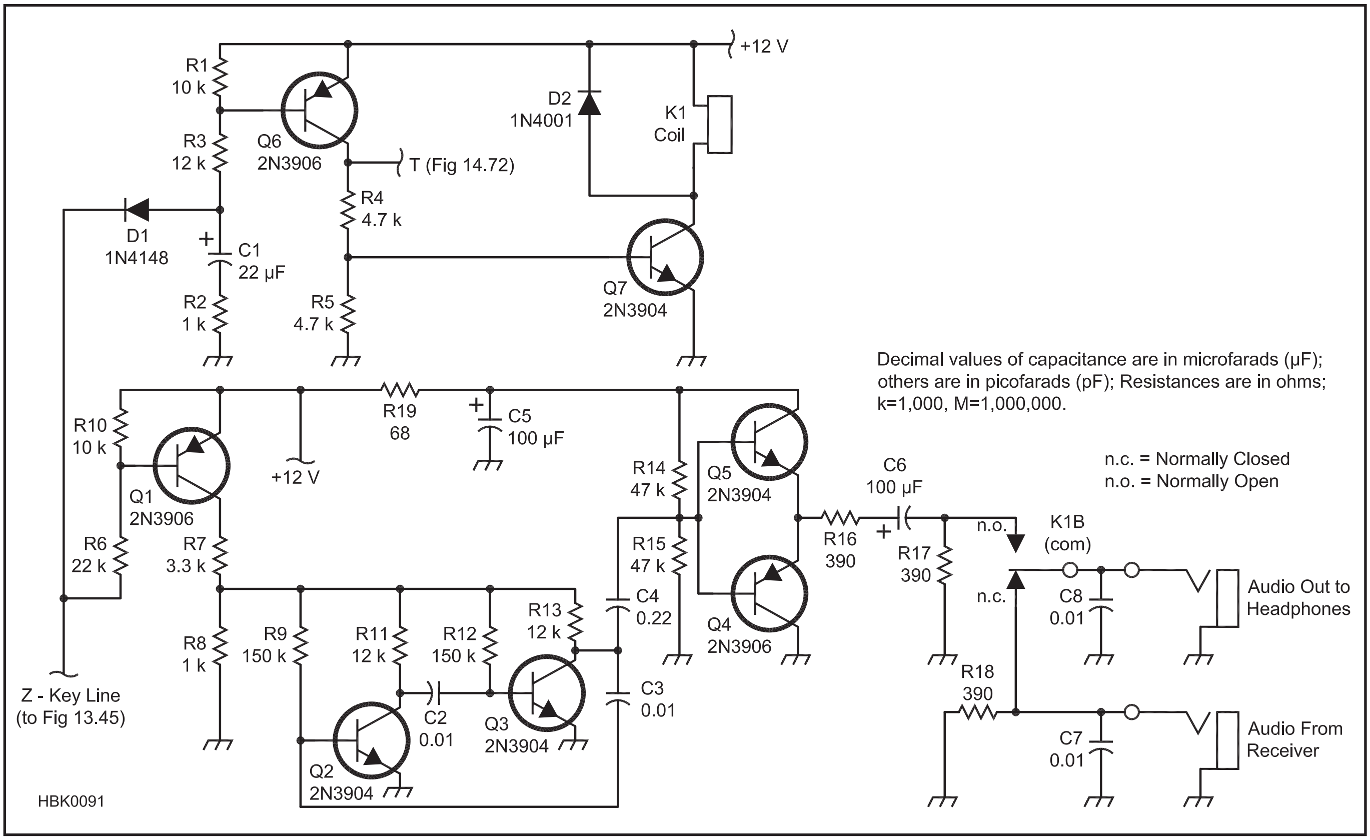
Some builders of the 40-meter version reported difficulty with tuning C14, the variable capacitor that tunes the collector circuit of the oscillator. The variable capacitor was too close to minimum C and a well defined peak was not always found. Of greater significance, tuning C14 to some values could allow the circuit to oscillate without crystal control of the frequency, producing oscillation in the 6.4-6.9 MHz region. Solutions to both problems are simple. First, change C3 from 100 to either 82 pF to remove the tuning ambiguity. (Removing a turn or two from the high L winding on T1 will accomplish the same end.) Second, adding C1 at 390 pF to the 40 meter circuit produces an oscillator that is always crystal controlled for any tuning of C14. Further experimentation with higher frequency versions revealed that the oscillators were generally well behaved but undesired modes could be found with extreme tuning of C14. Adding C1 to the circuit when it was initially absent always fixed this problem. The corrected component values are shown in Table 13.2.

