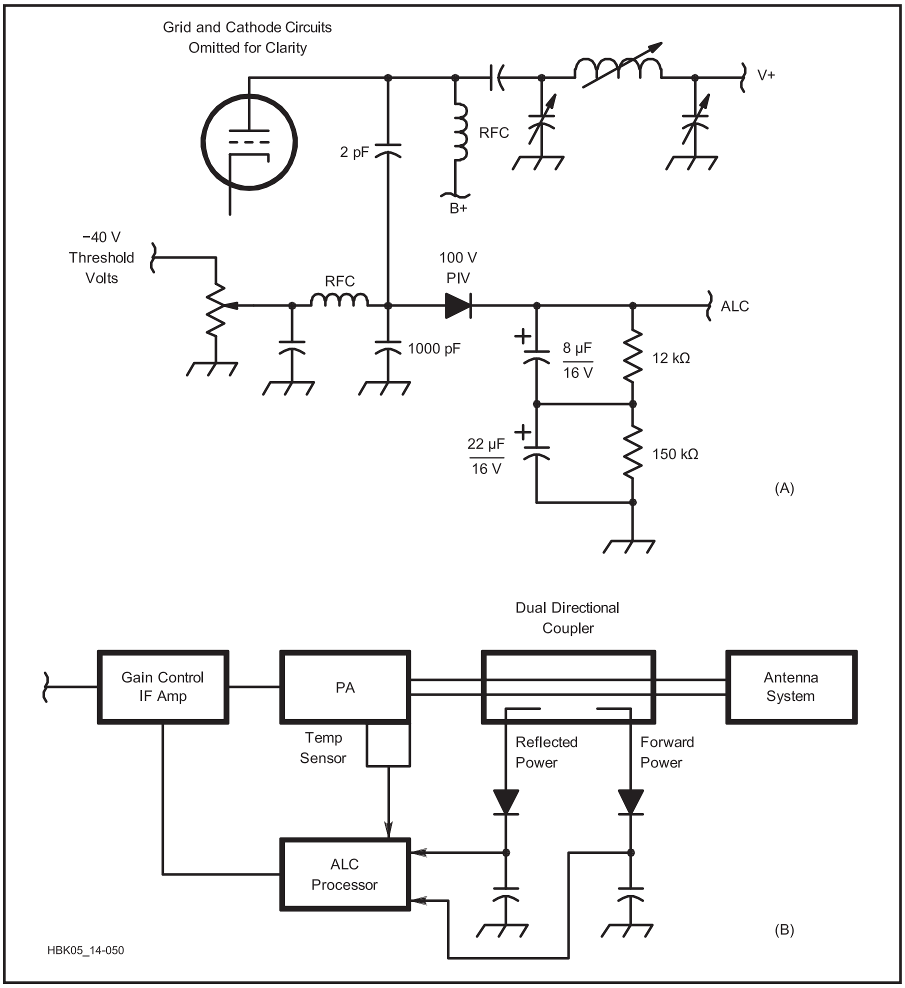

Fig 13.38 — At (A), an ALC circuit with speech processing capability. At (B), protection method for a solid-state transmitter.

Project: The MicroT2 — A Compact Single-Band SSB Transmitter

As an example of an SSB transmitter including many aspects of design covered heretofore, we present the MicroT2, a simple SSB transmitter that generates a high-quality USB or LSB signal on any single band from 1.8 MHz to 50 MHz. Rick Campbell, KK7B, developed the MicroT2 as a companion to the MicroR2 receiver project described in the **Receivers** chapter. While it is a bit more involved to generate an SSB signal than a CW signal, we greatly simplify the task if all the necessary circuitry is on a single PC board exciter module. Once we have a high-quality low-level SSB signal, a 5 or 500 W SSB transmitter is as easy to build as a 5 or 500 W CW transmitter. Simple transmitters are delightful, but relaxed standards are not. The MicroT2 is designed to be clean, stable and reliable, exceed FCC Part 97 requirements, and sound good, too. A more complete description of the circuitry in this transmitter can be found in *Experimental Methods in RF Design*[10] *(EMRFD)* of which the project's designer was a co-author.

