# CW Beacon Exciter for 50 MHz

By Michael Sapp, WA3TTS

A basic CW beacon exciter for the 50MHz amateur band is presented with an RF power output in the 400 milliwatt range. This project originated as a replacement for a local 50MHz beacon (W3HH/B) that had expired after many years of service in the EN90 grid square. For this new beacon, an emphasis was placed on using common components where possible and using a modular design which could be easy to maintain, repair, or upgrade. Careful attention was also made to meet and exceed FCC spurious emission requirements[1] with respect to minimizing higher-order harmonics and fundamental back wave suppression during key-up intervals. A remote control feature is also included for operating the beacon exciter in an unattended manner as required by FCC regulations[2].

Although this 50MHz CW beacon exciter can be used to drive a suitable power amplifier for higher power levels, the nature of the 6M amateur band is such that signal reports from rather remarkable distances can be received from other amateur and SWL stations using only this exciter by feeding the RF output into an omnidirectional antenna with a low loss coaxial transmission line. Of course, an optimal antenna location and height will yield improved results. Yet, a strong E-layer ionospheric band opening can yield surprising results even with a modest antenna. (More on this subject later in this article).

Below is a block level diagram of the basic 50MHz CW Beacon Exciter which is laid out with a separate "RF Section" and "Control, Keying, Audio & DC Power Section."

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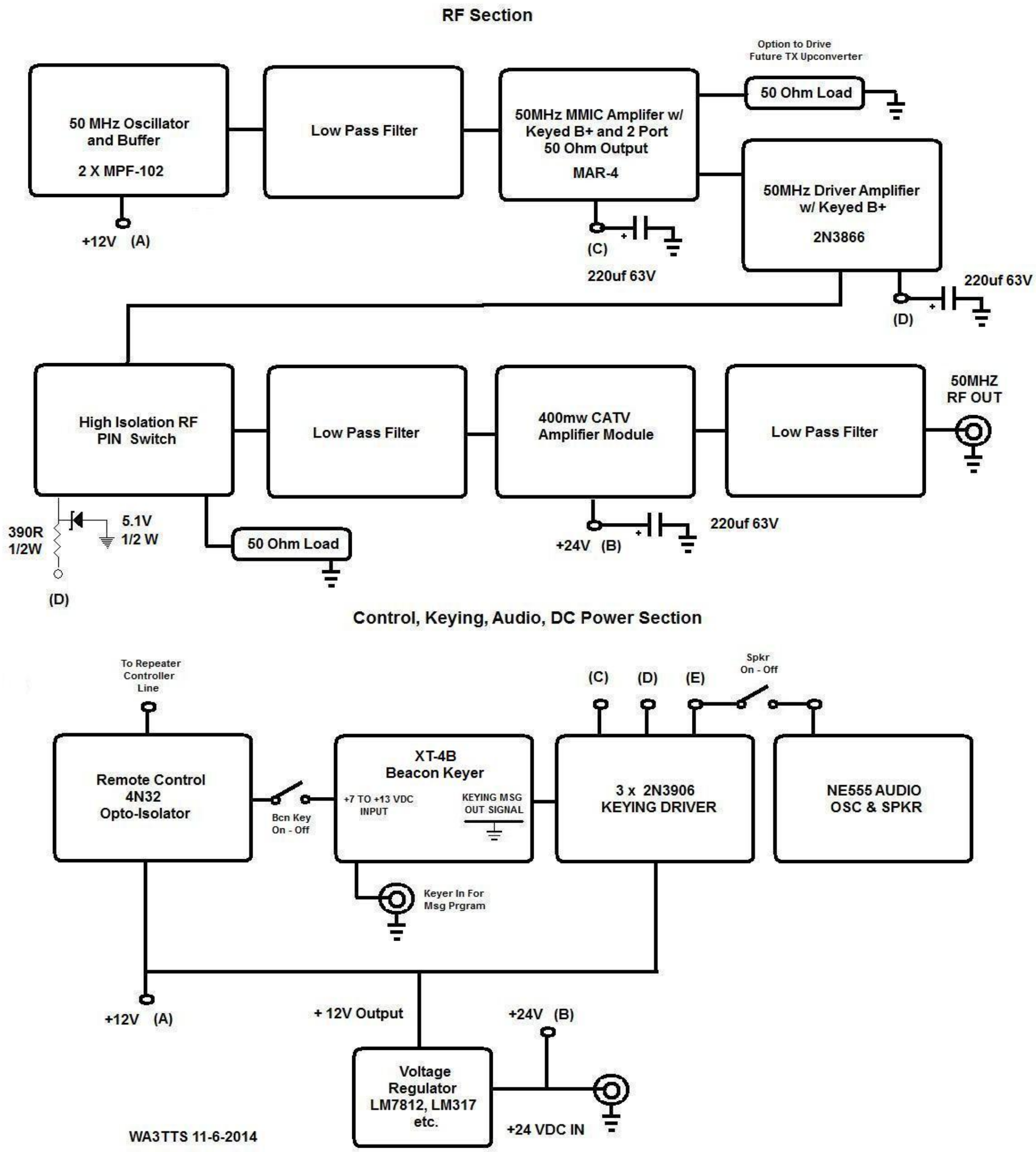
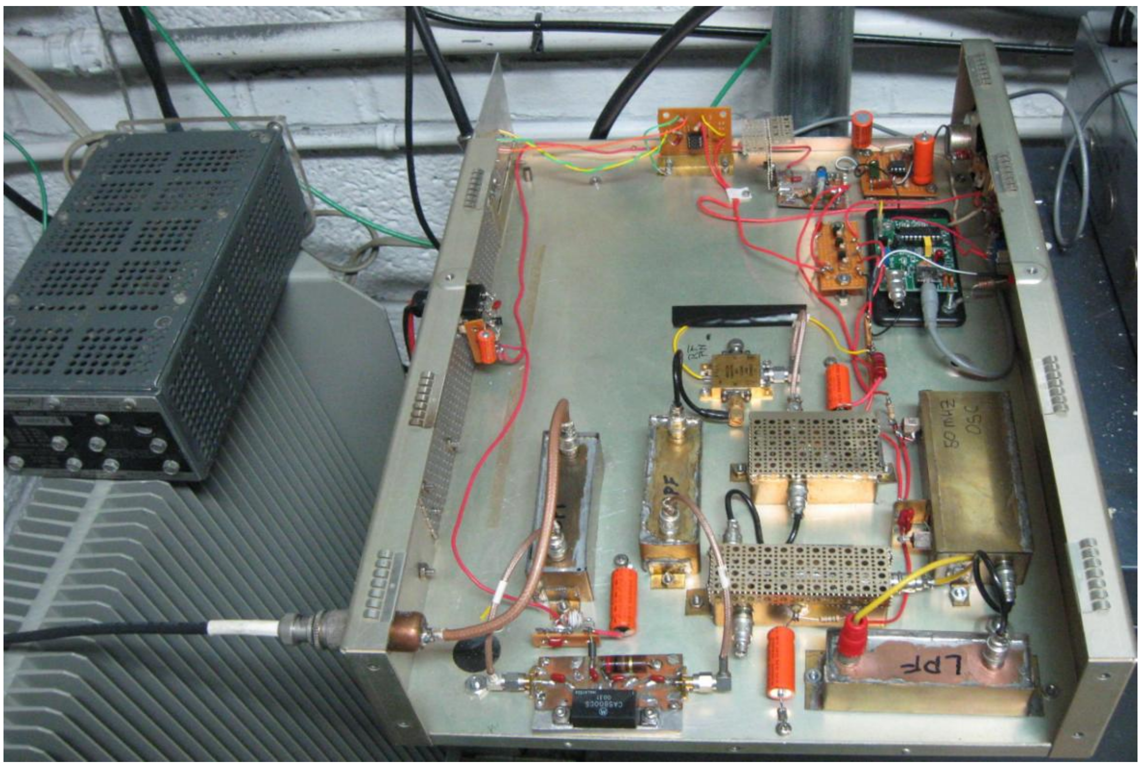
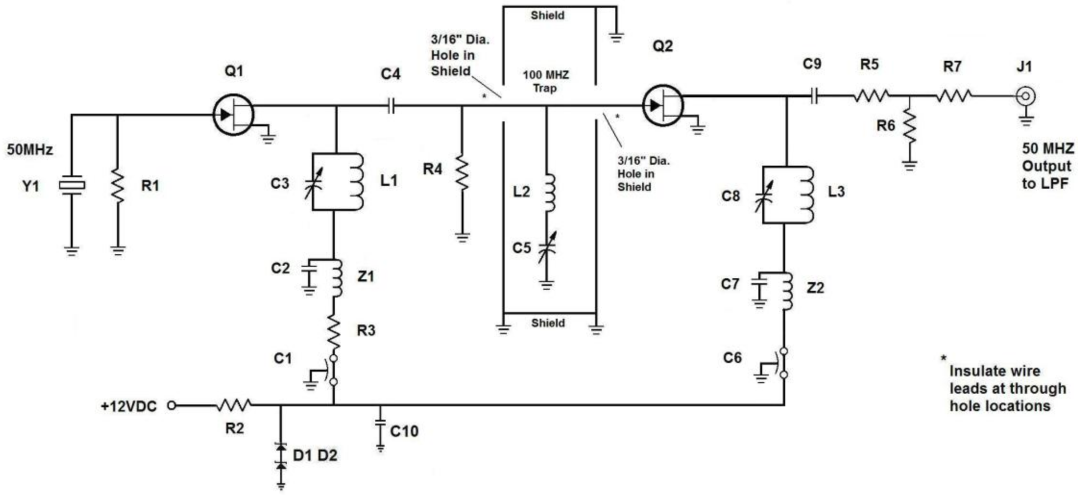
[1] FCC § 97.307 Emission Standards, (c), (e)
[2] FCC § 97.203 Beacon Station, (d)




This 50MHz CW Beacon Exciter was built in a surplus telecommunication equipment cabinet that was located on e-bay at an affordable cost. The cabinet is large enough to allow for upgrades or changes should any module require replacement or future additions considered. For example, the dual 50 ohm output from the MAR-4 amplifier module could be used to drive another transmitting upconverter from the second MAR-4 output port for multi-band beacon operation. A 9th order Chebychev low pass filter (LPF) before the MAR-4 amplifier stage provides excellent harmonic filtering to allow a clean 50MHz output from the MAR-4 amplifier stage to drive a future transmitting upconverter for a band of one's choice. Since this port is not currently in use, it is terminated into a 50 ohm non-inductive resistor that is soldered into the 2nd MAR-4 output connector. Phono plugs were used to lower connector costs for this project. (See 50MHz beacon photo below.)




50 MHz Oscillator & Buffer, Detail & Parts List.




Parts List

| | | | |
|---|---|---|---|
| Y1 | 50.06 to 50.08 MHz 3rd-overtone crystal | R1, R4 | 100K 1/4W. |
| Q1, Q2 | MPF-102. | R2, R6 | 150 ohms 1/4W. |
| D1, D2 | 5.1V Zener diode, 1/2W. | R3 | 100 ohms 1/4W. |
| C1, C6 | 0.001uF feedthrough (1000pF). | R5, R7 | 10 ohms 1/4W. |
| C2, C7 | 0.001uF, 50V polyester film capacitor. | C4 | 5 pF, 50V silver mica. |
| C3, C8 | 10 - 60 pF ceramic trimmer capacitor. | C9 | 22pF, 50V silver mica. |
| C5 | 1 - 20 pF ceramic trimmer capacitor. | C10 | 0.1uF, 50V poly film. |
| Z1, Z2 | 100uH (or more) 1/2W molded inductor. | J1 | 50 ohm BNC Female. |

L1, L3 220nH (0.22uH) 5T #24 enamel wire, close wound on .25" drill bit shaft, with 1/2" leads. Scrape enamel from 1/2" of the wire leads nearest to coil on drill bit shaft. Bend leads at right angle to coil. Remove coil from drill bit shaft and cut leads to 1/2" length. Lightly pull on the coil's 1/2 inch long leads until the 5 coil turns are slightly separated and 0.25" long. Check and adjust coil value on antenna analyzer at 50MHz in Inductance measuring mode. Trim coil leads as required after soldering into circuit. Check and readjust coil length.

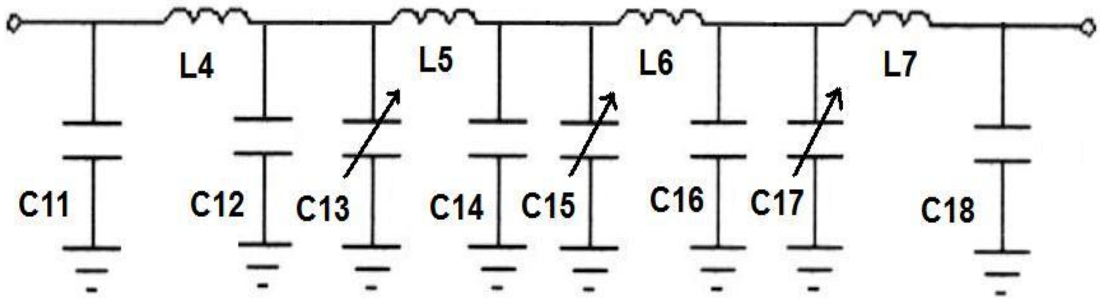
L2 260nH (.260uH) 5T #24 Enamel Wire Close Wound, 1/2" leads. Scrape enamel from 1/2" of the wire leads nearest to coil on drill bit shaft. Bend leads at right angle to coil. Remove coil from drill bit shaft and cut leads to 1/2" length. Check and adjust coil value on antenna analyzer at 50MHz in Inductance measuring mode. Check and readjust close-wound coil turns.

Shield: 015" or .025" T x 3/4" W K&S Metals Brass Strip #8233 or #8238.

Data Sheets & References

www.daycounter.com/Calculators/LC-Resonance-Calculator.phtml
www.pronine.ca/coilcal.htm
www.fairchildsemi.com/datasheets/MP/MPF102.pdf
www.icmfg.com/order_crystals.html

## 50 MHz Low Pass Filter & Parts List.




Note: Preset and ink "dot" mark position of C13 and C15 at 4pF.  Preset and ink "dot" mark C15 at 34pF. C15 tuning will have the greatest effect on return loss (SWR).
Parts List x 3 (Build 3 of these filters)

| | |
|---|---|
| C11, C18 | 100pF 100V silver mica |
| C13, C17 | 1-10pF ceramic trimmer |
| C12, C14, C16 | 150pF 100V silver mica |
| C15 | 10-60pF ceramic trimmer. |

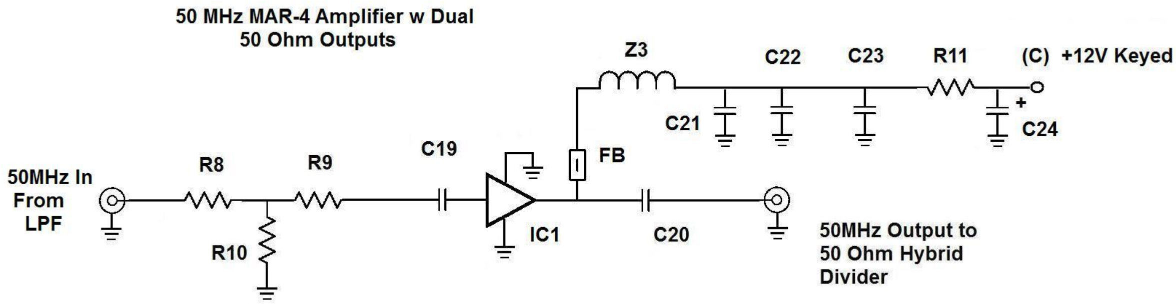
L4 , L7  184nH (.184uH)   4T #24 enamel wire wound on 0.25" drill bit shaft, close wound with 1/2" long leads.  Scrape enamel from 1/2" of the wire leads nearest to coil on the drill bit shaft. Bend coil leads at right angles to coil and cut leads to 1/2" length. Then remove coil from drill bit.  Then lightly pull or compress the coil's leads until the 4 coil turns are separated and the coil is .310"  long. Check and adjust coil value on antenna analyzer at 50 MHz. Trim coil leads as required after soldering into circuit.  Check and readjust coil length.

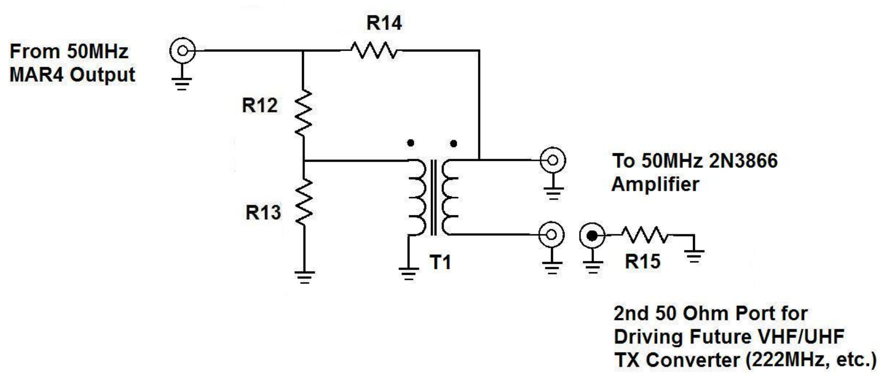
L5, L6   198nH (.198uH)  5T #24 enamel wire wound on 0.25" drill bit shaft, close wound with 1/2" long leads. Scrape enamel from 1/2" of the wire leads nearest to coil on the drill bit shaft. Bend coil leads at right angles to coil and cut leads to 1/2" length. Then remove coil from drill bit.  Then lightly pull or compress the coil's leads until the 4 coil turns are separated and the coil is .475" long. Check and adjust coil value on antenna analyzer at 50MHz in Inductance measuring mode. Trim coil leads as required when soldering into circuit. Check and readjust coil length.

Data Sheets & References

www.pronine.ca/cheblf1.htm
www.aade.com/filter.htm

## 50MHz  MAR-4 Amplifier, Details & Parts List




Parts List

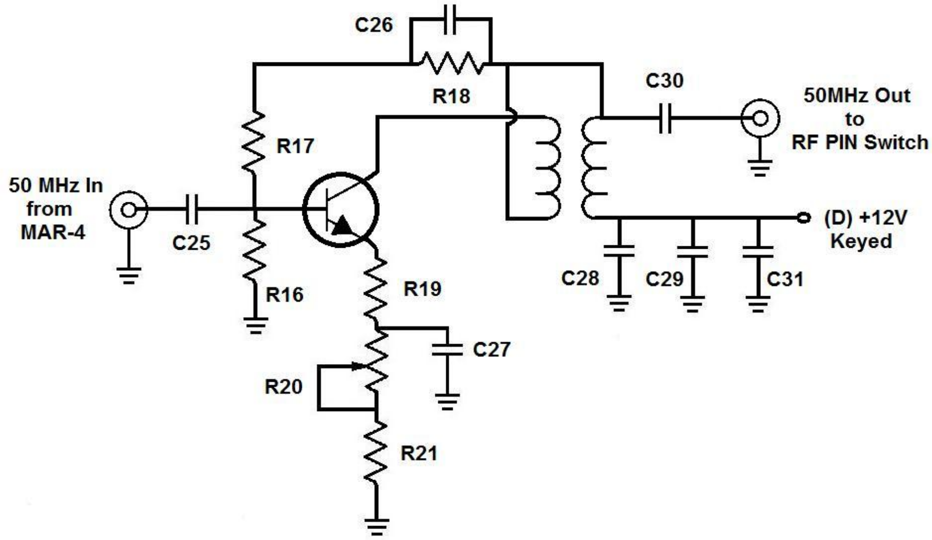
| | | | |
|---|---|---|---|
| R8, R9 | 10 Ohms 1/4W. | C19, C20, C21 | 0.001µF, 50V poly film. |
| R10, R11 | 150 Ohms 1/4W. | C22 | 0.01µF, 50V poly film. |
| R12, R13, R14, R15 50 Ohms 1/4W (R12-R15 can be pairs of 100 Ohm 1/4W resistors in parallel). | | C23 | 0.1uF, 50V poly film. |
| | | C24 | 220µF, 35V electrolytic. |
| IC1 | MAR 4 MMIC or equiv. | FB | T61 Ferrite bead. |
| T1 10T Bifilar #30 Wire on FT61-50 toroid. | | Z3 | 100uH 1/2W molded inductor. |

Data Sheet & Reference

www.minicircuits.com/pdfs/MAR-4+.pdf

"A Hybrid Combiner for Signal Generators," 1989 ARRL Handbook, Test Equipment & Measurements, 25-36.