Oscillation without crystal control was also observed with a misadjusted 80 meter circuit. Increasing the value of C1 helped but did not completely remove the problem. Analysis showed that the 80 meter oscillator starting gain was higher than was available on the higher-frequency bands. The gain was high enough that an instability was observed when the crystal was removed and the circuit was driven as an amplifier with a signal generator. Amplifier output jumped as the generator frequency was tuned.

Common "fixes" for amplifier instability include loading and the application of negative feedback. Increased loading through adjustment of R17 helped, but this eliminated the ability to adjust overall transmitter output with this control. So, negative feedback was tried. The resulting oscillator circuit is shown in the inset of Fig 13.45. Emitter degeneration is added in the form of a 33 Ω resistor (R27), while parallel feedback is realized by moving the 10 kΩ base bias resistor (R14) from the bypass capacitor to the Q1 collector. The circuit, as shown, would not oscillate without crystal control. Care is still required for initial adjustment (with a receiver or spectrum analyzer) to avoid crystal controlled oscillation on a crystal spurious resonance. For example, one oscillator tested achieved crystal controlled operation at 3.8 MHz with a crystal built for operation at 3.56 MHz. Crystal spurious modes of this sort are found in virtually all crystals and should not be regarded as a crystal problem.

TRANSMIT-RECEIVE (TR) SWITCHING

Numerous schemes, generally part of a transceiver, are popular for switching an antenna between transmitter and receiver functions. When carefully refined, full-break-in keying becomes possible, an interesting option for transceivers. But these schemes tend to get in the way when one is developing both simple receivers and transmitters, per-



Decimal values of capacitance are in microfarads (µF); others are in picofarads (pF); Resistances are in ohms; k=1,000, M=1,000,000.

n.c. = Normally Closed
n.o. = Normally Open

Fig 13.48 — Detailed schematic diagram and parts list for transmit-receive control section and sidetone generator of the universal QRP transmitter. Resistors are ¼ W, 5% carbon film. A kit of component parts is available from KangaUS (www.kangaus.com).

C1 — 22 µF, 25 V electrolytic.
C2, C3, C7, C8 — 0.01 µF, 50 V ceramic.
C4 — 0.22 µF, 50 V ceramic.
C5, C6 — 100 µF, 25 V electrolytic.
K1 — DPDT 12 V coil relay. An NAIS DS2Y-S-DC12, 700 Ω, 4 ms relay was used in this example.
Q1, Q4, Q6 — 2N3906, PNP silicon small signal transistor.
Q2, Q3, Q5, Q7 — 2N3904, NPN silicon small signal transistor.

haps as separate projects. A simple relay based TR scheme is then preferred and is presented here. In this system, the TR relay not only switches the antenna from the receiver to the transmitter, but disconnects the headphones from the receiver and attaches them to a sidetone oscillator that is keyed with the transmitter.

The circuitry that does most of the switching is shown in **Fig 13.48**. Line Z connects to the key. A key closure discharges capacitor C1. R2, the 1 kΩ resistor in series with C1, prevents a spark at the key. Of greater import, it also does not allow us to "ask" that the capacitor be discharged instantaneously, a common request in similar published circuits. Key closure causes Q6 to saturate, causing Q7 to also saturate, turning the relay on. The relay picked for this example has a 700 Ω, 12 V coil with a measured 4 ms pull-in time.