THE CASE FOR CRYSTAL CONTROL

A jumper on the PC board makes it easy to use an external VFO for frequency control if you wish. For some applications the narrow tuning range offered by the on-board VXO is sufficient, and the secure knowledge that the transmitter is actually on frequency and stable is a real virtue. **Fig 13.39** shows just one example — a simple battery-operated transmitter intended to keep in touch with the folks back home on an HF net frequency. The crystal oscillator in the transmitter functions as a calibrator for the receiver, so that the receiver may be tuned around the band and then easily reset to the net frequency. The current drain during receive is only 60 mA, because the entire transmitter is turned off except when actually transmitting.

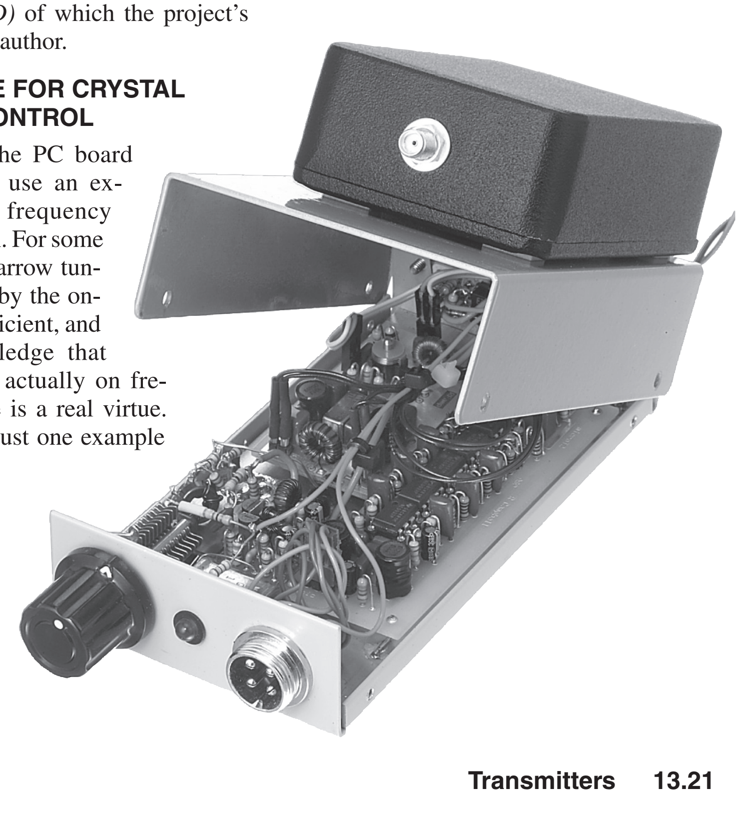

Fig 13.39 — This 40 meter version of the MicroT2 uses the on-board VXO. The black box on top is the 0.5 W amplifier.

EXCITER BLOCK DIAGRAM

Fig 13.40 is the block diagram of the circuitry on the PC board and **Fig 13.41** is a detailed schematic. It is a complete VXO SSB exciter on a 2.5 × 3.8 inch circuit board with 1 mW (0 dBm) peak output. The exciter uses the phasing method of SSB generation, which makes it easy to operate on different frequencies. In a phasing SSB exciter, two identical signals with a 90° phase difference are generated and then combined so that one sideband adds and the other subtracts. The signal quality from this exciter is not merely adequate for the HF amateur bands — it is exceptional.

RF Circuitry

The frequency generator consists of a VXO, buffer amplifier and quadrature hybrid. It has a lot of parts: three transistors; a voltage regulator IC, a Zener diode, four toroids and many resistors and capacitors. There are no adjustments. You just build it and it works. The frequency stability is better than that of most commercial radios, even when portable.

There are simpler VXO circuits, but this one is excellent. It provides 0 dBm sine wave