## 50MHz 2N3866 Driver Amplifier and Parts List




Parts List

| | | | |
|---|---|---|---|
| C25, C30 | 0.001µF, 50V silver mica. | C29 | 1µF 35V tantalum. |
| C26, C27, C28 | 0.01µF 50V polyester film. | C31 | 220uF 35V electrolytic. |
| R16 | 1K ohms 1/4W. | R17 | 560 ohms 1/4W. |
| R18 | 3.3K ohms 1/4W. | | |
| R19, R21 | 4.7 ohms 1/2W (or two 10 ohm 1/4W resistors in parallel). | | |
| R20 | 100 ohm 15T 3/4W Cermet potentiometer (Bourns 3006P-101LF or equiv.) | | |

T2 10T Bifilar #30 wire on a FT61-50 toroid core.

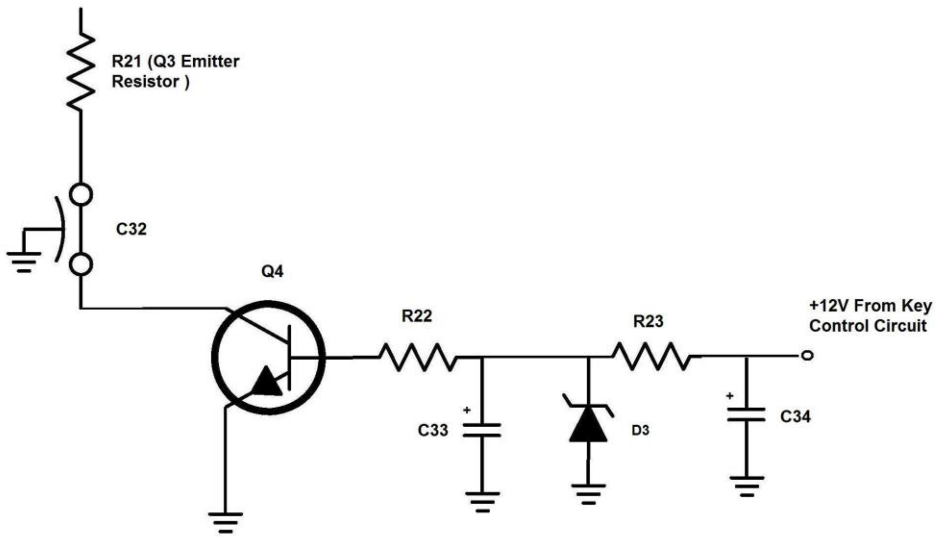
Q3 2N3866.
Q3 TO-5 heat sink (not shown).

Data Sheet & Reference

pdf1.alldatasheet.com/datasheet-pdf/view/15076/PHILIPS/2N3866.html
www.dxzone.com/dx21535/w7iuv-hf-preamplifier.html

"Three Watt Transmitting Converter for 6 Meters," 1989 ARRL Handbook, VHF Radio Equipment, 31-13.

50MHz 2N3866 Emitter Keying Option, Detail and Parts List




Parts List

C32 1000pF (0.001µF) 50V (or more) feed-through capacitor.
C33 100µF. 10V electrolytic.
C34 100µF. 35V electrolytic.

R22 1K 1/4W resistor.
R23 2.2K 1/4W resistor.

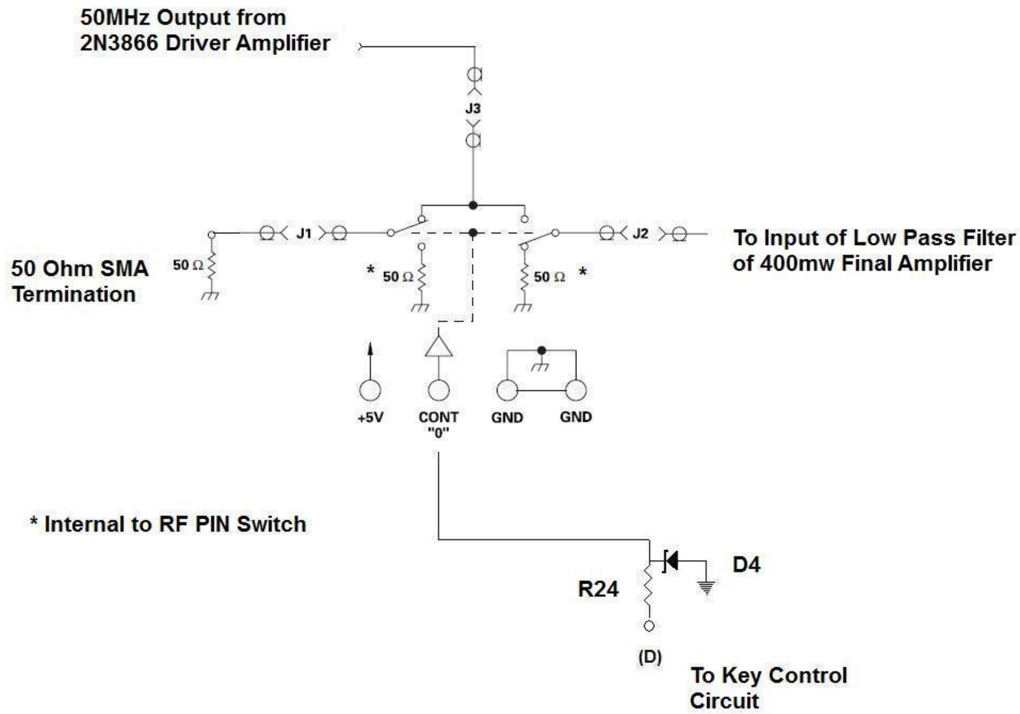
Q4 2N2222 NPN transistor.

D3 5.1V 1/2w Zener diode.

Data Sheet & Reference

www.sm5bsz.com/txmod/rt0282eng.htm

RF PIN Switch Detail & Parts List.




Parts List

RF PIN Switch Daico 0622 or Mini-Circuits ZSDR-230, SPDT and TTL control type.

50 ohm SMA termination.

R24 390 ohm 1/2W resistor.

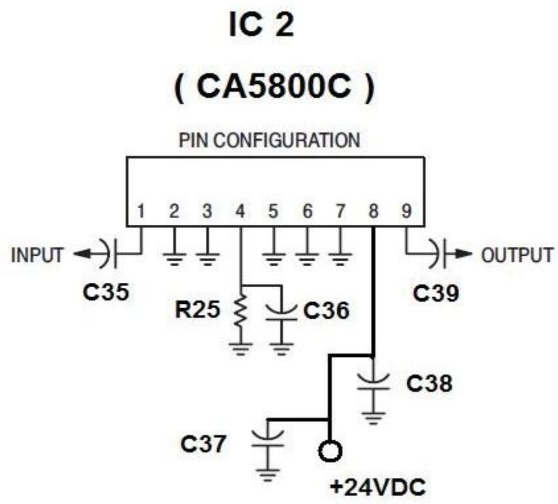
D4 5.1V 1/2W Zener diode.

SMA Jumper cables (2) for RF connections.

Data Sheet & Reference

pdf1.alldatasheet.com/datasheet-pdf/view/140517/DAICO/CDS0622.html

## Final Amplifier Module Detail & Parts List




Parts List

| | |
|---|---|
| C35, C39 | 0.001μF (1000pF) 50V silver mica. |
| C36, C38 | 0.1μF, 50V polyester film. |
| C37 | 220μF, 63V electrolytic. |

R25 200 ohm 1W (or 90 ohms 3W). See text.

RF Connectors (2) SMA or BNC female chassis mount.

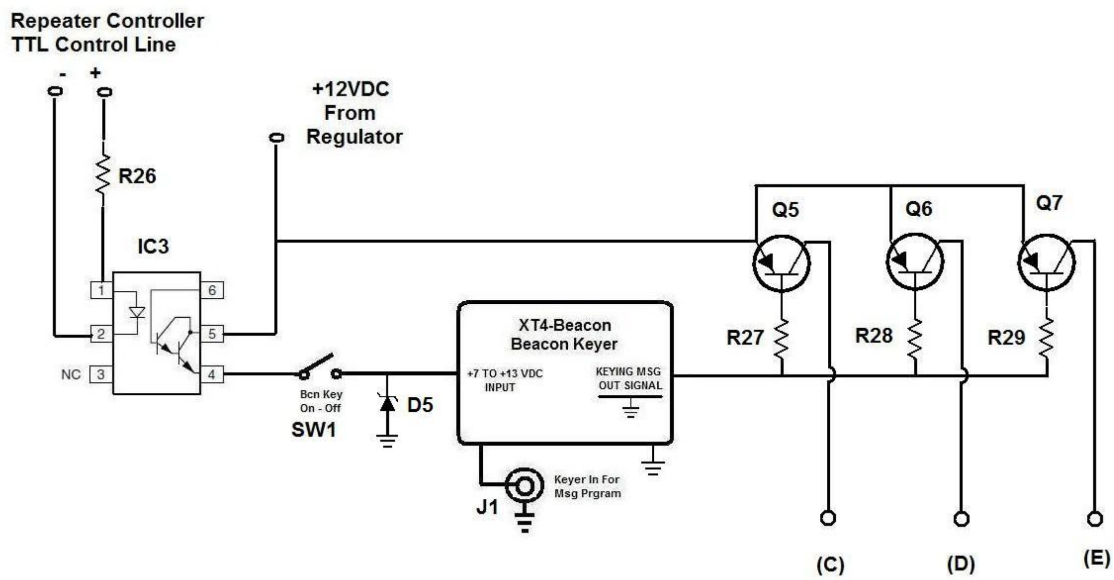
IC2 Motorola CA5800C 1W wide band linear amplifier module.

Data Sheet & Reference

www.freescale.com/files/rf_if/doc/inactive/CA5800C.pdf

Motorola RF Device Data Volume II, Fifth Edition, 1988.

## 50MHz Beacon Keying Control




Parts List

| | | | |
|---|---|---|---|
| R26 | 1K 1/2W. | SW1 | SPST low volt & current switch. |
| R27, R28, R29 | 4.7K 1/2W. | J1 | 1/8" stereo jack. |

IC 3 4N32 or 4N33 optoisolator. D5 12V 1/2W Zener diode.

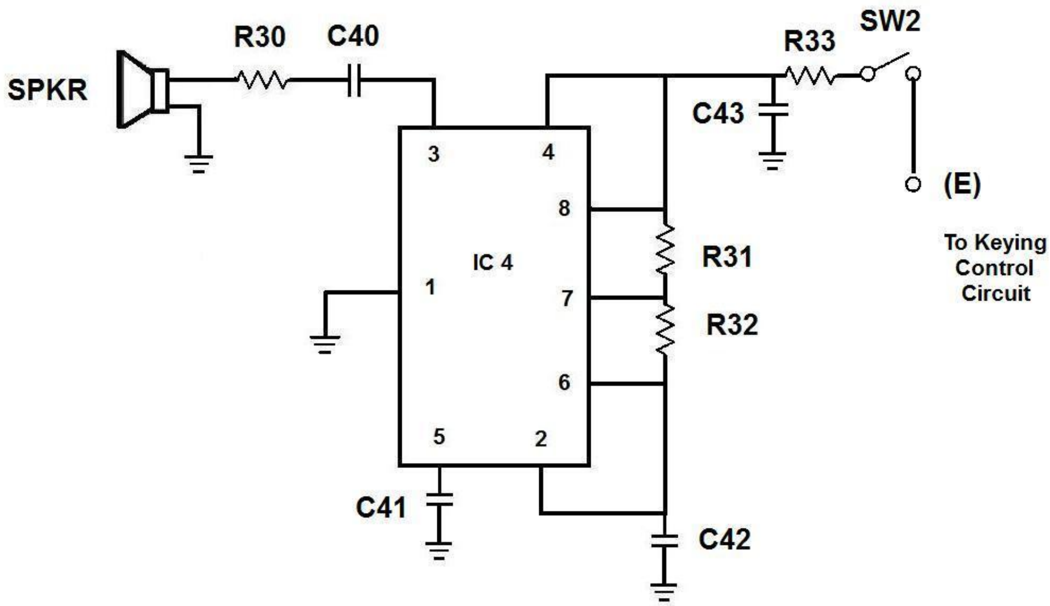
Q5, Q6, Q7 2N3906 PNP transistor.

XT-4B Beacon Keyer Module (www.unifiedmicro.com)

Data Sheet & Reference

www.vishay.com/docs/81865/4n32.pdf

555 Message Audio, Detail & Parts List.




Parts List

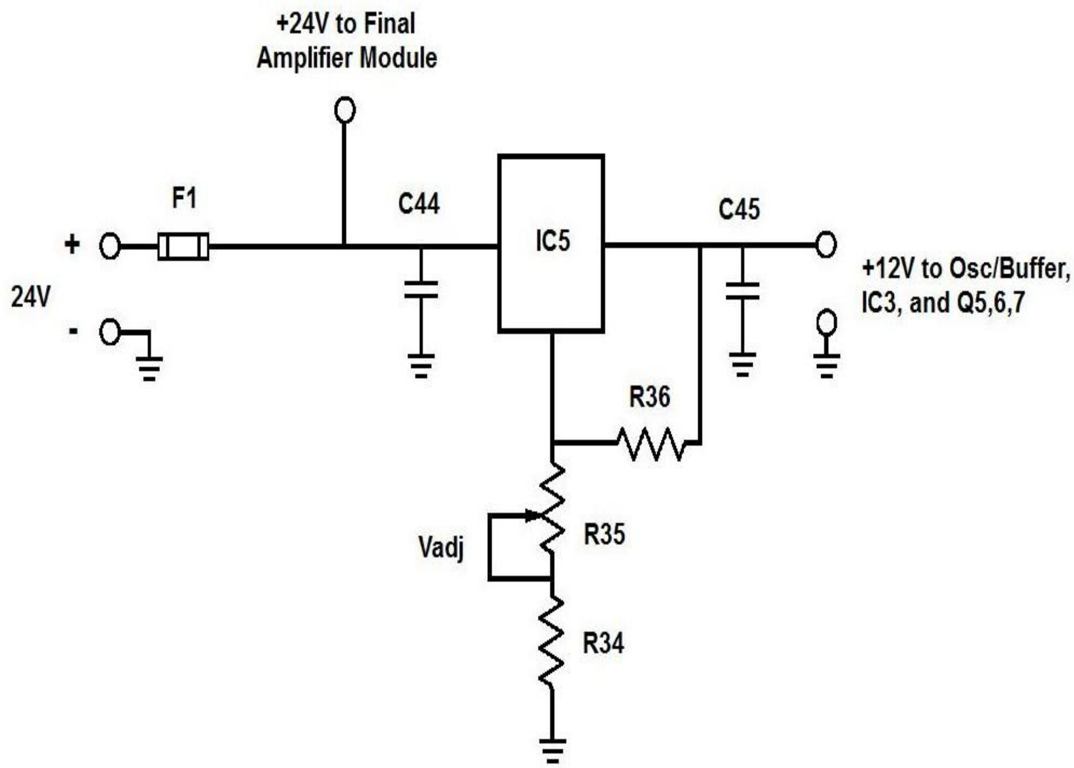
| | | | |
|---|---|---|---|
| C40 | 220µF, 35V electrolytic. | C41, C42 | 0.01µF. 50V poly film. |
| C43 | 22µF, 35V electrolytic. | | |
| R30 | 47 ohms 1/4W. | R33 | 10 ohms 1/2W. |
| R31, R32 | 15K ohm 1/4W . | | |
| IC4 | LM555. | SPKR | Small 8 Ohm speaker. |
| SW2 | SPST low current & voltage switch. | | |

Data Sheet & Reference

www.fairchildsemi.com/datasheets/LM/LM555.pdf
www.ti.com/lit/ds/symlink/ne555.pdf

"A High Performance Audio Communication System," UHF and Microwave Equipment, p32-60, 1988 ARRL Handbook.

Voltage Regulator, Detail & Parts List.




Parts List

| | | | |
|---|---|---|---|
| F1 | 2A fuse. | IC5 | LM317, adjustable voltage regulator. |
| C44 | 0.1µF, 50V poly film. | C45 | 1µF, 35V tantalum capacitor. |
| R34 | 1200 ohms 1/2W. | R35 | 1K ohm 3/4W 15T Cermet pot, 3/4W |
| R36 | 220 ohms 1/2W. | | (Bourns 3009P-1-102LF, etc.) |

IC5 Heat sink or mount kit (Not Shown)

Data Sheet & Reference

www.fairchildsemi.com/datasheets/LM/LM317.pdf

## Construction Notes

### Oscillator and Buffer Amplifier

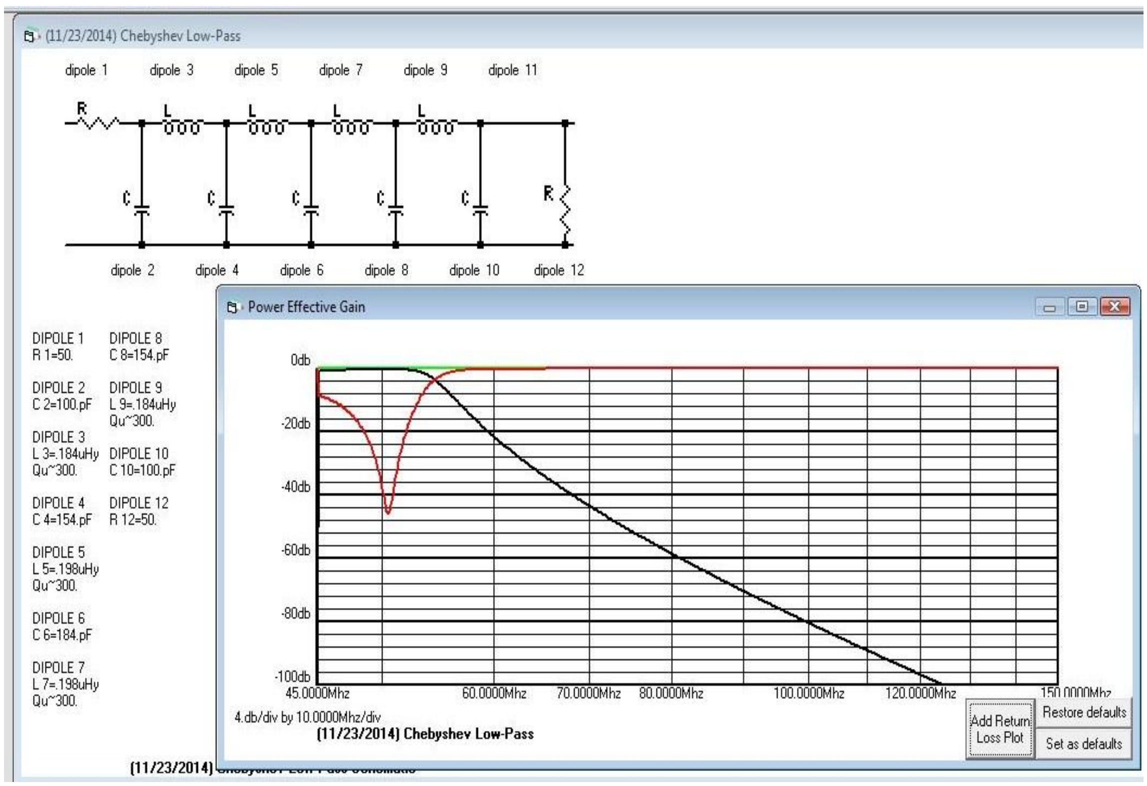
A simple MPF-102  overtone oscillator was used from the 1971 *ARRL Handbook* receiver project[3]. A 5pF output coupling capacitor was used to minimize oscillator loading interaction with the MPF-102 buffer amplifier stage. A 100Mhz shunt LC circuit is used to reduce the second harmonic of the 50MHz oscillator.  The buffer amplifier simply voltage-drives the 3dB T-attenuator pad with no attempt at RF impedance matching at the amplifier output, similar to the design philosophy found in active "Gilbert Cell" mixers (MC1496, NE602, etc.)  A brass sheet shielded-section isolates the 100 MHz shunt filter and further isolates the oscillator from the buffer amplifier.  Construction is dead-bug style on an FR4 ground plane and 3/4" wide by .025" brass strips form the enclosure side walls (K&S Metals #8233, etc.)