Relay contacts B switch, the audio line. R17 and 18 suppress clicks related to switching. A depressed key turns on PNP switch Q1, which then turns on the sidetone multivibrator, Q2 and Q3. The resulting audio is routed to switching amplifier Q4 and Q5. Although the common bases are biased to half of the supply voltage, emitter bias does not allow any static dc current to flow. The only current that flows is that related to the sidetone signal during key down intervals. Changing the value of R16 allows the audio volume to be adjusted, to compensate for the particular low-impedance headphones used.

There is an additional interface between Figs 13.48 and 13.45. Recall that Q4 of Fig 13.45 keys buffer Q2 while Q5 provides a time sequence control to oscillator Q1. Additional circuitry uses Q6, Q7 and Q8, and related parts. Under static key up conditions, Q7 is saturated, which keeps C11 discharged. Saturated Q7 also keeps PNP transistor Q8 saturated. This closed switch is across the emitter-base junction of Q4. Hence, pressing the key will start relay timing and will allow the oscillator to come on, but will not allow immediate keying of Q2 through Q4. Key closure causes Q6 in Fig 13.48 to saturate causing point T to become positive. This saturates Q6 of Fig 13.45 which turns Q7 off, allowing C11 to charge. When C11 has charged high enough, Q8 is no longer saturated and Q4 can begin its integrator action to key Q2.

This hold-off addition has solved a problem of a loud click, yielding a transmitter that is a pleasure to use. There is still a flaw resulting in the initial CW character being shortened. The result is that an I sent at 40 WPM and faster comes out as an E. Further refinement of timing component values should resolve this. The TR system circuitry is built on a narrow scrap of circuit board that is then bolted to the transmitter rear panel.

What's Next?

This has been an interesting project from many viewpoints. The resulting transmitter, which is usually used with the S7C receiver from *Experimental Methods in RF Design*,[22] is a lot of fun to use and surprisingly effective in spite of its crystal control. Primitive simplicity continues to have its place in Amateur Radio. Also, the development was more exciting than expected. The observed instabilities were interesting, as were the subtleties of the control system. Perhaps we should not approach simple CW systems with a completely casual attitude, for they continue to offer education and enlightenment.

There are clearly numerous refinements available for this transmitter. The addition of an adjustable reactance in series with the crystal will allow its frequency to move more. Try just a small variable capacitor. Two or more similar crystals in parallel form a "super VXO" topology for even greater tuning range. Higher power supply voltage will produce greater output power — over 10 W on the test bench. The transmitter could certainly be moved down to 160 meters for the top band DXer looking for QRP sport. It is not certain that the 2SC5739 will allow operation as high the 6 meter band. The transmitter could easily be converted to a modest power direct conversion transceiver using, for example, the Micromountaineer scheme offered in *QST*.[23]

13.4 Modern Baseband Processing

The term *baseband* refers to the signal or signals that comprise the information content at their natural frequency. For a communications audio signal, it would be a spectrum typically extending from 300 to 3300 Hz. Many transmitter architectures are designed to process and transmit a spectral range rather than any particular type of information. For example, the typical transmitter that shifts the modulating spectrum to occupy a single sideband adjacent to a suppressed carrier — our usual SSB transmitter, is just as happy to handle voice, modem tones or the two tones from an RTTY converter. The transmitter performs a linear operation to shift the input spectrum, the baseband signal, to the output frequency independent of the form or information content of the input spectrum.

This approach has a number of advantages for the transmitter designer and manufacturer. The baseband spectrum width, amplitude and dynamic range are inputs to the design process. The designer can thus focus on establishing the system between the baseband and the antenna port. This leaves the design of the baseband processing subsystem to perhaps another department or another company. Similarly the baseband processing equipment design may have multiple applications. Its output can be plugged into cable systems, HF transmitters or microwave systems as long as they support the required bandwidth, amplitude and dynamic range.

13.4.1 Digital Signal Processing for Signal Generation

The transmitter architecture that was described in Fig 13.27 was based on the classical analog approach to waveform generation and modulation with information content. Many current transmitters have replaced the early analog signal processing stages with a digital