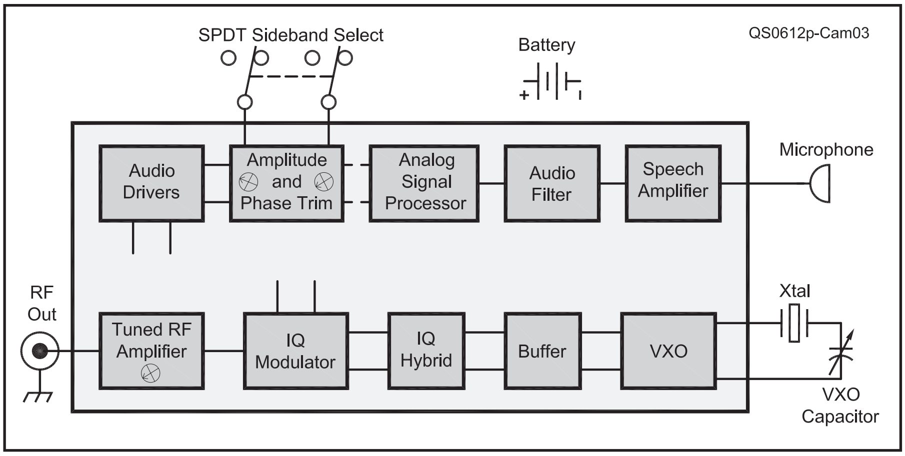

Fig 13.40 — Block diagram of the circuitry on the PC board.

output, draws 4 mA, and has virtually no start-up drift — about 2 Hz at 7 MHz. (It makes a lovely keyed CW generator too.) The three-resistor attenuator between the output of the VXO and input of the buffer amplifier is a convenient place to insert a frequency multiplier or externally generated VFO. Just leave off the top resistor to break the path. Note that the crystal and variable capacitor are mounted off the PC board. Frequency stability is determined by the temperature of the crystal. Slip a foam packing bead over the