### Low Pass Filter

A 50 ohm, in-out, 9th-order, Chebychev low pass filter is used after the oscillator and buffer stage as well as for the input and output of the final amplifier module. C15 will have the greatest effect on the filter's return loss (SWR). The filter can be tuned with an antenna analyzer feeding the filter input port and the output port terminated in 50 ohms. Another approach with an antenna analyzer is to use a 10 or 20 dB pad on the filter output with the attenuator feeding a frequency counter equipped with a relative level indicator. With this method, tune for the best return loss (SWR) that is consistent with

[3] "A Receiving Package For 1.8 to 144 MHz," 1971 ARRL Handbook, p142 - 148.

maximum signal throughput to the frequency counter (or other power level monitoring instrument). Mark each filter input and output after tuning, as this simple approach to filter tuning is not likely to result in bi-directional filter performance. A plot of the LPF using the AADE filter software is shown below:




MAR-4 With Dual 50 Ohm Output.

This stage was originally used with the intention of using the 50 MHz signal to also drive a 50 to 222 MHz transmit converter for a multi-band beacon project. If one is only building the 50MHz beacon, the power divider can be omitted and some additional attenuation used on the input-output of the prior LPF stage to make up the 6dB power reduction of the power divider. One could also substitute a 2N3866 gain stage for the MAR4 amplifier and adjust the gain accordingly.  Also note that the MAR-4 data sheet includes a B+ resistor (R11) value guide for device operation at various B+ levels.

## 50 MHz 2N3866 Driver Amplifier

The 2N3866 Driver Amplifier was salvaged from the prior EN90 beacon. To save time, it was not converted to emitter keying and the B+ was keyed along with a 220uf capacitor to limit key clicks from the B+ switching.   A better approach to this stage would be the well-known W7IUV HF Receiver Preamplifier[4] operated at 40 to 50 milliwatts of output power at 50MHz.  The usual FT-43 core for HF operation of the W7IUV preamplifier would have to be replaced with a Type 61 core for the higher 50MHz frequency range and the emitter resistor adjusted for the desired output level.  A RF milliwatt termination meter, such as a Bird 6250, is very useful for this purpose.

It is interesting to note that the "Three Watt Transmitting Converter for 6 Meters" in the 1988 ARRL Handbook uses an essentially identical set of W7IUV type amplifier stages as RF drivers for it's final amplifier along with a Type 61 ferrite transformer core[5].  One can also emitter-key the 50MHz  2N3866 driver amplifier with an NPN transistor (2N2222, etc.) to take advantage of the key-up bias cutoff condition as an alternative to using an RF PIN switch.

## RF PIN Switch

With the 400mW amplifier stage and filters constructed, I still had some back wave that was noticeable during beacon keying.  This condition was from

[4] W7IUV Preamp, http://www.w7iuv.com/
[5] "Three Watt Transmitting Converter for 6 Meters," VHF Radio Equipment 31-15, Figure 37, 1988 ARRL Handbook.

using the existing 2N3866 amplifier stage from the old W3HH beacon that had no emitter keying provision.   Rather than add emitter keying to the existing amplifier stage, a "quick fix" was to use an RF PIN switch between the driver and the final amplifier stage.  I had a few commercial RF PIN switches on hand, so they provided a quick way to obtain the desired CW back wave suppression without the use of emitter keying. For this project, there was a desire to get the beacon on the air as soon as possible, so the RF PIN switch provided a convenient solution versus modifying or building a new emitter-keyed 50MHz driver amplifier stage.

The SPDT RF PIN switch used was a Daico CDS0622 TTL driver type with internal 50 ohm terminations. These devices can be found on e-bay in the $30~$40 range. Cost wise, they are similar to that of a surplus SMA relay and can offer up to 60dB of port isolation. Check the data sheet carefully for isolation versus  frequency performance.  Another alternative SPDT RF PIN TTL switch commonly available is the Mini-Circuits ZSDR-230 which can also be found in a similar "used-surplus" price range.  (Note: Emitter keying of the  2N3866 driver stage could eliminate the need for the RF PIN switch.  The RF PIN Switch can be a useful option if an amplifier gain stage is already available, but not practical to modify for emitter keying.)

50MHz Final Amplifier

The final amplifier is a Motorola CA5800C designed for wide band operation from 10MHz to 1GHz with B+ voltages to 28V. Output power is 400mw typical (800mw PEP) at the 1dB compression point. These devices are still available "new-old-stock" on the surplus market in the $10 range, making it an economical choice. An "old" data sheet I had on had specified a 200 ohm 1W resistor from Pin 4 of the CA5800C to ground, However, newer data sheets specify a 90 ohm 3 watt resistor from Pin 4 to ground. It is important not to overdrive the final amplifier, so increase the 2N3866 stage gain slowly until the CA5800C amplifier output saturates, then reduce the drive level by a dB or more. Use adequate heat sinking. For example, I mounted the final amplifier board and CA5800C to a 0.25" thick aluminum plate, which was then bolted to the enclosure chassis. The amplifier module should run warm to the touch, but not hot to the touch.

Keying Control

An XT-4B Beacon Keyer module from Unified Microsystems is used for generating the CW beacon message. This CW message module requires +7 to +13 volts DC operating power at 5ma. The low current and voltage requirements allow a the use of a 4N32 or 4N33 opto-isolator IC as a simple remote control means for interfacing with a repeater controller for unattended beacon operation. Zener diode D5 was included as a reminder of the XT-4B's voltage requirements. If one decides to operate the 2N3866 50MHz driver stage at higher voltage by turning up the LM317 regulator output, keep in mind the XT-4B's DC voltage limits.

### 555 Timer Message Audio

A simple code practice oscillator can be used with the keying control circuit for occasions when one desires to reprogram the CW message. It is more convenient to have this feature than to remove and replace the XT-4B Beacon Keyer for each message change.

### LM317 Voltage Regulator

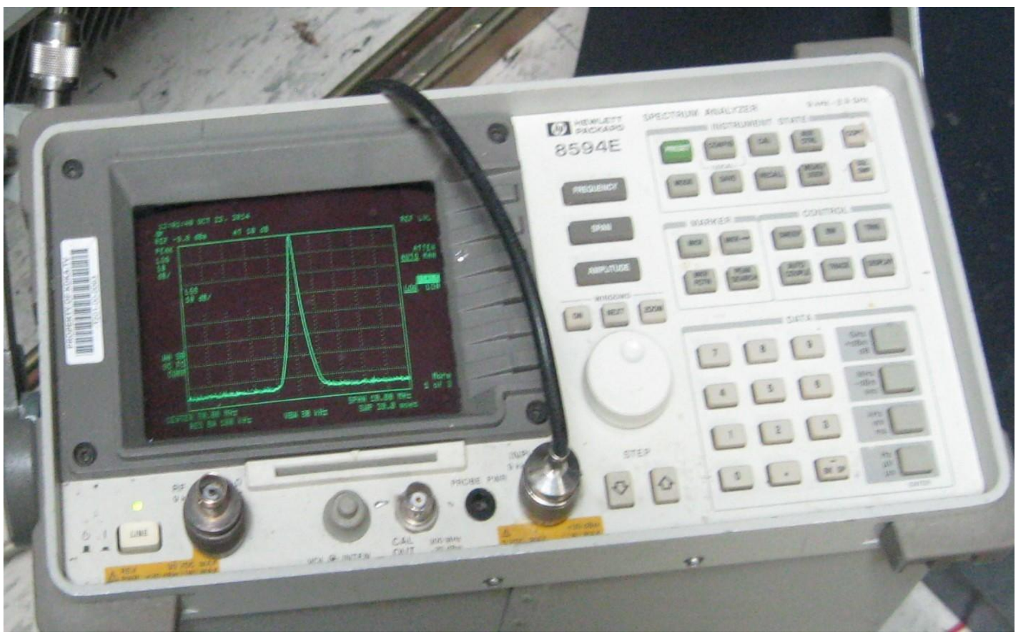
The LM317 provides an adjustable voltage level for the various beacon stages, which are individually Zener regulated to lower voltages where needed.

### 50MHz CW Beacon Performance Measurements

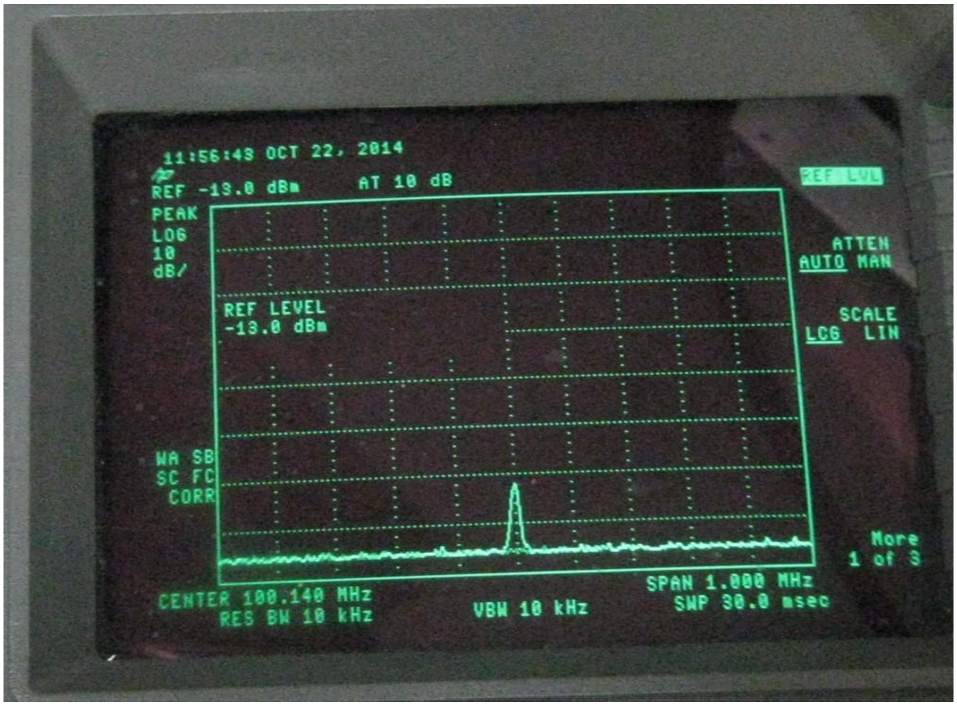
FCC Part §97.307 Emission Standards, (e) states: "The mean power of any spurious emission from a station transmitter or external RF power amplifier transmitting on a frequency between 30-225 MHz must be at least 60 dB below the mean power of the fundamental. For a transmitter having a mean power of 25 W or less, the mean power of any spurious emission supplied to the antenna transmission line must not exceed 25 µW and must be at least 40 dB below the mean power of the fundamental emission, but need not be reduced below the power of 10 µW. A transmitter built before April 15, 1977, or first marketed before January 1, 1978, is exempt from this requirement."

Applying these FCC requirements to this 400mW 50MHz beacon exciter, spurious emissions cannot exceed 25 microwatts (-16 dBm), and must be 40dB below the mean power of the fundamental emission (400mw in this case is +26dBm - 40dB =  -14 dBm), but need not be reduced beyond 10uW (-20 dBm).

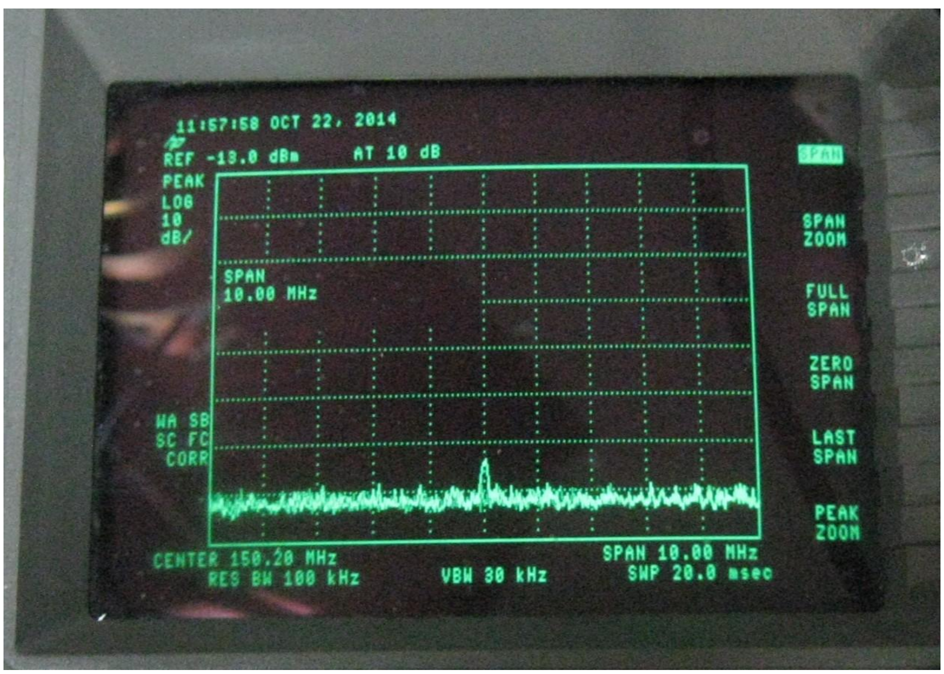
In addition, FCC Part §97.307  Emission Standards,(c) states: "All spurious emissions from a station transmitter must be reduced to the greatest extent practicable."




50MHz Beacon 400mW Fundamental Output




50MHz Beacon 2nd Harmonic -74 dB Down (+26dBm -74dB = -48dBm)




50MHz Beacon 3rd Harmonic -75 dB Down (+26dBm -75dB = -49 dBm)

While the average radio amateur may not have access to a spectrum analyzer, the current availability of low-cost DVB receiver "dongles" in the $20 range, and SDR receiver software, does provide an affordable alternative as an effective RF visual frequency and power measuring aid for projects such as this one. A switched 50-ohm attenuator and directional coupler, such as those offered in the Elecraft Mini-Module Kits, could complete a basic---but very useful---visual RF evaluation package for the radio hobbyist.

**One Special Phone Call**

This 50MHz beacon was completed and on the air around the time of the transition to digital television in the spring of 2009. Having the local CH2 TV station vacate 57MHz was a blessing, as the 50KW transmitter generated about 4 to 5 S-units of broadband noise at 50Mhz when pointing one's 6M beam in that direction from 4~5 miles away.

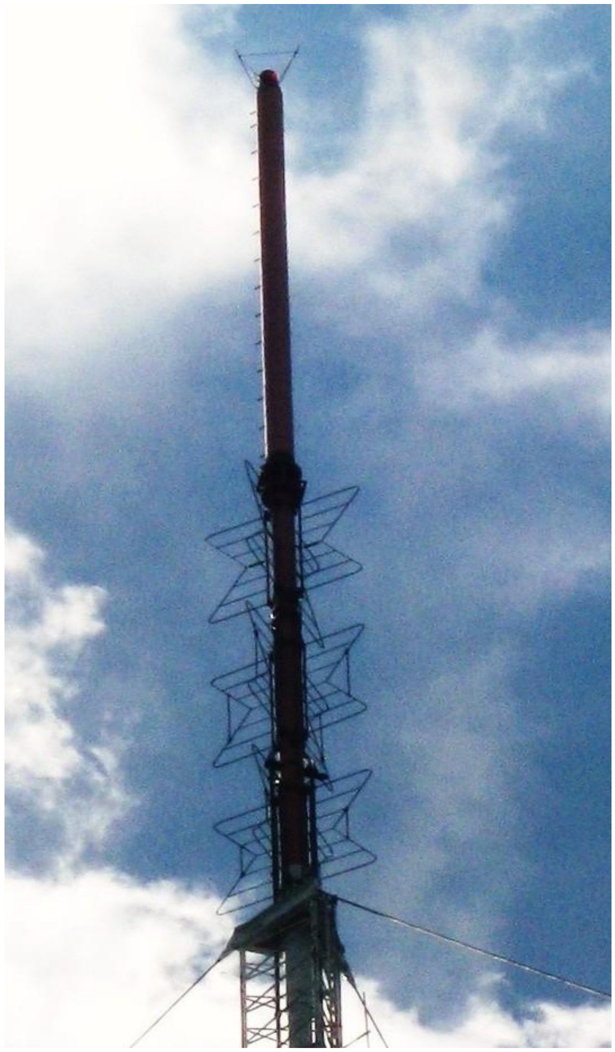
It was about this time, when one morning, I received a rather special phone call. The conversation went something like this. "Hello. I'm the engineer at the local CH2 TV station. I was tuning around the 6 meter band and heard your beacon, and thought I would give you a call. It sounds pretty good. Why don't you stop up at the transmitter site in the next few days as I would like to show you the new 50KW digital new digital transmitter."

Rather amazed by the invitation, I visited the transmitter site a few days later. One thing lead to another and the WA3TTS 50MHz beacon soon became the "pilot light " for the legacy CH2-TV broadcast antenna-- with the understanding that this special privilege could change at any time. At the writing of this article, it is coming up on 5 years since the DTV transition. During this time period, this modest 50MHz CW beacon has been in continuous operation at the local Pittsburgh CH2-TV transmitter site.

Rigid Feed Lines to the Dielectric Communications TF Series CH2
Superturnstile Antenna

Note the "Motorola VHF Low" LPF which keeps several watts of UHF TV energy from getting to the 50MHz beacon. A pair of Polyphasers in series also provide some extra surge protection. An electrical 1/4 wave delay line made from RG59 cable provides the 90 degree phasing for the second element of the turnstile antenna.

**Local CH2-TV Legacy Antenna System**



Local CH2-TV Legacy TF Series Dielectric Communications CH2 Superturnstile[6] Antenna @ 1000' HAAT[7].

A special thank you to the local Pittsburgh CH2-TV engineer for hosting this modest 50MHz CW beacon and for teaching us, through example, the true nature of the Free Space Path Loss equations[8].

[6] http://www.dielectric.com/inc/catalogs/TV_Planner-press_ready.pdf
[7] Height Above Average Terrain.
[8] http://www.rohde-schwarz-usa.com/rs/rohdeschwarz/images/8GE01_Antenna_Basics.pdf

50MHz Beacon Parts List by Component Type

Capacitors, Fixed

| | |
|---|---|
| C1, C6, C32 | 0.001µF Feedthrough (1000pF). |
| C2, C7, C19, C20, C21 | 0.001µF 50V polyester (poly) film capacitor. |
| C4 | 5 pF 50V silver mica. |
| C9 | 22pF 50V silver mica. |
| C10, C23, C36, C39, C44 | 0.1µF 50V poly film. |
| C11, C18, | 100pF 100V silver Mica. |
| C12, C14, C16 | 150pF 100V silver Mica. |
| C22, C26, C27, C28, C41, C42 | 0.01µF 50V poly film. |
| C24, C31, C40 | 220µF 35V electrolytic. |
| C25, C30, C35, C39 | 1000pF (.001µF) 50V silver mica. |
| C29, C45 | 1µF 35V tantalum. |
| C33 | 100µF 10V electrolytic. |
| C34 | 100µF 35V electrolytic. |
| C43 | 22µF 35V electrolytic |
| C37 | 220µF 63V electrolytic. |

Capacitors, Variable

| | |
|---|---|
| C3, C8, C15, | 10 - 60 pF ceramic trimmer capacitor |
| C5 | 1 - 20 pF ceramic trimmer capacitor. |
| C13, C17 | 1-10 pF ceramic trimmer. |

Resistors, Fixed

| | |
|---|---|
| R1, R4 | 100K 1/4W |
| R2, R6, R10, R11 | 150 ohms 1/4W. |
| R3 | 100 ohms 1/4W. |
| R5, R7, R8, R9 | 10 ohms 1/4W. |
| R12, R13, R14, R15 | 50 ohms 1/4W |

(R12-R15 can be pairs of 100 ohm 1/4W resistors in parallel).

| | |
|---|---|
| R16, R22 | 1K ohms 1/4W. |
| R17 | 560 ohms 1/4W. |
| R18 | 3.3K ohms 1/4W. |
| R19, R21 | 4.7 ohms **<u>1/2W</u>** (or two 10 ohm 1/4W resistors in parallel). |
| R23 | 2.2K ohms 1/4W. |
| R24 | 390 ohm 1/2W resistor. |

| | |
|---|---|
| R25 | 200 ohm 1W (or 90 ohms 3W). See text. |
| R26 | 1K 1/2W. |
| R30 | 47 ohms 1/4W. |
| R31, R32 | 15K ohm 1/4W. |
| R33 | 10 ohms 1/2W. |
| R27, R28, R29 | 4.7K 1/2W. |
| R34 | 1200 ohms 1/2W. |
| R36 | 220 ohms 1/2W. |

50 ohm SMA termination.

Resistors, Variable

R20 100 ohm 15T 3/4W Cermet Potentiometer (Bourns 3006P-101LF or equiv.)
R35 1K ohm 3/4W 15T Cermet pot, 3/4W (Bourns 3009P-1-102LF, etc.)

Inductors

| | |
|---|---|
| Z1, Z2, Z3 | 100uH (or more) 1/2W molded inductor. |
| FB | T61 Ferrite bead. |
| T1, T2 | 10T Bifilar #30 Wire on FT61-50 toroid. |
| L1, L3 | 220nH (.220uH) 5T #24 enamel wire, close wound on .25" drill bit shaft, with 1/2"leads, then adjust coil length to .250" long. |
| L2 | 260nH (.260uH) 5T #24 Enamel Wire Close Wound, 1/2" leads. |
| L4 , L7 | 184nH (.184uH) 4T #24 enamel wire wound on .25" drill bit shaft, close wound with 1/2" long leads, then adjust coil length to .310" long. |
| L5, L6 | 198nH (.198uH) 5T #24 enamel wire wound on .25" drill bit shaft, close with 1/2" long leads, then adjust coil length to 0.475" long. |

Semiconductors

| | |
|---|---|
| D1, D2 , D3, D4 | 5.1V Zener Diode 1/2W. |
| D5 | 12V 1/2W Zener diode. |
| Q1, Q2 | MPF-102. |
| Q3 | 2N3866. |
| Q4 | 2N2222 NPN transistor. |
| Q5, Q6, Q7 | 2N3906 PNP transistor. |
| IC1 | MAR 4 MMIC or equiv. |
| IC2 | Motorola CA5800C 1W wide band linear amplifier module. |
| IC 3 | 4N32 or 4N33 optoisolator. |
| IC4 | LM555. |
| IC5 | LM317 Adjustable voltage regulator. |

Other Components

Y1 50.06-50.08 MHz 3rd Overtone Crystal (ICM, etc.)

RF PIN Switch Daico 0622 or Mini-Circuits ZSDR-230, SPDT and TTL control type.

XT-4B Beacon Keyer Module ( www.unifiedmicro.com ).

TO-5 heat sink

IC5 TO-220 Heat sink or mount kit

SPKR Small 8 ohm speaker.

F1 2A fuse. (& fuse holder).

J1 50 ohm BNC Female.

J1 1/8" stereo jack

SMA Jumper cables (2) for RF connections (for RF PIN switch).

RF Connectors (2) SMA or BNC female chassis mount. (Final amplifier).

SW1, SW2 SPST low volt & current switch.

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**QST Issue:** May 2011
**Title:** A Transmitter for Fox Hunting
**Author:** Mark Spencer, WA8SME

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# A Transmitter for Fox Hunting

*If you want to try fox hunting, someone needs to bring the tramsitter.*

**Mark Spencer, WA8SME**

Fox hunting is introduced to teachers during the ARRL Education and Technology Program (ETP) Teachers Institutes (**www.arrl.org/teachers-institute-on-wireless-technology**). This is a very popular activity among the teachers because they see the value of an outdoor activity that uses many aspects of the science and technology of radio. This can reinforce what the students learn about in the classroom. In addition, it relates to the real world of radio direction finding that the students see on many science and nature TV documentaries (see Figure 1).

Our first fox transmitter controller was developed to allow common handheld 2 meter radios to serve as hidden transmitters for ETP classes.[1] This flexible micro-

[1]Notes appear on page 36.

KD7RPP

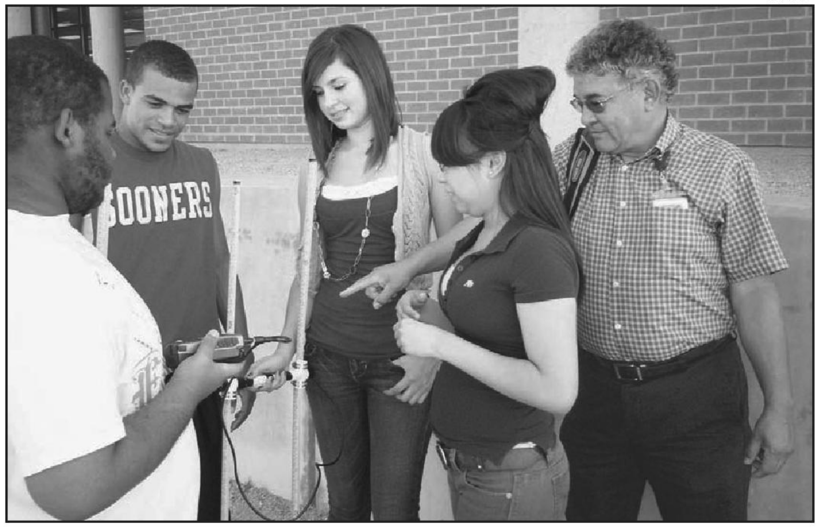



**Figure 1 — Miguel Enriquez, KD7RPP, a Teachers Institute instructor, introducing fox hunting concepts to his students.**

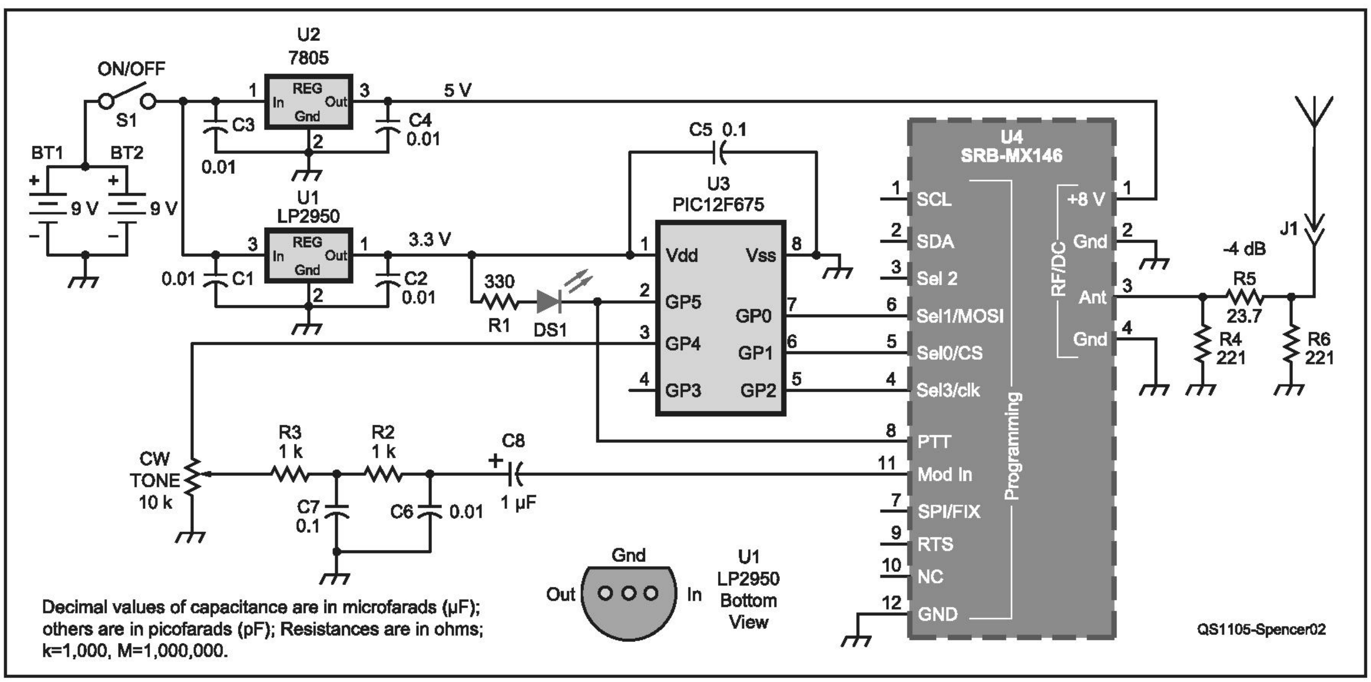



**Figure 2 — ETP fox hunter controller circuit diagram and parts list. Digi-Key parts are available from www.digikey.com.**

**BT1, BT2 — 9 V transistor radio type battery.**
**C1-C4, C6 — 0.01 μF polystyrene or ceramic capacitor.**
**C5, C7 — 0.1 μF polystyrene or ceramic capacitor.**
**C7 — 1 μF polystyrene or ceramic capacitor.**
**DS1 — LED.**
**J1 — Jack to match desired antenna connection.**
**R1 — 330 Ω, ¼ W, 5% resistor.**
**R2, R3 — 1 kΩ, ¼ W, 5% resistor.**
**R4, R6 — 221 Ω, ¼ W, 1% SMD resistor. (Digi-Key p237fct-nd).**
**R5 — 23.7 Ω, ¼ W, 1% SMD resistor. (Digi-Key p221fct-nd)**
**S1 — SPST PC board mounting miniature toggle switch.**
**U1 — 3.3 V regulator IC, LP2950 (Digi-Key lp2950cs-3.3-nd).**
**U2 — 5 V regulator IC, 7805 (Digi-Key mc7805ct-bpms-nd).**
**U3 — PIC microprocessor PIC12F675 (Digi-Key PIC12F675-I/P-nd).**
**U4 — SRB-MX146 2 meter transmitter module (see text).**

controller-based controller worked well, but proved to be fairly fragile because of all the interconnecting plugs and cables, and the variety of handhelds in use. Nothing stops a lesson or demonstration faster than an equipment failure. Time is far too valuable.

Our solution to this reliability issue is the simple fox transmitter project presented here. Duplicating this project provides a valuable learning experience covering the use of microcontrollers and also serial communications along with producing a fun, homebrew project. This fox transmitter is made up of a PIC microcontroller and a very frequency agile 2 meter transmitter module. The microcontroller programs the frequency of the transmitter, turns the transmitter on and off at intervals during the fox hunt activity and generates the fox ID as well as the control operator's call sign in Morse code. It is all in an affordable and rugged package.

## Transmitter Module

The 2 meter transmitter module is an SRB Module Transmitter SRB-MX146 available from RPC-Electronics.[2] The module is designed for APRS operation and is a low power (less than 1 W), FM transmitter for sending APRS position packets. The module requires an external antenna, a dc power source, connections to the data audio source and PTT lines. In addition, connections to switches or a microcontroller are needed to set the operating frequency (see Figure 2).

The frequency of the transmitter can be set by three different methods, all detailed in the device documentation. First, four switches can be attached to the module to switch select one of 16 preset APRS channels. Second, the user can hard wire the appropriate pins to a specific channel if frequency agility is not required. This simplifies the interface circuitry for the module. Third, an ASCII stream of data can be sent to the transmitter module via Integrated Circuit (I2C) or Serial Peripheral Interface (SPI) protocols to set any frequency within the 2 meter band. This data stream is sent to the module by a microcontroller or computer. Frankly, the detail of the documentation that comes with the transmitter module is a bit sparse, particularly with regard to programming the frequency. The following discussion of SPI, along with the module documentation will help you better understand how to program the frequency.

## Serial Peripheral Interface

The SPI protocol is used to send data between devices serially, one bit at a time. In SPI there are slave and master devices. There can be bidirectional communications between the master and the slave(s). For this project, we instead use one way communications between the master, the microcontroller, and the slave, the transmitter module. It requires up to four interconnecting lines (three in this case) between the master and slave devices to accomplish SPI. The Sel0/CS is the device select line. This line is used to signal a connected device that the upcoming data stream is intended for the device. The Sel1/MOSI is the data output line from the master to the slave. Finally, the Sel3/CLK is the clock line that provides the clock pulses that clock the data bits from the data line.

The computer or microcontroller that sends data via SPI goes through the following steps.

1. The SPI-CS line is brought to the low state (ground) to signal the slave device that it is about to receive some data.

2. The first bit of the data to be sent is set on the SPI-MOSI line, either high or low (1 or 0). Data can be sent either most significant byte (MSB) or least significant byte (LSB) first, depending on the devices involved.

3. The SPI-CLK line is pulsed high then low to clock in the bit presented on the SPI-MOSI line to the slave.

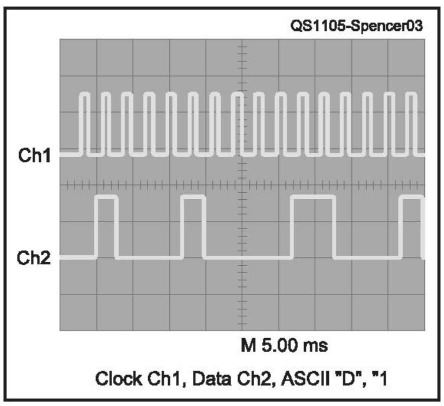



Figure 3 — SPI data stream.

4. Steps 2 and 3 are repeated to send the complete byte(s) of data.

5. Finally, the SPI-CS line is brought to the high state (1) to signal the slave that the data transmission is complete and the received data can be accepted.

The oscilloscope snapshot in Figure 3 illustrates the SPI process for sending the first few characters of the data stream to the transmitter module. The scope snapshot was triggered by the SPI-CS line going low. The top trace shows the clock pulses while the bottom trace shows the data bits that are clocked into the transmitter module.

The frequency can be sent to the transmitter module in a number of formats. I will mention only a few here while the module documentation has more detail. The frequency can be sent in binary, hexadecimal or decimal number format, and in Hz, kHz or MHz units. For me, sending the frequency in decimal format in Hz units was more intuitive and gave finer control over the frequency.

What was not clear in the module documentation is that the data that is sent to the transmitter module has to be sent as ASCII characters, not as decimal numbers. ASCII is a code that is sent to computer display devices to represent the character to be displayed. For instance, to display the decimal number 1, you need to send a value that represents the character "1", not the actual number 1. The ASCII number that represents the character "1" is 49. If you send the decimal number 1 to a computer display device, you probably would see nothing happen at best, or some unexpected garbage because the decimal number 1 is a control code for START OF HEADING. A subset of the ASCII number set for the relevant data that is sent to the transmitter module to set the frequency is listed in Table 1.

For example, to set the transmitter module to the frequency of 146.52 MHz, the ASCII formatted data stream D146520000

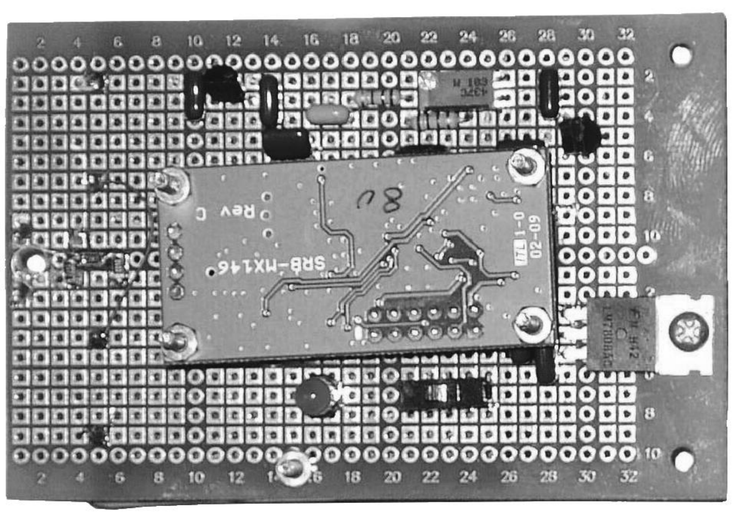


Figure 4 — ETP fox prototype.

**Table 1**
**Decimal Digit to ASCII Conversion**

| *Decimal Digit or Letter* | *ASCII Coded Digit* |
|---|---|
| 0 | 48 |
| 1 | 49 |
| 2 | 50 |
| 3 | 51 |
| 4 | 52 |
| 5 | 53 |
| 6 | 54 |
| 7 | 55 |
| 8 | 56 |
| 9 | 57 |
| D | 68 |

would be sent over the SPI-MOSI line to the module with the MSB sent first in each byte. In other words, the actual ASCII number sequence to accomplish this frequency setting would be: 49, 68, 52, 54, 53, 50, 48, 48, 48, 48.

Once the frequency is set, it is a simple matter of bringing the PTT line of the transmitter module low and applying an audio signal to the audio input line to begin transmitting. There is one precautionary quirk of the module. The voltages applied to the input lines of the module must be at CMOS levels (3.3 V maximum). Therefore the controlling interface voltages must be adjusted accordingly.

## The Microcontroller

The fox transmitter project uses the PIC12F675 microcontroller. This powerful little device is programmed to set the frequency of the transmitter module and then begin the fox transmission cycle of one minute on, sending the fox ID in Morse code, the control operators call sign at the end of the one minute transmission period, then shut down for four minutes before the cycle is repeated. The frequency, fox ID (MOE, MOI, MOS, MOH, MO5) and the control operator's call sign are programmed into the microcontroller's firmware (which can be changed with re-programming).