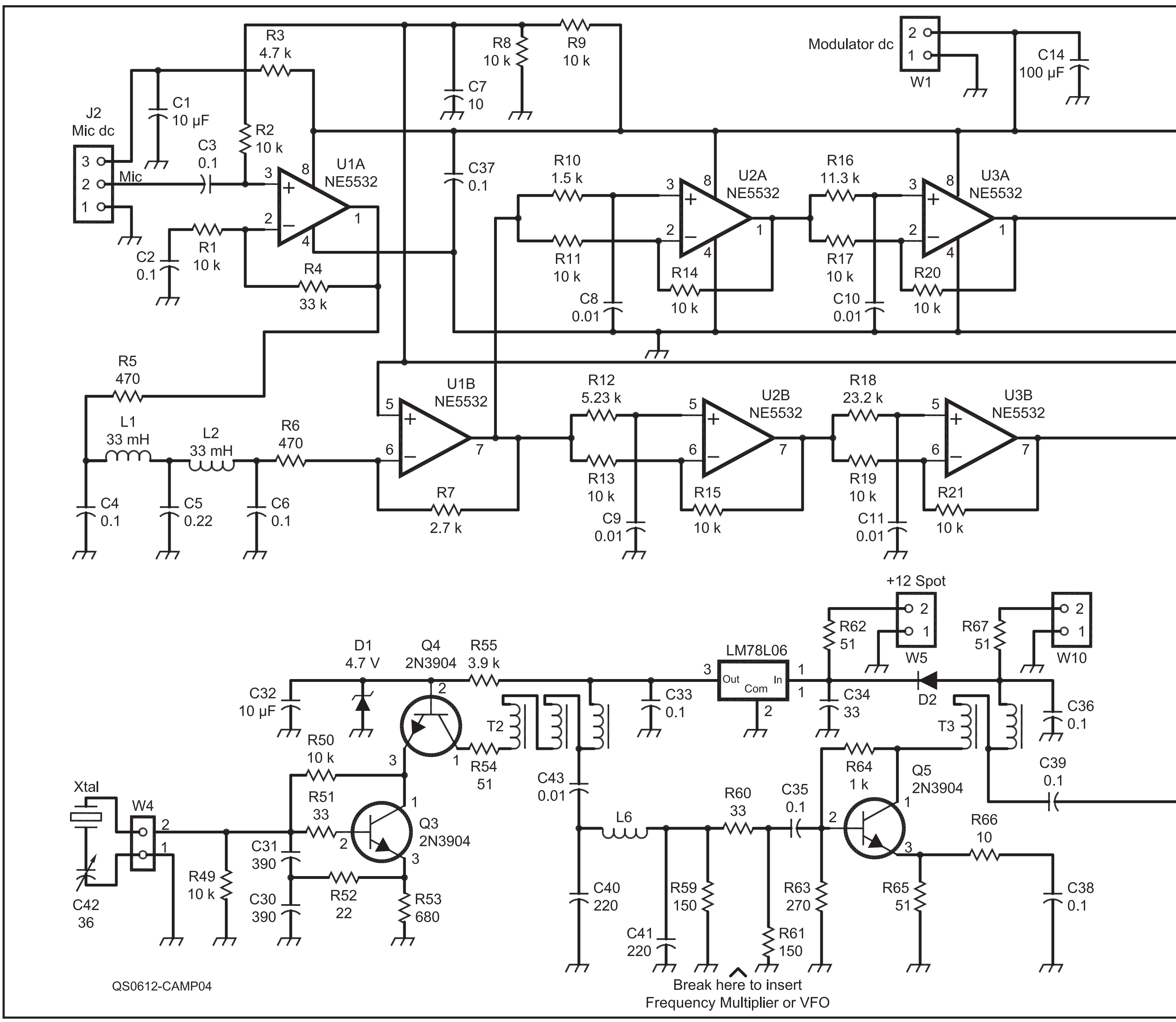

Fig 13.41 — Schematic diagram of the 40 meter version of the MicroT2. See Table 13.1 for parts values. A kit version including parts and PC board is available from Kanga US (www.kangaus.com).

crystal and support it by its leads between the PC board and VXO capacitor. A front-panel-mounted crystal socket looks very classy, but noise picked up by the crystal body gets into the oscillator, and the signal radiated by the crystal sounds like one with poor carrier suppression. If you use a crystal socket, put it inside the case or behind a shield door.

The buffer amplifier provides a 50 Ω source of broadband drive to the quadrature hybrid and isolates the frequency generator from impedance variations at the mixer local oscillator (LO) ports. The simple arrangement used in the MicroR2 receiver doesn't work here, because high-level audio into the diode ring mixers modulates not just the signal at the RF port, but the impedance at the LO and IF ports as well. Experiments confirm that a directly connected VFO experiences severe frequency pulling on voice peaks. The gain of the buffer is set to provide +7 dBm drive to each mixer with an input level of 0 dBm. It draws some current and the transistor gets a little warm — but only while transmitting.

The quadrature hybrid is a venerable circuit first described by Reed Fisher in *QST*.[11] It is the lumped element equivalent of a pair of tightly coupled quarter-wavelength transmission lines. The total capacitance does not need to be symmetrical between the two ends of the inductor, as is commonly shown. It may all be at one end or divided unequally. When driven from a 50 Ω source and terminated in a 51 Ω resistor and two mixer LO ports, the 90° phase difference is nearly perfect across a wide band and the amplitude difference between the two outputs is within 0.5 dB across a 10% bandwidth — more than enough bandwidth to cover the usual SSB portion of any amateur band.

A pair of Mini-Circuits TUF-3 mixers serves as the I and Q balanced modulators. These provide good carrier suppression without adjustment, and reasonable output at a modest distortion level. The carrier