The microcontroller software that I developed is simply modified by changing the frequency and call sign variables in the program to the specific data needed by the builder. The software is available on the QST-in-Depth website.[3]

It all comes together in the circuit depicted in Figure 2. The fox transmitter is powered by two 9 V batteries wired in parallel (a modification of this arrangement will be mentioned in a moment). The 9 V from the batteries is connected to the high current 5 V regulator that provides power to the transmitter module. The transmitter module is available in two forms, a high power (500 mW and 8 V)

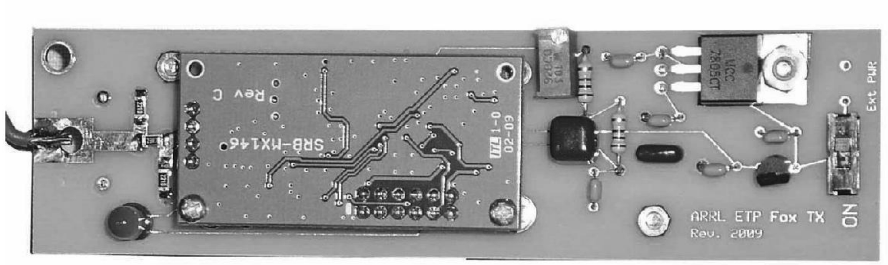



**Figure 5 — ETP fox final project.**

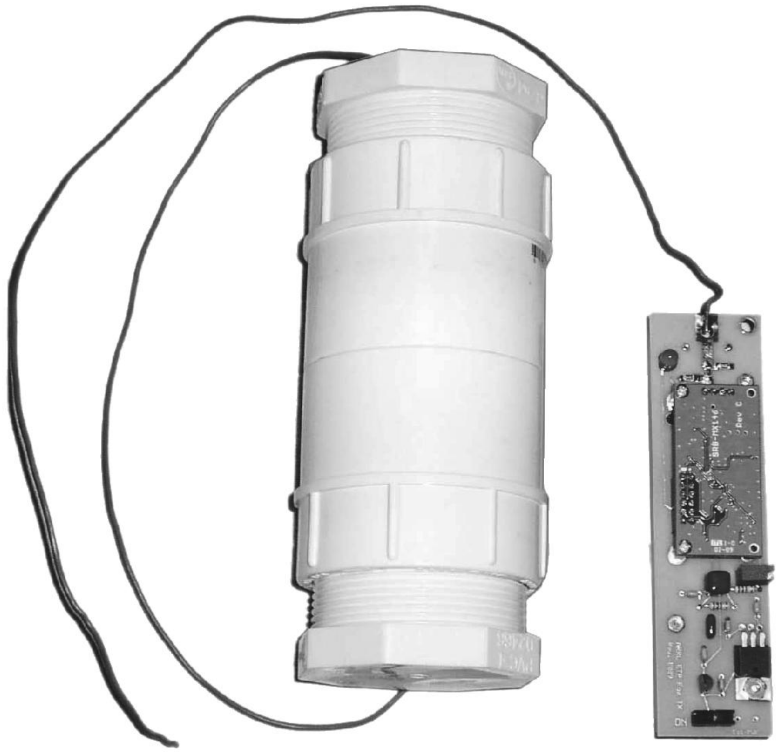


**Figure 6 — ETP fox ready for action in a PVC protective housing.**

## Hamspeak

**APRS** — Automatic position reporting system. System that accepts global positioning system (GPS) position data from a GPS satellite receiver and processer, formats it into an AX-25 packet for transmission via Amateur Radio, usually on 144.39 MHz. Position data is available via radio or over the Internet.

**ASCII** — American Standard Code for Information Interchange. A computer "alphabet" obtained by mapping each printable and control character into a seven bit data word (often implemented with eight bits by including an error checking parity bit). See **www.cs.tut.fi/~jkorpela/chars.html**.

**CMOS** — Complementary metal oxide semiconductor. An integrated circuit logic family with particularly low power requirements.

**Fox hunt** — Competitive Amateur Radio activity in which hams track down a transmitted signal. Usually directive antennas and triangulation are used.

**Oscilloscope** — Type of electronic test instrument traditionally with a cathode ray display screen that shows time on the horizontal axis and voltage on the vertical axis.

**PIC microcontroller** — Programmable interface controller. One of a family of processor based integrated circuits that can be programmed to perform multiple functions.

**PTT** — Push-to-talk, a method of transmit-receive switching in which a button or lever on the microphone is used to actuate the circuitry used to switch from receive to transmit mode.

and a low power (350 mW and 5 V) module. I chose the low power module for the fox and therefore the voltage regulator is a 7805. If you choose the high power module, the 9 V batteries should be wired in series and the voltage regulator should be a 7808. The second 3.3 V regulator provides power to the PIC12F675.

I mentioned that the transmitter module requires CMOS level voltages on the control and data lines. I chose to power the PIC12F675 with 3.3 V to simplify the interfacing with the transmitter module. Normally the PIC12F675 is powered at 5 V, but is rated to operate between 2 and 5.5 V, so it handles 3.3 V just fine (and this certainly uncomplicates the interconnecting circuitry).

The audio frequency generated by the PIC12F675 to produce the Morse code is in the form of a square wave. The resistor and capacitor components between the microcontroller output line and the transmitter audio input line provides some filtering and microphone gain control to clean up the square wave.

Finally, I use the fox transmitters to demonstrate the concepts of fox hunting to teachers often times in very close and confined spaces. This requires the use of some low power transmitters and 350 mW is some significant power close in. Therefore, approximately 4 dB of attenuation was added to the circuit to cut the power down a bit. More or less attenuation can be added if needed for your particular application.

The hand wired prototype of the fox transmitter is shown in Figure 4. Formal circuit boards were designed for the final fox transmitters to make them more uniform and rugged as shown in Figure 5. The narrow board design allows for the foxes to be housed in PVC pipe fittings to make them more rugged and water resistant (see Figure 6).

## In Summary

Fox hunting is a great, and useful, activity for Scout groups, schools and ham groups. It combines outdoor activities with some science of radio and radio operating techniques in a refreshing way that just might stimulate further interest in ham radio — and just might help save someone's life. This fox transmitter project might be a good one for a club homebrew project that supports not only club activities but also could support your local school or Scout organizations, and give you an opportunity to introduce ham radio in a very positive way.

**Notes**

[1]See **www.arrl.org/etp-kits-projects**, click on SCHOOL FOX HUNTING ACTIVITY, then LEARN MORE.

[2]**www.rpc-electronics.com/rf.php**

[3]**www.arrl.org/qst-in-depth**

*ARRL member and Amateur Extra class operator Mark Spencer, WA8SME, was the ARRL Education and Technology Program (ETP) Coordinator when this article was written. He recently transitioned to an engineering position with a firm that does rapid research and development of prototype unmanned underwater and other autonomous maritime vehicles for the Office of Naval Research and other Department of Defense agencies. He still maintains close ties to the ETP and provides as much support as time permits. So if you need some help or have some questions about this project, please be patient. One side point of interest; Mark states that he has used every content area presented during the ARRL Teachers Institute and the skills he learned in his over 45 years as a ham radio operator in his position as a Research and Development engineer. Quite a validation of the ETP — and ham radio! Mark can be reached at* **wa8sme@comcast.net**.



# New Products

## AIM *UHF* ANTENNA ANALYZER FROM ARRAY SOLUTIONS

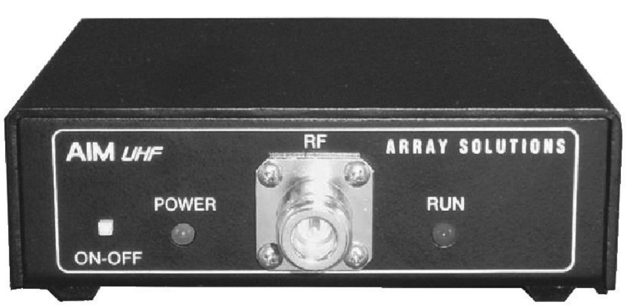
◊The AIM *UHF* antenna analyzer from Array Solutions is similar to the AIM 4170C but with extended frequency coverage. The new unit operates from 5 kHz to 1 GHz and features a temperature compensated oscillator (TCXO), scan averaging up to 256 times and an expansion port for accessories. The package includes a wall power supply, calibration loads, a USB cable, free software updates and a printed *Quick Start* guide. Price: $895. For more information, visit **www.arraysolutions.com**.

## LOOPS-N-MORE VHF ANTENNAS

◊ Loops-N-More offers halo type half-wave loop antennas for the 6, 2 and 1.25 meter amateur bands. Based on the proven KB6KQ designs, the antennas are made from 6061 aluminum with stainless steel hardware. Rated at up to 750 W, these antennas are horizontally polarized and designed for SSB/CW operation from mobile or home stations. Price: 6 meter loop, $135. 2 meter or 1.25 meter loop, $65. For more information, visit **loopsnmore.com**.

## ICOM IC-7410 HF/6 METER TRANSCEIVER

◊ ICOM's new IC-7410 replaces the IC-746PRO. The '7410 uses faster digital signal processing and technology developed from the current IC-7600/7700/7800 series of transceivers. Optional 3 kHz and 6 kHz roofing filters are available. The IC-7410 comes with a standard type B USB connector on its back panel. Modulation input, audio output, RTTY demodulator output and CI-V command can be controlled via the USB cable. Also, a conventional CI-V remote control jack is built into the IC-7410. Optional RS-BA-1 remote control software has been announced with details to come. Price class: $2000. For more information, visit your local dealer or **www.icomamerica.com**.

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**QST Issue:** Oct 2005
**Title:** A Fast TR Switch
**Author:** Jack Kuecken, KE2QJ

**Jack Kuecken, KE2QJ**


# A Fast TR Switch

## Here are two approaches to integrating a separate receiver into your equipment lineup.

Some time ago I purchased an ICOM PCR1000 receiver. This very small radio is representative of a new class of radios offered by ICOM, Ten-Tec and others. The radio has no controls on the panel. In fact, there scarcely is a panel. It is controlled entirely by a computer over an RS-232-C connection, and virtual controls appear on the computer display. The mouse or keyboard can be used to set frequency, volume and mode, and perform all the normal radio functions.

The PCR1000 is a versatile receiver. It covers 100 kHz through 1.3 GHz, except for cellular telephone frequencies. Modes include AM, FM, SSB and CW. Aftermarket *Bonito* software (now supplied with the radio) adds DSP filtering functions and modes like RTTY, FAX, SSTV and PSK31 that are not offered on older transceivers. The UT-106 DSP hardware option adds an automatic notch filter and noise reduction.

I was interested in using the PCR1000 in my ham station, along with a separate transmitter. Although the radio will function with a chunk of wire for an antenna, it hears much better with a resonant antenna. The input is matched to 50 Ω. An obvious choice would be to use it with the antenna used for transmitting, but to do that I needed to make some kind of TR switch.

Some measures must be taken to disconnect the receiver from the antenna when the transmitter is operating. Otherwise the transmitter power will surely damage the front end. Even connecting the receiver to a full size matched antenna in the vicinity of a kilowatt transmitter on another antenna could destroy the input stages, so I needed a fast acting TR switch to isolate the receiver from the powerful transmitted signal. This article describes the development of two TR switches, one using a reed relay and the other PIN diodes.

### The Reed Switch

The first switch I developed for this purpose employed a low-power RF reed relay from Wabash Magnetics,[1] as shown in Figure 1. The relay (K1) is "T'd" onto the line connecting the transmitter or transceiver and the linear amplifier. When the reed relay contact closes, it connects the external receiver antenna input in parallel with the transceiver. This T configuration costs perhaps 3 dB, or half an S-unit, in received signal strength.

Since the switch is exposed to the high power RF only in the open condition, a common reed relay could probably be used. If a relay had been used to isolate the transmitter, it would have had to pass approximately 100 W. In this case a true RF reed is required since the iron reed in a common switch is lossy at radio

[1]Notes appear on page 59.

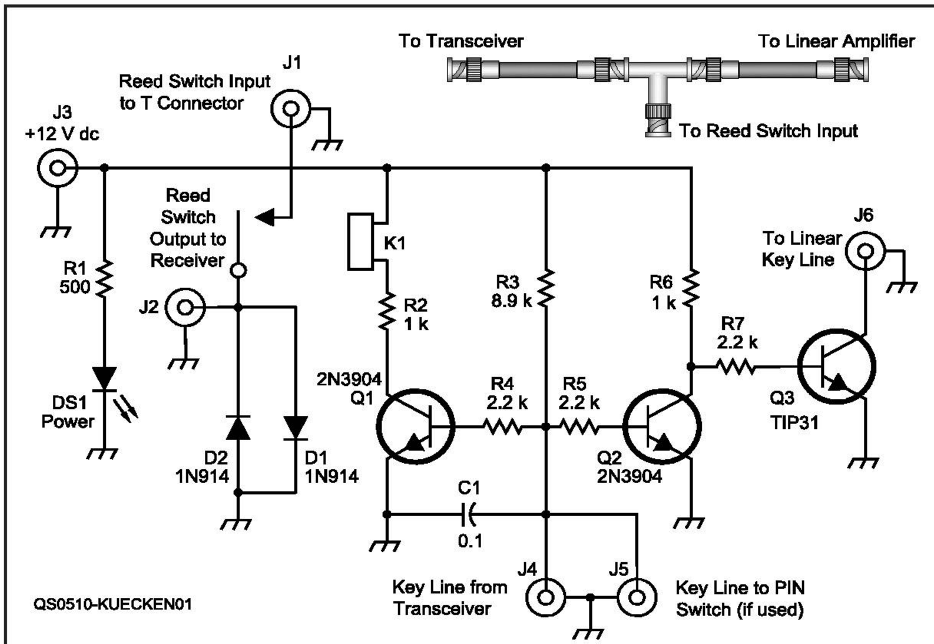



**Figure 1—Schematic and parts list for the reed relay TR switch. Resistors are 1/4 W.**

**D1, D2—High speed switching diode, 1N914 or equivalent.**
**DS1—LED.**
**J1, J2—Chassis mount BNC connectors.**
**J3-J6—Chassis mount phono connectors.**
**K1—SPST normally open reed relay with 12 V coil. See text and Note 2.**
**Q1, Q2—Small signal PNP transistor, 2N3904 or equivalent.**
**Q3—NPN power transistor, TIP31 or equivalent.**

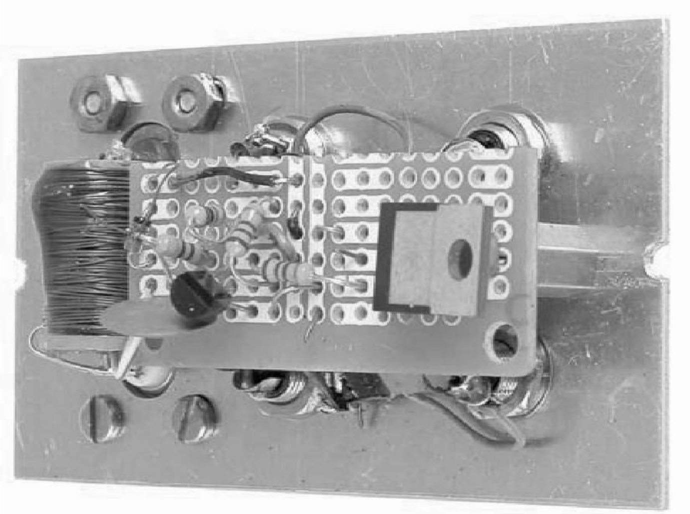


**Figure 2—Interior of the reed switch. The connectors all mount on a small aluminum plate which fits the wooden enclosure shown in the title photo. The reed relay is mounted directly to the input and output connectors. The control circuitry is on a RadioShack project board. Component layout is not critical.**

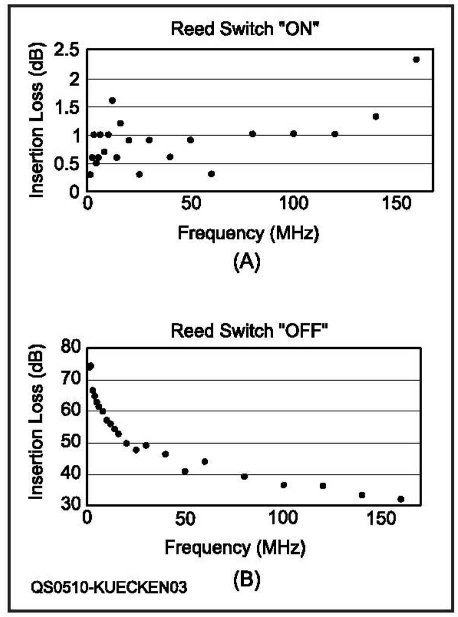



**Figure 3—Insertion loss measured with the reed switch ON (A) and OFF (B).**

frequencies and will heat up. If it heats to the Curie point (the temperature at which a material loses its magnetic properties), it will drop open and present an extreme SWR to the transmitter.

The key line on my Ten-Tec Omni C transceiver goes low on transmit. Looking at Figure 1 you can see that with the key line high, both 2N3904s are biased on and K1 is closed and the TIP31 is turned off. When the key line goes low on transmit, the 2N3904s are cut off, K1 opens to disconnect the receiver, and the TIP31 saturates and keys the linear. I needed the TIP31 because the load of the 2N3904 control transistors was enough to key my Ameritron AL-80A linear even with the switch in the receive mode. D1 and D2, the set of back-to-back diodes across J2, represent a safety measure against transmitter startup transients (more on this later).

## Reed Switch Construction

Figure 2 shows the inside of the reed switch. The reed itself is a glass cylinder about 3/32 inch in diameter that is covered with a coil of wire. The winding is adequate to permit closing of the reed with about 5 mA of current. The transistor drives about 10 mA through the coil. The reed switch (green) bridges directly between the two BNC chassis connectors. An external BNC T adapter is used to connect the transceiver and the linear amplifier and clips on the input chassis connector. The PCR1000 auxiliary receiver is fed through the other chassis connector. I built the control circuitry on a RadioShack project board.

The assembled switch in its wooden case can be seen in the title photo. There is a single key line input (J4) and two key line outputs (J5 and J6). One output (J5) is in parallel with the transceiver key line and goes to the PIN switch (if used). The output from Q3 goes to a tune-up interlock and then to the linear amplifier key line. I used phono connectors and shielded cable for the 12 V supply and the key lines to avoid RF pickup in the control circuitry. The extra phono connector is wired in parallel with the 12 V jack to provide convenient power for another device such as the PIN switch described later. This version does not have the POWER LED (DS1).

Figure 3 shows the measured insertion properties of the reed switch. Insertion loss with the switch on is very low, and the loss (isolation) with the switch off is quite respectable.

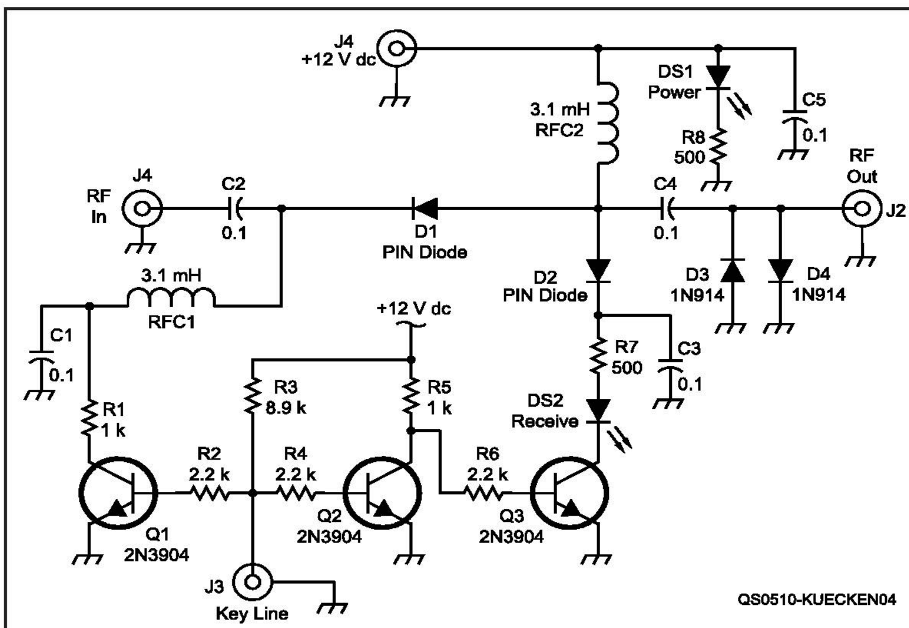



**Figure 4—Schematic and parts list for the PIN diode TR switch. Resistors are 1/4 W.**

**C1-C5—0.1 µF ceramic capacitor.**
**D1, D2—PIN diode (see text and "Alternative Parts" sidebar).**
**D3, D4—Switching diode, 1N914 or equivalent.**
**DS1, DS2—LED.**
**J1, J2—Chassis mount BNC connector.**
**J3, J4—chassis mount phono connector.**
**Q1-Q3—Small signal PNP transistor, 2N3904 or equivalent.**
**RFC1, RFC2—3.1 mH RF choke, 225 turns 30 gauge enameled wire wound on a 5/16 inch diameter, 5/8 inch long plastic tube. See text.**

### The PIN Switch

After building the reed switch, I decided to try another approach. Figure 4 shows the schematic diagram of a fast TR switch that I built with PIN diodes. The PIN diode is a special kind of silicon diode that is capable of passing RF when forward biased, making it ideal for use in RF switches. See the sidebar "About PIN Diodes."

Note that Q1-Q3 are all operated in a digital mode—they are all either cut off or saturated. They do not operate in a linear mode. In the receive condition the key line is open and Q1 is biased ON. This biases the PIN diode D1 ON, connecting the receiver to the input terminal. When Q1 is ON, Q2 is biased ON and Q3 draws no current through the shunt element. Thus the shunt PIN diode, D2, is OFF.

When the transceiver is keyed OFF, the key line pulls the base of Q1 low, cutting off the forward bias to D1, switching it OFF. The low line also turns Q2 OFF. This causes Q3 to saturate and forward bias D2, which shorts the feedthrough signal to ground.

I built the original switch using Unitrode diodes with a rating of 100 V and a carrier lifetime on the order of 5 µs. The parts I used are no longer available (see the sidebar, "Alternative Parts"). Note that the 100 V rating makes these PIN diodes marginal for direct connection to the output of a 100 W transmitter. More on this later.

I measured the effect of the bias current on the Unitrode diodes used for the series and shunt elements individually. For the series diode, insertion loss ranged from 0.9 dB with 3 mA of bias current to 1.2 dB with 7 mA. For the shunt diode, insertion loss ranged from 42.9 dB with 3 mA bias current to 52.9 dB with 15 mA. The test setup consisted of a Hewlett Packard signal generator for the signal source and a Tektronix spectrum analyzer with a well matched 50 Ω input for the measuring device. A low-SWR RF bypass switch I developed for an earlier project for *ARRL Antenna Compendium Vol 5* switched the signal directly to the spectrum analyzer or through the device under test.[2]

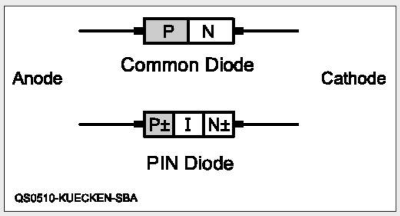
### PIN Switch Construction

Figures 5 and 6 show the construction details of the PIN diode switch. D1-D4, RFC1-RFC2 and C1-C5 mount on a piece of double-sided Teflon-fiberglass circuit board that I had on hand. (Regular G-10 or FR-4 board would work just fine here too.) To make pads for component mounting, I cut gaps in the foil on one side. The far side foil was left intact as a continuous ground plane. Jumpers were soldered to connect ground areas on the top to the solid ground plane. An etching pattern is available from the ARRL Web site.[3]

Originally, I built the switch with surface mount capacitors. I was interested in using these tiny capacitors because they have no leads and should have very high resonant frequencies in the circuit. Unfortunately, several of the capacitors failed in the course of measurements. After a bit of exasperation, I realized that the thin circuit board was flexing and breaking the capacitors. I switched to the conventional ceramic capacitors shown in the photos.

Perhaps the most visible part of the assembly is the pair of RF chokes. These are wound on a 5/16 inch diameter plastic tube between a pair of 1 inch fiberglass washers. The washers were epoxied on the ends of the tube about 5/8 inch apart and

### About PIN Diodes




The PIN diode is constructed with a layer of intrinsic (undoped) semiconductor material between very highly doped P type and N type material called P+ and N+. This contrasts with a normal high speed switching diode such as the 1N914 which has a simple PN junction.

An ordinary PN junction diode can be used to switch RF currents on and off. In order to completely close off the current, the diode must be reverse biased with a voltage equal to the peak RF voltage to be blocked. For example, to block an RF signal of 10 V p-p, the diode anode must be 10 V dc more negative than the cathode. If the diode is to remain turned on for the complete RF cycle, the dc bias current must exceed the RF current. For example, if the diode is expected to pass 0.1 A of peak RF, it must have a forward bias of at least 0.1 A dc.

The behavior of the PIN diode is notably different. Because of the intrinsic layer, the RF takes a significant time to travel between the P+ and N+ regions. The delay characteristic is important for RF switching. The PIN diode is normally OFF for RF and only requires a bias to turn ON. If the length of an RF cycle is shorter than this delay and the diode is not forward biased, the current flow will be negligible and the diode will appear to be OFF. If a forward bias current is applied, some RF current will flow and the diode switch will be ON.

Over a limited range, the diode acts like a current controlled resistor to RF. Resistance decreases with increasing bias current. Used in conjunction with a fixed resistor, the PIN diode can be used to construct an electronically controlled RF attenuator.

The capacitance of the diode itself and the diode package will permit some RF feedthrough current in the OFFcondition. Feedthrough in the OFF condition will always be greater than zero, so a switch intended to provide high levels of isolation will frequently have two PIN diode elements. A series element (D1 in Figure 4) disconnects the switch from the source, and a shunt element (D2 in Figure 4) shorts out most of the feedthrough signal. When the switch is ON, the series element will be biased ON and the shunt element will be unbiased and OFF. Conversely, when the switch is OFF, the series element will be unbiased and OFF and the shunt element will be biased ON to short out the feedthrough signal.

### Alternative Parts

The Unitrode PIN diode product line was purchased by Microsemi* more than 10 years ago, and the parts that I used in the prototype are no longer available.

Several parts in the current Microsemi product line would work well in this switch. Their GC4432 diode, which has a 300 V breakdown rating, would be especially suited to the series position (D1). The GC4412, which has a smaller ON resistance of 0.4 Ω would work for the shunt position (D2). The carrier lifetimes are a bit smaller, at 1.5 and 0.7 µs, than the Unitrode part. With its 300 V breakdown, the GC4432 could be directly connected to a 100 W transceiver output provided that the SWR on the line is modest. The GC4495 part, with a 1000 V breakdown, should be capable of switching the output of the 1.5 kW linear.

An excellent reference, *The PIN Diode Circuit Designer's Handbook*, is available for download at **www.microsemi.com/literature/pinhandbook.pdf**. This 137 page *Handbook* contains a wealth of information on PIN diodes and their applications. It includes several design examples of interest to hams, and even one featuring an Amateur Radio TR switch.

*Microsemi, 75 Technology Dr, Lowell, MA 01851, tel 978-442-5600, **www.microsemi.com**.

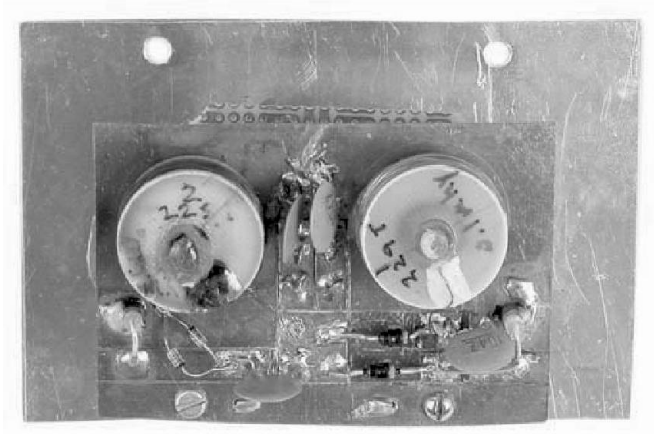


**Figure 5—Construction details of the PIN diode TR switch. The capacitors, RF chokes (upper half) and PIN diodes (lower right) mount on a piece of PC board material. Mounting pads for components are created by cutting away the foil with a sharp knife. The back side is left intact.**

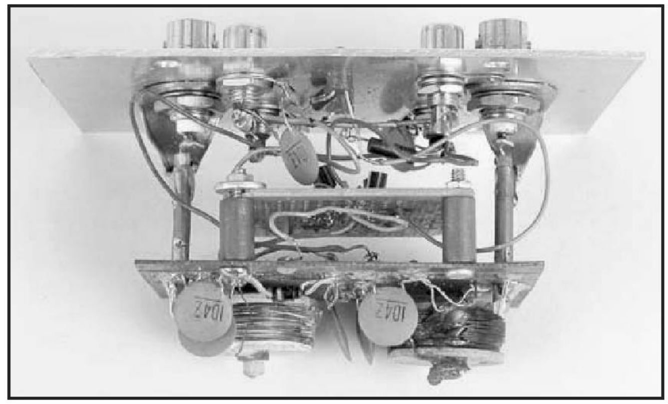


**Figure 6—Another view inside the PIN switch. The control circuitry is on a RadioShack project board secured under the diode board. Short lengths of 0.141 inch 50 Ω semi-rigid coax connect the BNC jacks to the diode board and provide mechanical support.**

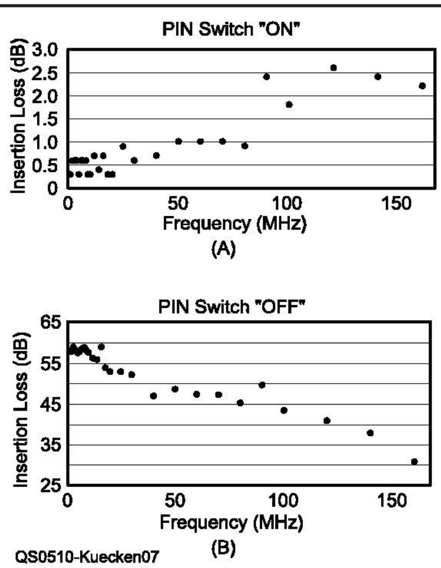



**Figure 7—Insertion loss measured with the PIN diode switch ON (A) and OFF (B).**

225 turns of 30 gauge wire wound on. Gray fingernail polish holds the windings in place. A small wooden shaft holds the choke to the board. The chokes measure 3.1 mH and provide plenty of isolation for RF at the lowest frequency of 1.8 MHz.

Figure 6 shows additional details. The transistors and resistors are mounted on a RadioShack project board on spacers under the diode board. Short pieces of semi-rigid coaxial cable run from the BNC connectors to the RF board and also provide mechanical support. The outer conductor is soldered to brass tabs, providing a ground connection. The title photo shows the switch mounted in the wooden case.

Figure 7 shows the insertion loss of the switch in the on and off conditions. Insertion loss is quite low when the switch is on, and isolation is pretty good when it is off.

The PIN switch alone has enough isolation to protect the receiver. However, as noted earlier, the 100 V rating on the PIN diodes is marginal for direct connection to a 100 W transmitter. On a 50 Ω line, 100 W corresponds to 70.7 V RMS and 100 V peak. With any significant SWR the voltage on the line can easily exceed the 100 V peak level.

I usually use the PIN switch along with the reed switch. The reed switch output, J2, connects to the PIN switch input at J1. The PCR1000 connects to J2, the PIN switch output. The PIN switch key line, J3, connects to J5 on the reed switch. The combination of reed and PIN switches provides a very high degree of isolation for the receiver and solves the problem of marginal diode ratings. With better diodes (or at low power levels with the 100 V diodes), the PIN switch alone would be fine.

## Surprises

Initial measurements with a Tektronix 100 MHz real time sampling oscilloscope held a few surprises. I learned that the key line and the RF output of my Ten-Tec Omni C are not exactly synchronized. The key line goes low about 3.5 ms *after* the RF comes on and there is some relay bounce on the key line. Because of this delay, there is some RF present at the output of the TR switch until the key line closes. Oscilloscope screen shots showing the switch output under various conditions are available from the ARRL Web site in the template package described in Note 3. Other transceivers may or may not exhibit similar behavior.

Referring back to Figures 1 and 4, the set of back-to-back 1N914 diodes across the switch output line clip the RF leak-through down to a single diode drop. They represent a safety measure against startup transients. Unfortunately, they can be a source of intermodulation distortion in the presence of strong received signals. With a slightly more sophisticated arrangement, I could derive the key line signal from the RF switch circuitry so that the transceiver would be keyed only after the switching had taken place. This may be the next project.

**Notes**

[1] Wabash Magnetics, Control Products Group, 1450 First St, Wabash, IN 46992, **www.kurz-kasch.com**. Reed relays suitable for use in the TR switch are available from a number of sources, including Surplus Sales of Nebraska (**www.surplussales.com**) and Ocean State Electronics (**www.oselectronics.com**).

[2] J. Kuecken, "A High-Efficiency Mobile Antenna Coupler," *ARRL Antenna Compendium Vol 5* (Newington: 1996), pp 182-188. Available from your local dealer, or from the ARRL Bookstore, ARRL order no. 5625. Telephone toll-free in the US 888-277-5289, or 860-594-0355, fax 860-594-0303; **www.arrl.org/shop/**; **pubsales@arrl.org**.

[3] A template package including the PIN switch RF board etching pattern and additional oscilloscope screen shots is available from the ARRL Web site at **www.arrl.org/files/qst-binaries/kuecken1005.zip**.

*Jack Kuecken, KE2QJ, is a consulting engineer in antennas, transmission line devices and instrumentation. He has published 14 books and numerous technical articles, including seven contributions to volumes 3-6 of* The ARRL Antenna Compendium *series. His book* Antenna and Transmission Lines *is available through MFJ Enterprises. You can reach Jack at 2 Round Trail Dr, Pittsford, NY 14534 or* **ke2qj@aol.com**.

# A Homebrew High Performance HF Transceiver — the HBR-2000

*VE7CA shows us that it's still possible to roll your own full feature HF transceiver — and get competitive performance!*

**Markus Hansen, VE7CA**

Have you ever dreamed of building an Amateur Radio transceiver? Have you thought how good it would feel to say "The rig here is homebrew." I did, but I am not dreaming anymore. I am the proud owner of a homebrew, high performance, 100 W HF transceiver. I have named it the HBR-2000.

I am writing this article to encourage you to stop dreaming and pick up your soldering iron. In my early years as a ham radio operator, I built several transmitter kits and later, as I gained experience, I began building solid state direct conversion receivers and low power (QRP) single band transmitters. Six years ago I said to myself: "I am not going to dream any longer. I am going to build my dream transceiver." Here is a description of how it all came together. Note that this is not a construction article, but rather a description of the process.

I began by first making a list of the features and specifications I wanted in a high performance transceiver. Then I began drawing various circuit blocks that, combined together, would meet the requirements of my wish list of features. The HBR-2000 block diagram is shown in Figure 1.

The secret to being able to successfully build a major project such as this is to divide it into many small modules as indicated in the block diagram. Each module represents a part of the whole with each being built and tested before starting on the next. To choose the actual circuits that were to be built into each module I searched past issues of *QST*, *QEX*, *The ARRL Handbook for Radio Communication*[1] and publications dedicated to homebrewing such as *Experimental Methods in RF Design*[2] by W7ZOI, KK7B and W7PUA, recently published by ARRL. If you do not own a copy of these, I highly recommend that you order copies today. In my opinion, these are the two most valuable books you can have in your ham shack if you want to design and build a transceiver.

I cannot overemphasize the importance of learning by reading, building a circuit and then taking measurements. After you build a particular circuit and measure the voltage at different points, you begin to understand how that particular circuit works. Ward Silver, NØAX, has been running an excellent series in *QST* called "Hands-On Radio." I found this month-by-month electronic tutorial especially helpful. I followed along each month as Ward explained how different radio circuits and components work and how to calculate, adjust and measure parameters of various circuits. If you are not an electrical engineer, or your electronics knowledge is a little rusty, go back and read these issues to help increase your knowledge of modern day electronic components and theory.

When I found an article containing a circuit that fulfilled the design features I had previously chosen, I checked my parts bins and then began procuring the parts I didn't have on hand. In some cases, if an etched PC board was available, I ordered it. I did not go on to the next module until I had finished the first module, including testing it to make sure it worked as expected. After I built the first module I followed the same process to decide on the circuit and build the second. I would then connect the two modules together and check to make sure that, when combined, they performed as expected. It is really that simple — one step at a time. Anyone who has had some building experience can build a receiver and transmitter using this procedure.

For a receiver, I recommend beginning with the audio output stage. In my case, I had on hand an extra printed circuit (PC) board for the "R1 High Performance Direct Conversion Receiver" by Rick Campbell, KK6B, featured in the August 1993 issue of *QST*. Rick took particular care to design a low distortion audio stage preceded by a field effect transistor (FET) mute switch and a double balanced mixer that can be used as the product detector. After mounting all the components on the PC board, I wired a speaker to the audio output pad and +12 V to the power input pad to test if I had audio output. I did this by injecting an audio signal from a code practice oscillator into the input stage of the pre-amp and confirmed that, indeed, the audio amplifier was working. Using a 40 meter variable frequency oscillator (VFO) from a low power rig that I had previously built I connected the VFO output to the mixer local oscillator (LO) port. I made sure that I didn't over-power the mixer as the LO port is rated at no more than +7 dBm. After attaching an antenna to the antenna port, I was able to hear CW signals coming out of the speaker. Hurrah, it worked!

After building the audio amplifier and product detector module, I built the beat frequency oscillator (BFO) circuit. From there, I built the intermediate frequency and automatic gain control (IF/AGC) module, then the VFO and the heterodyne LO system, then the receiver mixer and on and on until I reached the antenna. At that point I had a functioning receiver. It was a thrilling day when I hooked

[1]Notes appear on page 38.

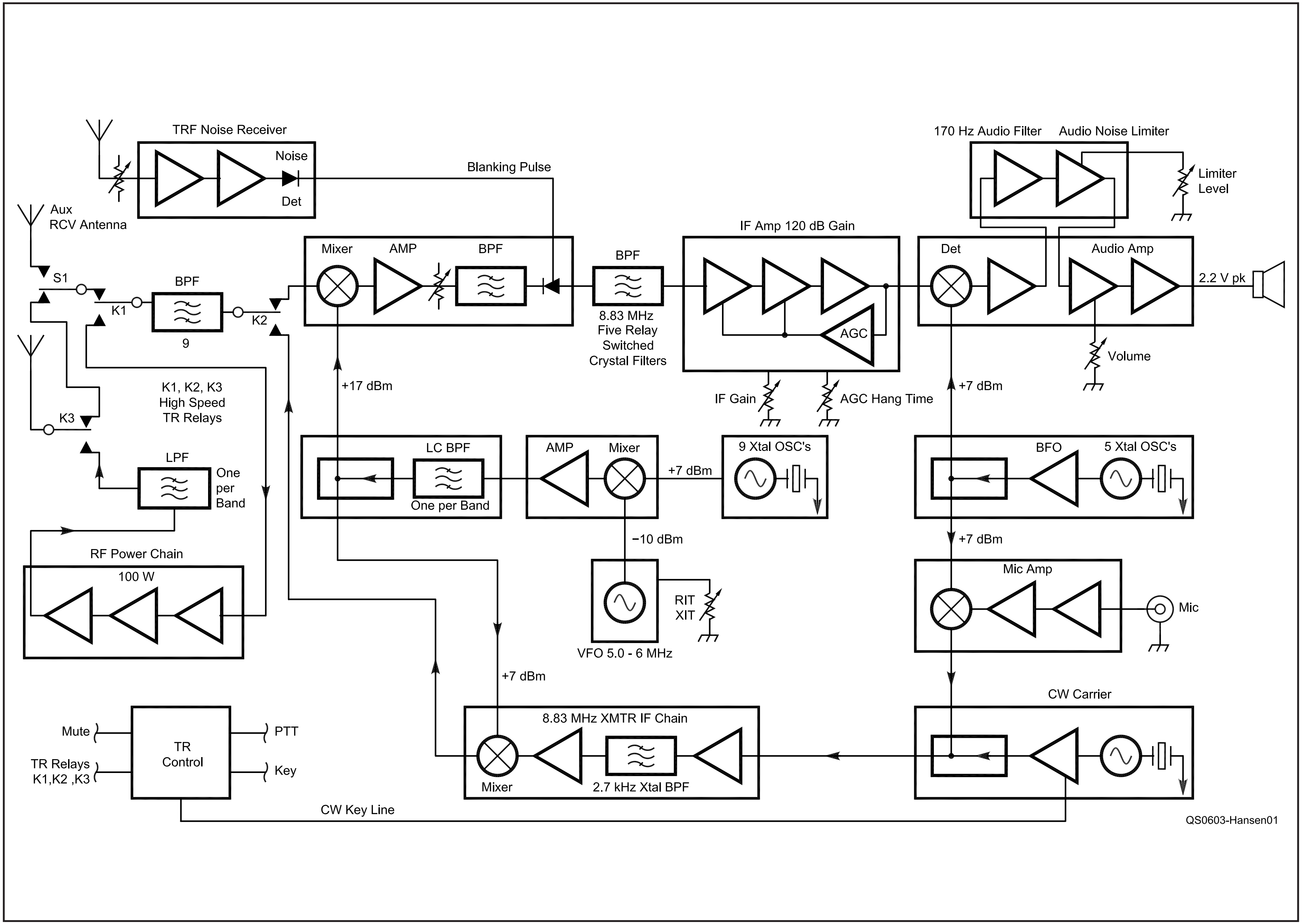



**Figure 1 — Block diagram of the HBR-2000.**

up an antenna to the receiver and could tune across the amateur radio bands listening to signals emanating from the speaker.