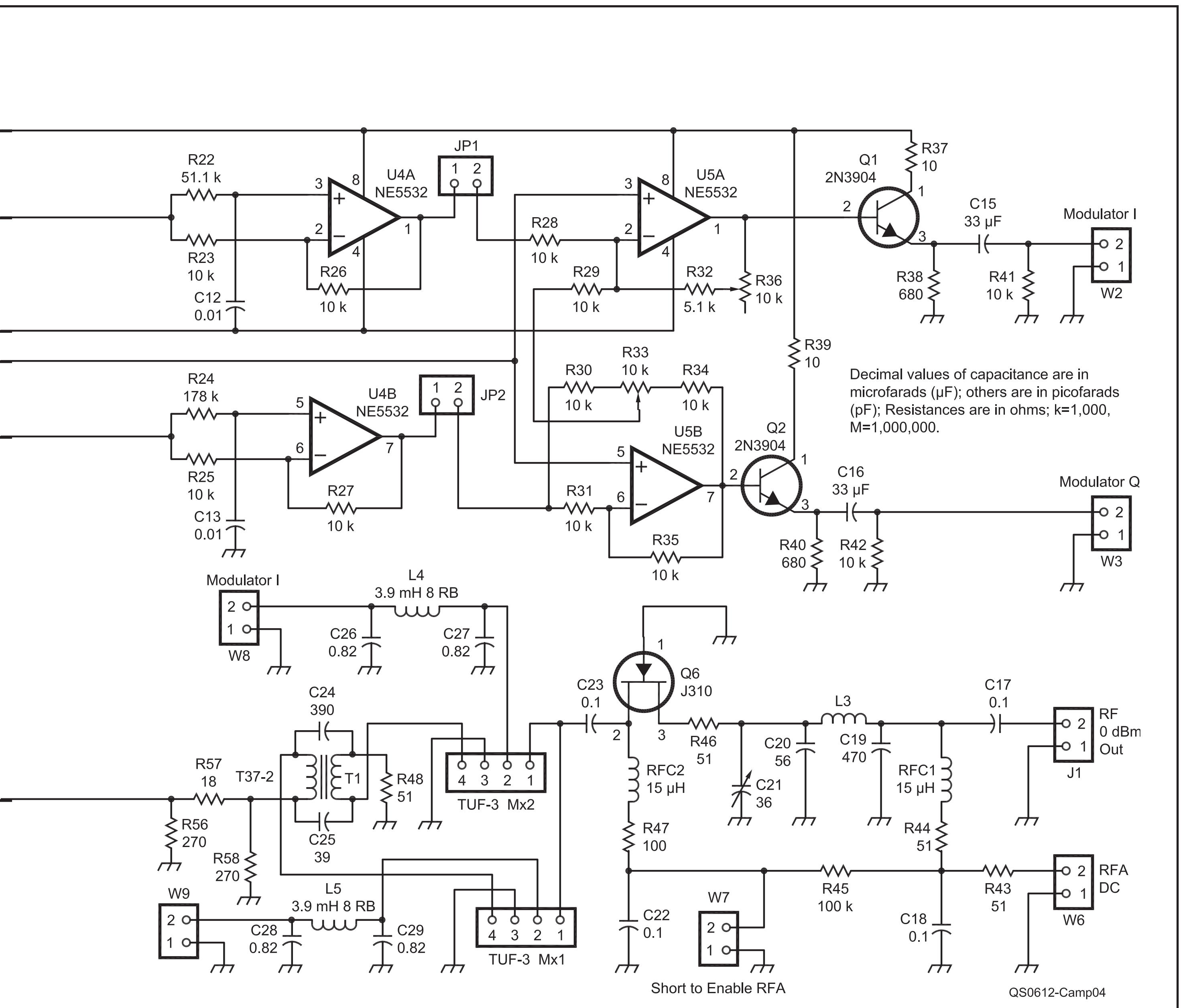

Table 13.1
MicroT2 Parts List

Parts for 40 meter version. See Note A.
C1, C7, C32, C34 — 10 µF, 16 V electrolytic capacitor.
C2-C4, C6, C17, C18, C22, C23, C33, C35-C39 — 0.1 µF, 5% polyester capacitor.
C5 — 0.22 µF, 5% polyester capacitor.
C8-C13 — 0.01 µF polyester capacitor, matched to 1%.
C14 — 100 µF, 16 V electrolytic capacitor.
C15, C16 — 33 µF, 16 V electrolytic capacitor.
C19 — 470 pF NP0 ceramic capacitor.
C20 — 56 pF NP0 ceramic capacitor.
C21 — 3-36 pF poly trimmer capacitor.
C24, C30, C31 — 390 pF, NP0 ceramic capacitor.
C25 — 39 pF, NP0 ceramic on back of board capacitor.
C26-C29 — 0.82 µF, 5% polyester capacitor.
C40, C41 — 220 pF, NP0 ceramic capacitor.
C42 — 36 pF, VXO variable off board capacitor; see Note C.
C43 — 0.01 µF ceramic capacitor.
D1 — 4.7 V Zener.
D2 — 1N4148 diode.
L1, L2 — 33 mH inductor.
L3 — 40 turns #30 enameled wire on T37-2 toroid core; see Note D.
L4, L5 — 3.9 mH inductor.
L6 — 22 turns #28 enameled wire on T30-2 toroid core; see Note D.
Mx1, Mx2 — Mini-Circuits TUF-3 diode ring mixer.
Q1-Q5 — 2N3904 transistor.
Q6 — J310 field effect transistor.
RFC1, RFC2 — 15 µH molded RF choke.
R1, R2, R8, R9, R28-R31, R34, R35, R41, R42, R49, R50 — 10 kΩ resistor.
R3 — 4.7 kΩ resistor.
R4 — 33 kΩ resistor.
R5, R6 — 470 Ω resistor.
R7 — 2.7 kΩ; audio gain select resistor; see Note E.
R10 — 1.5 kΩ, 1% resistor.
R11, R13-R15, R17, R19-R21, R23, R25-R27 — 10.0 kΩ, 1% resistor.
R12 — 5.23 kΩ, 1% resistor.
R16 — 11.3 kΩ, 1% resistor.
R18 — 23.2 kΩ, 1% resistor.
R22 — 51.1 kΩ, 1% resistor.
R24 — 178 kΩ, 1% resistor.
R32 — 5.1 kΩ resistor.
R33, R36 — 10 kΩ trimpot resistor.
R38, R40, R53 — 680 Ω resistor.
R37, R39, R66 — 10 Ω resistor.
R43, R44, R46, R48, R54, R62, R65, R67 — 51 Ω resistor.
R45 — 100 kΩ resistor.
R47 — 100 Ω resistor.
R51, R60 — 33 Ω resistor.
R52 — 22 Ω resistor.
R55 — 3.9 kΩ resistor.
R56, R58, R63 — 270 Ω resistor.
R57 — 18 Ω resistor.
R59, R61 — 150 Ω resistor.
R64 — 1 kΩ resistor.
T1 — 17 turns two colors #28 enameled wire bifilar wound on T37-2 toroid core; see Note D.
T2 — 5 turns #28 enameled wire trifilar wound on FT23-43 toroid core; see Note D.
T3 — 7 turns #28 enameled wire bifilar wound on FT23-43 toroid core; see Note D.
U1-U5 — NE5532 or equivalent dual low-noise high-output op-amp.
U6 — LM7806 or equivalent 6 V three terminal regulator.

Note A: C19, 20, 24, 25, 30, 31, 40, 41; L3, L6 and T1 values are for operation in the 40 meter band.
Note B: The total reactance of the parallel combination of C24 and C25 plus the capacitance between the windings of T1 is $-j50\ \Omega$ at the center of the tuning range. Placing most of the capacitance at one end is a different but equivalent arrangement of the quadrature hybrid we often use with equal capacitors. C25 is only needed if there is no standard value for C24 within a few percent of the required value. C25 is tack soldered to the pads provided on the back of the PC board, and may be a surface mount component if desired.
Note C: Capacitor C42 is the VXO tuning capacitor for the exciter.
Note D: L3, L6, and T1, T2 and T3 are listed as number of turns on the specified core rather than a specific inductance. For those who wish to study the design with a calculator, simulator and inductance meter, L3 should be about $+j300\ \Omega$ at 7.2 MHz, L6 should be $+j100\ \Omega$ at 7.2 MHz and each winding of T1 should be $j50\ \Omega$ at 7.2 MHz. T2 and T3 are noncritical broadband transformers with about 40 µH total inductance using the specified number of turns.
Note E: Resistor R7 sets the audio signal processor gain. If the gain is set too high, intermodulation distortion products generated in the diode ring modulators will be objectionable. Select R7 for a peak exciter output level no greater than 0 dBm.

suppression may be improved by soldering the metal cans of the TUF-3 mixers directly to the PC board ground. IM products in the opposite sideband are more than 30 dB down at the exciter output. The aggressive low-pass filtering right at the mixer IF ports prevents wideband noise and harmonic distortion in the audio stages from contributing to the I and Q modulation. Energy outside the modulation bandwidth is then just intermodulation distortion in the mixers and linear amplifiers. Sideband suppression will be more than 40 dB if the four 0.82 µF capacitors and two 3.9 mH inductors are matched to within 1%. The resultant carrier suppression is greater than 50 dB on any of the HF bands.

The exciter's output RF amplifier uses a common-gate JFET. This stage provides a broadband resistive termination to the mixer RF port IQ summing junction to isolate it from variations in impedance at the exciter output. The RF amplifier has relatively low gain, good harmonic suppression and a very clean 0 dBm SSB signal at the output. This is an appropriate level to drive a linear amplifier, balanced mixer or transverter. It is also a low enough level that it is easy to adjust the exciter with simple equipment. The exciter output signal meets FCC regulations for direct connection to an antenna for flea power experiments.