One of the things you will learn as you begin building your own equipment is that RF radiates. RF travels along power, speaker and control leads. All of these leads act like little antennas. This fact, coupled with the fact that the receivers we use today are very sensitive, can make for some challenges. After you build a particular module, you don't want RF from outside sources to get into the modules you build and you don't want RF signals produced inside the modules to travel to other parts of the receiver, other than through shielded coaxial lines. The reason that you don't want RF floating around the receiver is that stray RF can produce unwanted birdies in the receiver, adversely affect the AGC system or cause other subtle forms of mischief. To prevent this from happening I enclosed each module in a separate RF tight box and used coax for all the RF lines with BNC or phono connectors on each end. All dc and control lines are connected via feed through insulators.

My modules are enclosed in boxes made from unetched copper clad material. For the covers I cut sheet brass half an inch wider and longer than the size of the PC box. I then laid the box on top of the brass and centered the box so that there is about ¼ inch overlap around the perimeter of the box and drew a line around the box with a felt pen. I then cut the corners out with tin snips and bent the edges of the brass cover over in a vise. By drilling small holes around the perimeter of the box, inserting wires through the holes, soldering the wires to the inside of the box and to the overlapping edges you produce an RF tight enclosure. See Figure 2 for an example of this technique.


**Figure 2 — Sample of a box made with PC board with a sheet brass cover overlapping all four sides. Note the BNC connectors and feed through insulator.**

## Types of Construction

When you begin building your own radio equipment you will find that there are many different methods of mounting electronic components. There are methods employing single and double sided etched PC boards, perforated boards, Manhattan breadboarding techniques and others. My audio board and IF board are etched PC boards purchased from FAR Circuits. But the construction method I learned to appreciate the most is a method known as "ugly construction." This method was originally in the August 1981 issue of *QST* in which Wes Hayward, W7ZOI, described how he built the legendary "Ugly Weekender."

You can find a detailed description of this method in *Experimental Methods in RF Design*. An unetched copper clad board is used for a base (or ground plane). Begin building by starting at the circuit input and work towards the circuit output, soldering components in place as you go along. The ground side of components such as resistors, capacitor or ground leads of an IC are soldered directly to the ground plane. The wires coming from the top side of the component are used to connect to other components. When I have an IC in a circuit, I turn it upside down on the PC board, mark pin 1 with a black dot using a felt tip marker pen and then bend the ground lead over and solder it to the ground plane. That holds it in place while I make the other connections. As I solder components in place, I draw a picture diagram of each component and the connecting wires. I use a red pencil to draw dc power lines, and a different color to draw control lines like TR switching lines, etc. This is a very important step, and it is particularly helpful when troubleshooting a circuit that isn't working.

The beauty of the ugly construction method is you can see all the wiring. You do not have to turn it over to see where the connection leads are as you do with etched PC boards as the traces are on the bottom of the board and the components are on the top. (This is not the case with surface mountings techniques but that is another story.) Ugly construction is particularly appreciated after you have built a board and mounted it inside one of the boxes you made. You don't have to take the board out to make changes to a circuit because everything is on the top of board. Also you can build a circuit using the ugly construction method much more quickly than laying out a PC board design, etching it, drilling holes and then mounting the components.

Once you become proficient in building "ugly" style, you won't go back to etched circuit boards unless you plan to make many boards of the same circuit.

## Hooking it all Together

Each module is designed for an input and output impedance of 50 Ω except for the audio output that, in my case, is 8 Ω for speaker connection. Thus I am able to employ 50 Ω coax cable with BNC connectors to connect the RF paths between the different modules. An added benefit of this construction method is that if I decide in the future to try a different

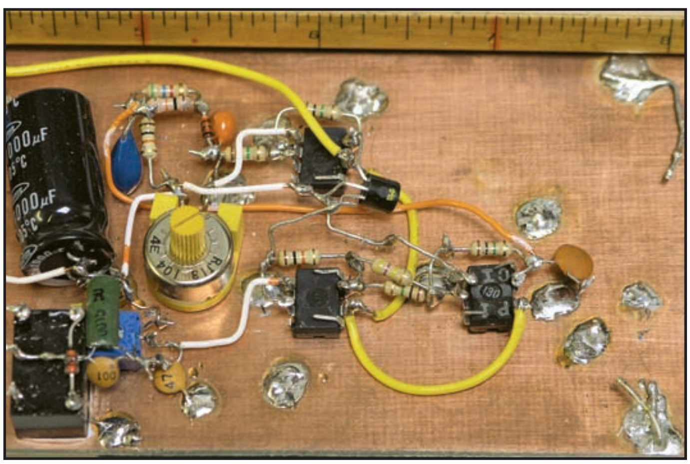


**Figure 3 — Sample of "ugly construction" method.**

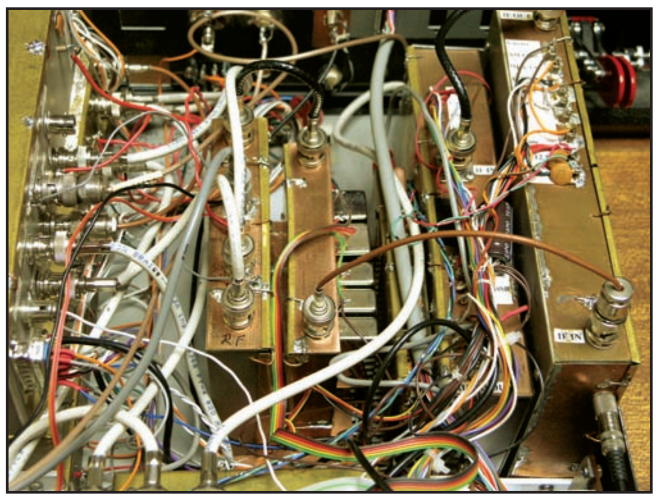


**Figure 4 — The inside of the HBR200. All the boxes are connected together with 50 Ω coax and BNC connectors for the RF runs. All dc power and control leads, in and out of the boxes, are through feed through insulators.**


**Figure 5 — The VE7CA work shop shows some of the home built and surplus test equipment used in the construction of the HBR-2000.**

circuit for a particular module, I build the new circuit and mount it in a new box, disconnect the old design and insert the new one in its place. In fact I have already done this very thing on several occasions. I tried three different front end receiver mixer designs before settling on the final mixer design. Since I had more than one mixer circuit, all in separate boxes, I was able to make accurate, comparative measurements by substituting one box for another, thus allowing me to make an educated decision as to the mixer design I was going to keep.

## Measurements

Making meaningful and accurate measurements is a major part of producing a successful project. You must make measurements as you progress in the building process or you have no way of knowing whether a module is performing according to your design specifications. Let's look at it this way. If you are building a receiver and you want it to be competitive in the HF bands, it should be able to detect a very weak signal, say –130 dBm (0.07 µV). In order to make this weak signal audible, it has to be amplified by the receiver to a certain level. I decided from experience that, 2.5 $V_{PP}$ into an 8 Ω speaker, at maximum volume, was sufficient.

If I inject an S3 signal at 14.025 MHz into my receiver antenna input, and turn the audio volume control to maximum setting, my scope reads 2.5 $V_{PP}$ across the speaker leads and the tone I am listening to is loud. It just didn't happen that way. Each module has either gain or loss. RF band-pass filters, IF filters and mixers are generally lossy. So, loss in one stage has to be compensated for by gain in other stages, typically the IF stage and the audio stage. Once the distribution of gain is decided upon by the designer, the gain of the different stages must be measured to ensure that they are performing as designed. This requires the use of test instruments.

As an example, if one wants a double balanced mixer to perform according to the manufacturer's specifications, the LO port has to be driven with the correct level of RF power and at the right impedance. One of the specifications I had chosen for the HBR-2000 was that it should have a very strong front end. To accomplish this I chose a mixer that requires that the LO port be fed with +17 dBm at 50 Ω. Having the test equipment to measure these parameters gave me the assurance that I was going to obtain the results I was looking for.

## Test Equipment

When I decided to build my dream transceiver I began the process of either building or purchasing surplus test instruments. I built crystal controlled, very low power oscillators and attenuators to measure receiver sensitivity. I also built high power oscillators and a combiner to measure receiver blocking and dynamic range. In addition I purchased a used oscilloscope and later was able to find a used signal generator. I also built a spectrum analyzer, which turned out to be one of the most useful instruments, since my HBR-2000 has 19 band-pass filters and 22 low-pass filters. You will find instructions how to build this instrument in the August and September 1998 issues of *QST* in an article by Wes Hayward, W7ZOI, and Terry White, K7TAU. Later I built the RF power meter featured in June 2001 *QST*, authored by Wes Hayward and Bob Larkin, W7PUA. These instruments allowed me to adjust and measure the performance of each module that I built. Of course all measurements are carefully entered into a journal for future reference in case of a problem.

Be resourceful when collecting test equipment. Check your local ham club. You


**Figure 6 — The 100 W amplifier board.**

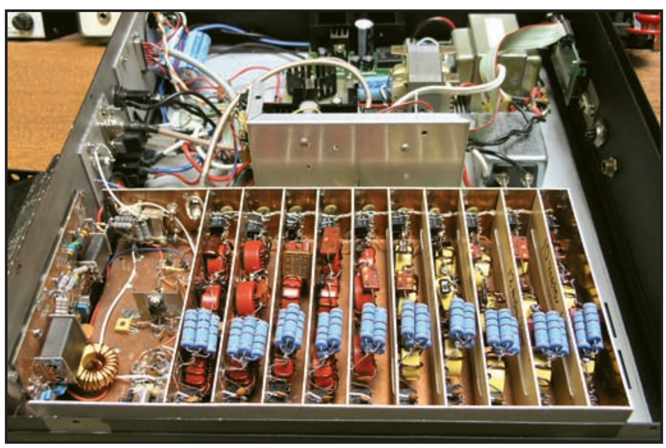


**Figure 7 — The 100 W amplifier, 10 low pass filters and the power supplies are located in separate subenclosures.**

**Figure 8 — VE7CA's partly homebrew Amateur Radio station.**

**Table 1**
**HBR-2000 Test Measurements**

| | | | |
|---|---|---|---|
| Image rejection all bands: | >135 dBm. | | |
| Spacing: | *20 kHz* | *5 kHz* | *2 kHz* |
| Two-tone blocking dynamic range: | >126.0 dB | 124.0 dB | 122.0 dB |
| Third-order intermodulation dynamic range: | 103.5 dB | 102.5 dB | 93.0 dB |
| Third-order intercept: | 25.5 dBm | 24.0 dBm | 14.5 dBm |
| Receive to transmit time: | 8 ms (incl 2 ms click filter). | | |
| CW, full QSK transmit to receive time: | 8 ms (30 WPM = 20 ms dot). | | |

may find that a member will even donate a piece of test equipment that is surplus or not being used when they find out you are building your own radio equipment. Other sources are ham radio flea markets, swap and shop nets or auction sites. You will be surprised how little you have to spend to assemble a good selection of test equipment.

## Other Circuits

Here are some of the sources used for deciding on the circuits for the other modules in the HBR-2000 design. The VFO design is from *QST* June 1991, "Build a Universal VFO" by Doug DeMaw, W1FB. The first mixer, post-mixer amplifier and crystal heterodyne oscillator design was taken from "A Progressive Communication Receiver" design by Wes Hayward and John Lawson, K5IRK, which appeared in November 1981 *QST* and was also featured in *The ARRL Handbook* for many years. This is a classic radio article with many good circuit ideas. The IF subsystem design is from B. Carver, K6OLG, "A High-Performance AGC/IF Subsystem," May 1996 *QST*, pp 39-44. The receiver input RF band-pass filter and diplexer designs along with the noise blanker and 100 W amplifier circuits were taken from the John Stephensen, KD6OZH, three part series beginning in the May/June 2000 issue of *QEX* titled "The ATR-2000: A Homemade, High-Performance HF Transceiver." The BFO and power supply circuits were lifted right out of *The ARRL Handbook*. The transmitter portion of the transceiver consists of combinations of various circuits found in *Experimental Methods in RF Design*.

It is no secret; all the circuits you need to build a high performance transceiver are available in the various ARRL publications mentioned in this article.

## Receiver Specifications

There may be some reading this article who question whether an amateur can build a competitive grade contest class transceiver from scratch. For the skeptics, the actual measured performance [confirmed in the ARRL Lab — *Ed.*] of the HBR-2000 is shown in Table 1.

Receiver sensitivity measurements on all bands are within ±0.5 dB of –130 dBm. All measurements were made with an IF filter bandwidth of 400 Hz. Test oscillators are two separately boxed crystal oscillators, low-pass filtered and designed for a 50 Ω output impedance. MDS measurements were made with an HP-8640B signal generator and a true reading RMS voltmeter across the speaker output.

The receiver measurements were made following ARRL procedures as outlined in the ARRL "Lab Test Procedures Manual." If you are an ARRL member, you can find a copy of this document at **www.arrl.org/members-only/prodrev/testproc.pdf**. Making accurate receiver measurements is not a trivial matter and should be approached with the understanding of the limitation of the test equipment being used and thorough knowledge of the subject.

The question I am often asked is, "Is it possible for a ham to build a transceiver that is comparable to high performance commercially available Amateur Radio transceivers?" I am here to tell you it is possible. Recently I had the opportunity to compare my HBR-2000 to a high end commercial transceiver that is used by many major contest station operators. I found that on many occasions during the March 2005 ARRL CW DX Contest that while using the HBR-2000, I was able to hear and work very weak DX stations that were sandwiched between two very closely spaced, strong local stations calling CQ (50 to 60 dB over S9). On many occasions the same weak DX station was not discernible in the commercial transceiver. Why? Because I employed a single conversion receiver design with a very good 250 Hz IF filter following the first mixer. The commercial transceiver has a 6 kHz wide roofing filter in the first IF so that the two very loud CW signals were within the same filter bandwidth as the weak signal and together they produce intermodulation distortion products and close-in synthesizer noise that covers up the weak signal. You have to hear it to believe it.

You may notice that I have not made any attempt to miniaturize the HBR-2000. Modern transceivers tend to use closely spaced small knobs except for perhaps the VFO. While you are adjusting one knob, it is easy to touch and move another knob and not know it. Also, many functions employ concentric knobs with very small labels that I find hard to read in low light. Small is great for portable rigs, but for a home station transceiver you should be able to adjust one knob and not have to worry about touching another. With large knobs and large labeling, I am able to operate my transceiver without the need for my reading glasses. By building my own equipment I am the one who decided the receiver front panel layout, what size knobs I was going to use and where they would be located. That is a real bonus!

Building something with my own hands provided me with a lot of enjoyment. Therefore, I was not in a hurry to finish building the HBR-2000. Why hurry to build something? When it is finished you have to find another project to build to satisfy the enjoyment you feel while building. It took me five years, while also working full time, to completely finish the HBR-2000. I had the receiver working after two years and the transmitter portion took another two years followed by one more year refining the QSK circuit, adding a noise blanker and a 100 W power amplifier. You may say that is a long time but I feel it is worth it. I am now enjoying the fruits of my labor.

**Notes**

[1]Available from your ARRL dealer or the ARRL Bookstore, hardcover ARRL order no. 9493, softcover ARRL order no. 9485, Telephone 860-594-0355, or toll-free in the US 888-277-5289; **www.arrl.org/shop/**; **pubsales@arrl.org**.

[2]Available from your ARRL dealer or the ARRL Bookstore, ARRL order no. 8799, Telephone 860-594-0355, or toll-free in the US 888-277-5289; **www.arrl.org/shop/**; **pubsales@arrl.org**.

*Markus Hansen has been an Amateur Radio operator since 1959. He has no formal electronics training but likes experimenting and writing articles about his experiences. He has had articles published by the ARRL in* QST, QEX *and the* Antenna Compendium *series. You will find Markus in many of the HF CW contests as well as on 6 meters. He is always on the outlook for the last few countries that he needs for the DXCC Honor Roll. His Web site,* **www.shelbrook.com/~ve7ca**, *describes additional technical details about the HBR-2000 as well as other homebrew projects and antennas that he has built. You can reach Markus at 674 St Ives Cres, North Vancouver, BC V7N 2X3, Canada, or at* **ve7ca@rac.ca**.