The transmitter shown here adds the simple two transistor circuit in **Fig 13.42** for 0.5 W PEP output. The seventh order Chebyshev low-pass filter on the output is noncritical and assures a clean signal that easily meets FCC regulations.

Audio Section

The top half of the PC board contains all of the audio circuitry. There are no PC board traces connecting the two halves, and it is okay to cut the board into separate functional blocks for packaging flexibility, or to use the audio and RF portions of the circuitry in other projects.

The speech amplifier drives a passive low-pass filter using two series inductors and three shunt capacitors. The combination of this low-pass filter and the mixer IF port filters limits speech frequencies to just over 3 kHz for natural sounding speech and good spectral purity. There is no ripple in the audio passband.

The position of the sideband select switch in the signal path allows switching without readjusting the amplitude and phase trimmers. For most applications, one sideband will be used exclusively, and the sideband switch may be replaced by a pair of jumpers on the PC board. If that results in the wrong sideband, reverse the connections between the audio driver transistors and mixers.

The I and Q Class A audio drivers are emitter followers directly driven by the amplitude and phase trim op-amps. Emitter followers were used successfully in the original T2 and work well.[12] An emitter follower can only source current, so it must be biased with more than the negative peak current required by the mixer IF ports.

Q1 and Q2 each have a quiescent current of more than 10 mA. For a receive application, a different approach would save operating

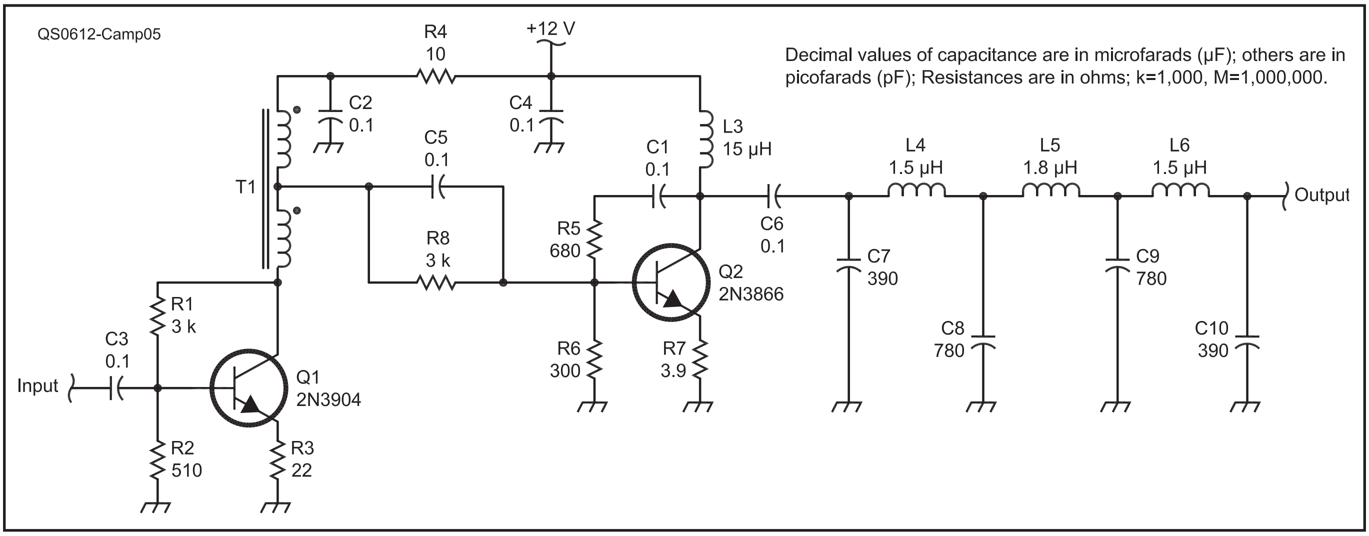

Fig 13.42 — Schematic diagram of 0.5 W power amplifier with low-pass filter shown in the photographs. T1 is 10 turns of #28 enameled wire bifilar wound on an FT37-43 toroid core.

current. Since the exciter draws only a fraction of the total transmitter current in most applications and is turned completely off during receive, use of clean Class A emitter followers to drive the mixer IF ports is a good trade-off. Another option is connecting the feedback resistor to the emitter rather than the base of each follower. A circuit simulator shows a tiny bit less distortion — but also some potential high frequency instability with that connection. This design sticks with the proven, conservative approach, and drops the distortion still further by burning a little more current in each of the transistors.

ADJUSTING THE SSB EXCITER

There are only three adjustments on the SSB generator PC board: RF AMPLIFIER TUNING, AMPLITUDE TRIM and PHASE TRIM. Each adjustment may be set once and then left alone. Adjust the SSB exciter by ear using a wideband audio noise source — such as a spare SSB receiver tuned to noise. Plug a cable into the "noise receiver" headphone jack and connect to the exciter microphone input, starting with the volume all the way down. With about 60 dB of attenuation on the RF output of the exciter, feed it directly into another receiver with selectable sidebands. Turn off the receiver AGC, if possible, and reduce the RF GAIN so that the peak exciter signal does not move the S-meter. Tune the receiver to zero beat on carrier leakage and then slowly turn up the volume on the noise source until the exciter noise output is a strong signal in the receiver.[13]

Switch back and forth between upper and lower sideband on the receiver and confirm that one sideband is much stronger than the other.[14] Switch to the desired sideband (if it is the wrong one, reverse the connections between the I and Q modulators and audio drivers) and peak the RF amplifier capacitor. Then switch to the opposite sideband and adjust the amplitude and phase trimpots for zero noise output. Alternate between the two trimpots, as these two adjustments become increasingly critical as each one approaches zero. Once adjusted, the energy in the opposite sideband will be more than 40 dB below the energy in the desired sideband. At that level, intermodulation products in the opposite sideband will dominate, and all you will hear are the familiar unintelligible pops and clicks on voice peaks common to any clean SSB signal driving a practical linear amplifier.

OTHER MODES WITH THE MICROT2

This exciter is very similar to the one in a 1958 Central Electronics 20A SSB exciter. If you look at the front panel of the 20A you see a mode switch marked USB, LSB, DSBsc, AM, NBPM, CW. The back of the switch has just a bunch of wires and resistors used to unbalance a modulator, turn off the I or Q audio channel, etc. We could get all of those modes out of this exciter, too, by inserting a switch in the wires connecting the I and Q modulator outputs to the I and Q mixer IF inputs.

Connecting either the I or Q signal path (but not both) will result in DSB. Connecting only the I (or Q) path and inserting a little carrier by connecting a 4.7 kΩ resistor from that side to the +12 V supply will generate AM. Connecting only the I path and inserting a 4.7 kΩ resistor from the Q mixer IF port to +12 V will generate narrowband phase modulation (NBPM). Disconnecting both the I and Q paths, or simply turning off the power to the AF section, and connecting 4.7 kΩ resistors from either or both mixer IF ports will generate CW. For CW, key both the voltage on the mixer IF ports and the RF amplifier enable line. **Fig 13.43** is a good circuit to accomplish this.

SO, HOW DOES IT SOUND?

Try evaluating SSB exciters this way: First, translate the frequency to some very quiet

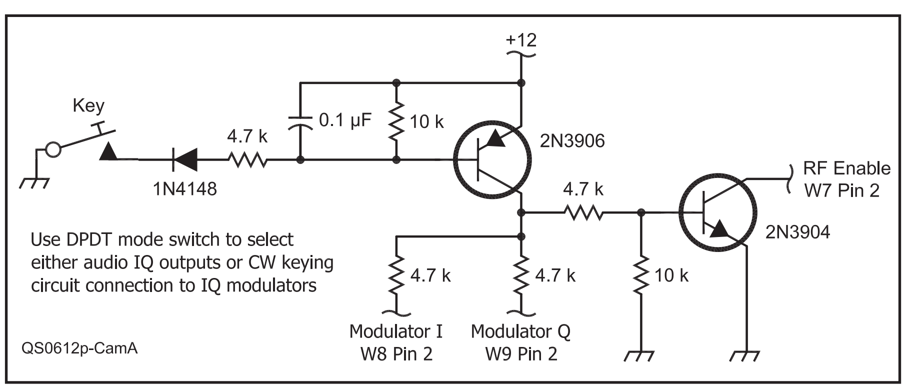

Fig 13.43 — Schematic diagram of suggested keying circuit.

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.