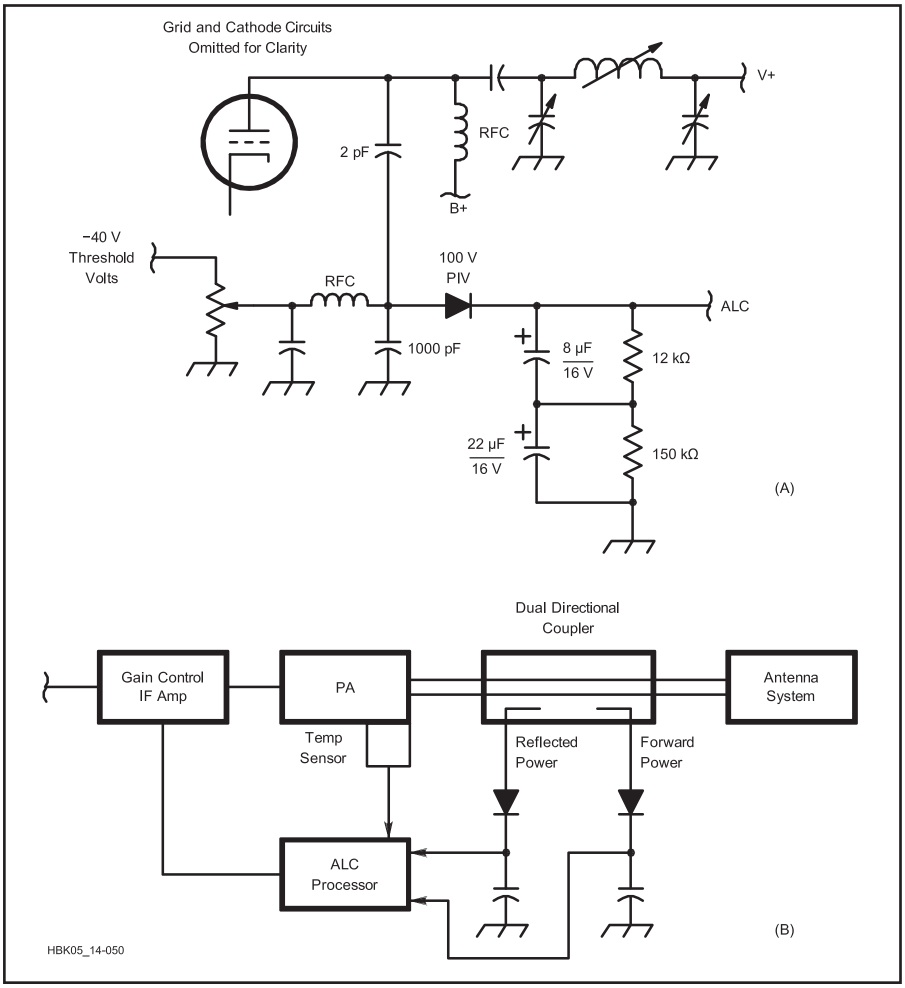



**Fig 13.38 — At (A), an ALC circuit with speech processing capability. At (B), protection method for a solid-state transmitter.**

## *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.

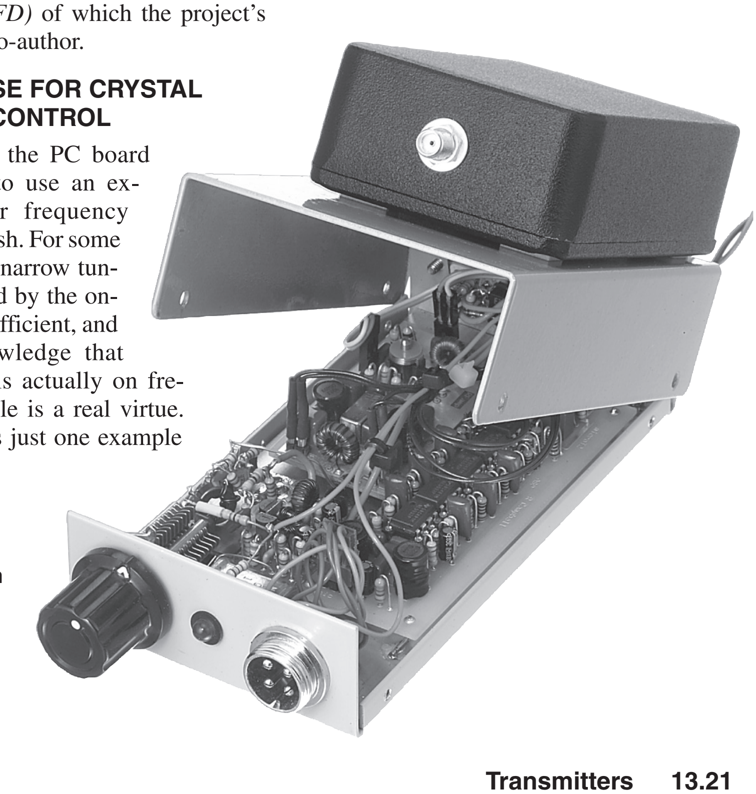


**Fig 13.39 — This 40 meter version of the MicroT2 uses the on-board VXO. The black box on top is the 0.5 W amplifier.**

### 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

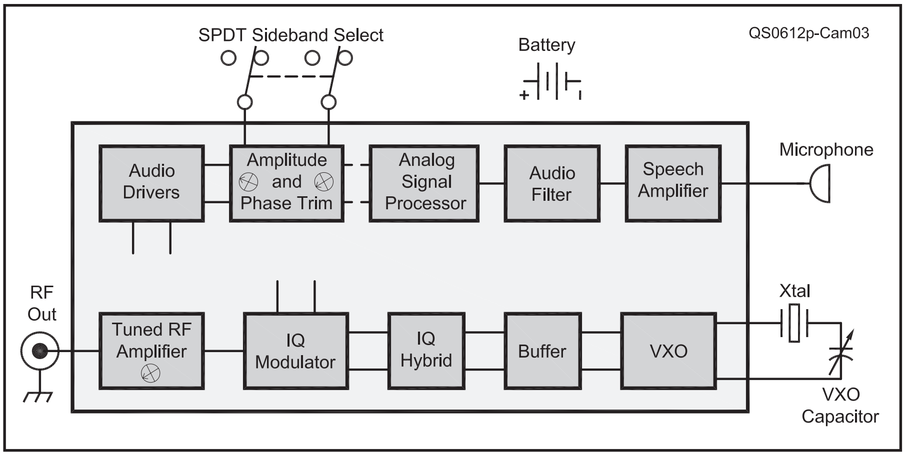



**Fig 13.40 — Block diagram of the circuitry on the PC board.**

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

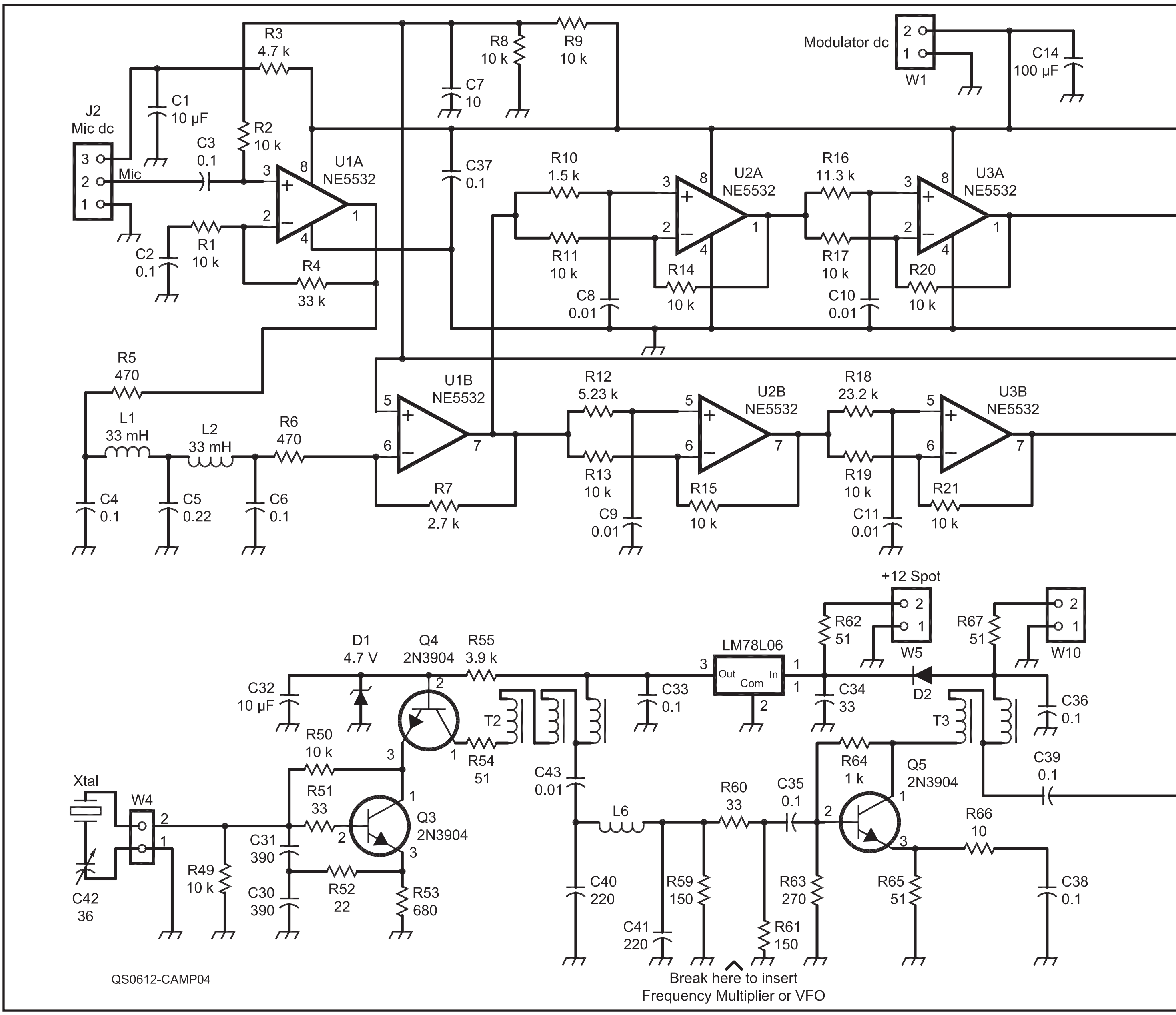



**Fig 13.41 — Schematic diagram of the 40 meter version of the MicroT2. See Table 13.1 for parts values. A kit version including parts and PC board is available from Kanga US (www.kangaus.com).**

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

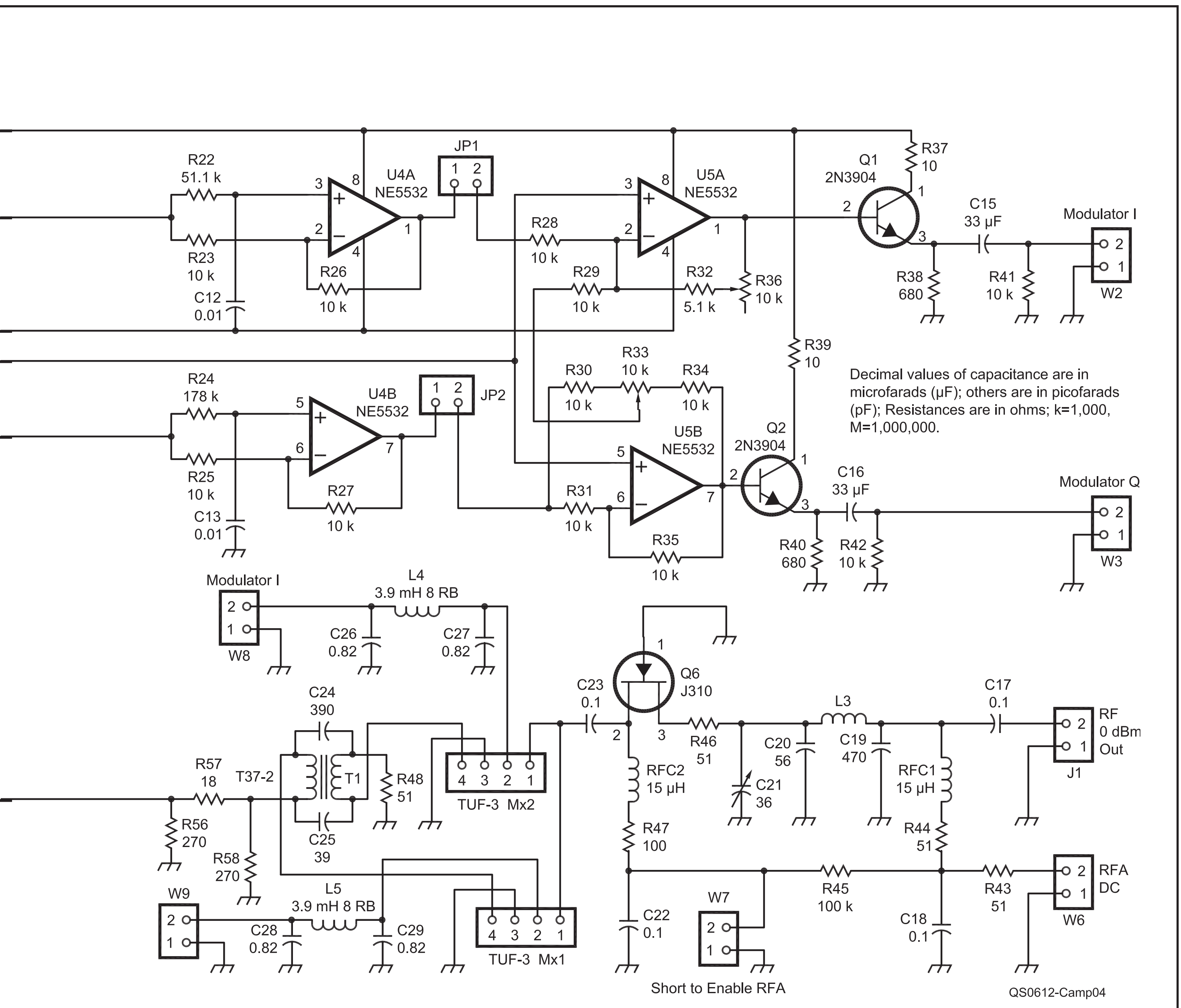


**Table 13.1**
**MicroT2 Parts List**

**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 $-j50$ Ω 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 $+j300$ Ω at 7.2 MHz, L6 should be $+j100$ Ω at 7.2 MHz and each winding of T1 should be $j50$ Ω 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

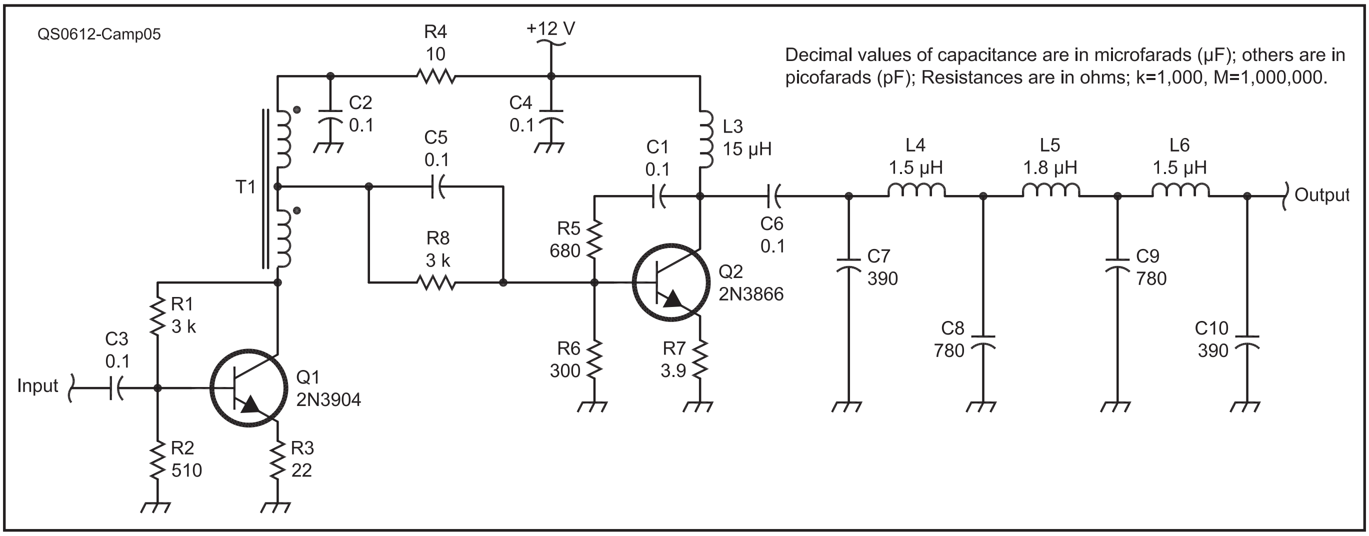



**Fig 13.42 — Schematic diagram of 0.5 W power amplifier with low-pass filter shown in the photographs. T1 is 10 turns of #28 enameled wire bifilar wound on an FT37-43 toroid core.**

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

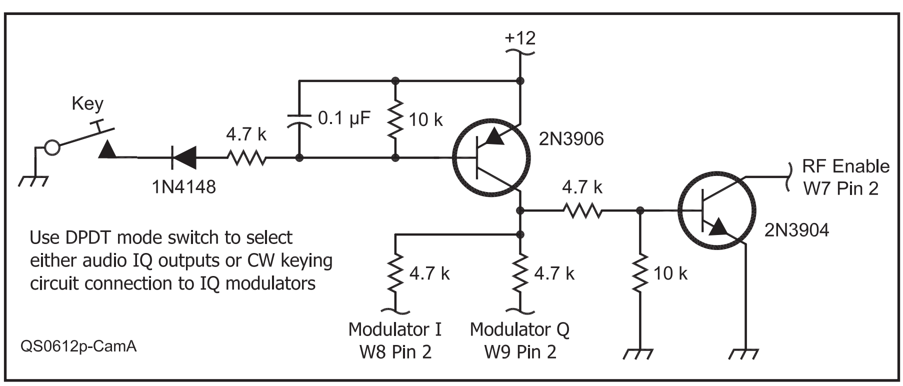



**Fig 13.43 — Schematic diagram of suggested keying circuit.**

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.**

**Hamish Kellock, OH2GAQ**

Haltiakallio4, Espoo 02300, Finland; **hamish.kellock@pp.inet.fi**

# A Microwave Transverter Controller

*Flexible, sophisticated control of multiple transverters from a single point.*

For many years I have been interested in VHF, UHF and microwave experimentation, and this controller is one of the outcomes of these interests. The unit is self-contained, and collects many of the functions needed to operate and control a microwave station on many bands from 1296 MHz upwards. Incorporated in the design is a formalized and relatively simple interface to connect the controller to any high or low power microwave transverter (such as 1296 MHz, 10 GHz, 24 GHz and higher frequencies), so that full multi-band station control can be made from a single unit, and band selection can be made also, with direct readout of the transmit frequency and/or receive frequency. Up to four different transverters can be connected at any one time to the controller.

A conventional way to proceed to make a microwave station, especially for portable operating, is to use a small commercial transceiver (such as an ICOM IC-706 or similar) at 144 MHz, then use it to drive the microwave transverter(s). For fixed station use a similar approach is used, but with perhaps a higher quality transceiver being employed. A collection of additional control and sequencing units, interfaces to computers, frequency stabilizing units and so on are employed to complete the station. As most commercial transceivers with acceptable performance are generally able to deliver up to 100 W PEP SSB, the electrical efficiency is somewhat low at the level needed for a typical transverter, which is generally 1 to 10 mW, or maybe up to a few watts if the transverter has an appropriate attenuator either built in or used externally.

Figure 1 shows the block diagram of the OH2GAQ Microwave Transverter Controller, while Figures 2, 3 and 4 show photos of the finished prototype. The overall unit size is 260 mm wide × 95 mm high × 315 mm deep, which is quite comparable to a typical table-top transceiver. The power supply for the controller is 12 V and 26 V dc.

The functions included in the Controller are:

- Microphone preamp and simple audio clipping, level control and band-pass filtering.
- Transformer-isolated input from a computer-generated analog audio signal.
- Switch selected audio source.
- Upper/Lower SSB generation (at 9 MHz, filter type) and up-conversion to an output signal in the range of 28 to 30 MHz.
- A direct digital frequency synthesizer to generate the LO for up-conversion of the 9 MHz SSB signal. The DDS reference is derived from a 10 MHz Rubidium reference oscillator incorporated in the unit.
- A Rubidium reference oscillator and low-noise distribution amplifier, including a 50 Ω line driver to route the reference to a bank of remotely located microwave transverters.
- A 144 MHz transverter, with 10 mW output, using the same reference oscillator at 116 MHz as the DDS to ensure adequate frequency stability. The transmit side is supplied with 28 MHz SSB; the receive side is fed to an external receiver.
- An ICOM compatible CI/V output to allow control of a typical ICOM receiver such as the R75, used by the author as a tuneable IF at 28 MHz.
- Muting control for the receiver during transmit.
- Receiver audio conditioning and an isolation transformer to allow connection of the received signal to a computer analog audio interface.
- Control input from a computer to allow computer-controlled receive/transmit switching when this mode is selected.
- A microprocessor-based control module to control and monitor all of the above, and with interfaces to a computer (using either R232 or USB-2) and up to four microwave transverters. The transverter interface has a transmit signal output, a transmitter health signal input and a couple of analog monitoring signal inputs as well.

## Implementation Details

The main functional blocks in the controller are made from a combination of commercially available units or kits, possibly with some modifications, and some items that are designed as part of the controller. The commercial items used have generally been chosen on the basis of performance versus cost and/or availability.

Modules that have been designed as part of the project have normally had schematic capture and layout done by using the *Eagle CAD* tool, although the SSB generator and crystal PLL were originally designed using a simple computer drawing tool. *Eagle* has been an excellent tool for schematic capture and later layout. The main controller board was manufactured by a circuit board manufacturer, because it has large numbers of through holes. All the others were made at home by using a laser printer onto photo paper, then thermally transferring the pattern onto the circuit board stock before etching. There have been several good descriptions of this method, which can generally be found by searching the Internet or looking at the ARRL or RSGB *Handbooks*. The most challenging board was the crystal PLL oscillator, where the PLL chip (ADF4112)

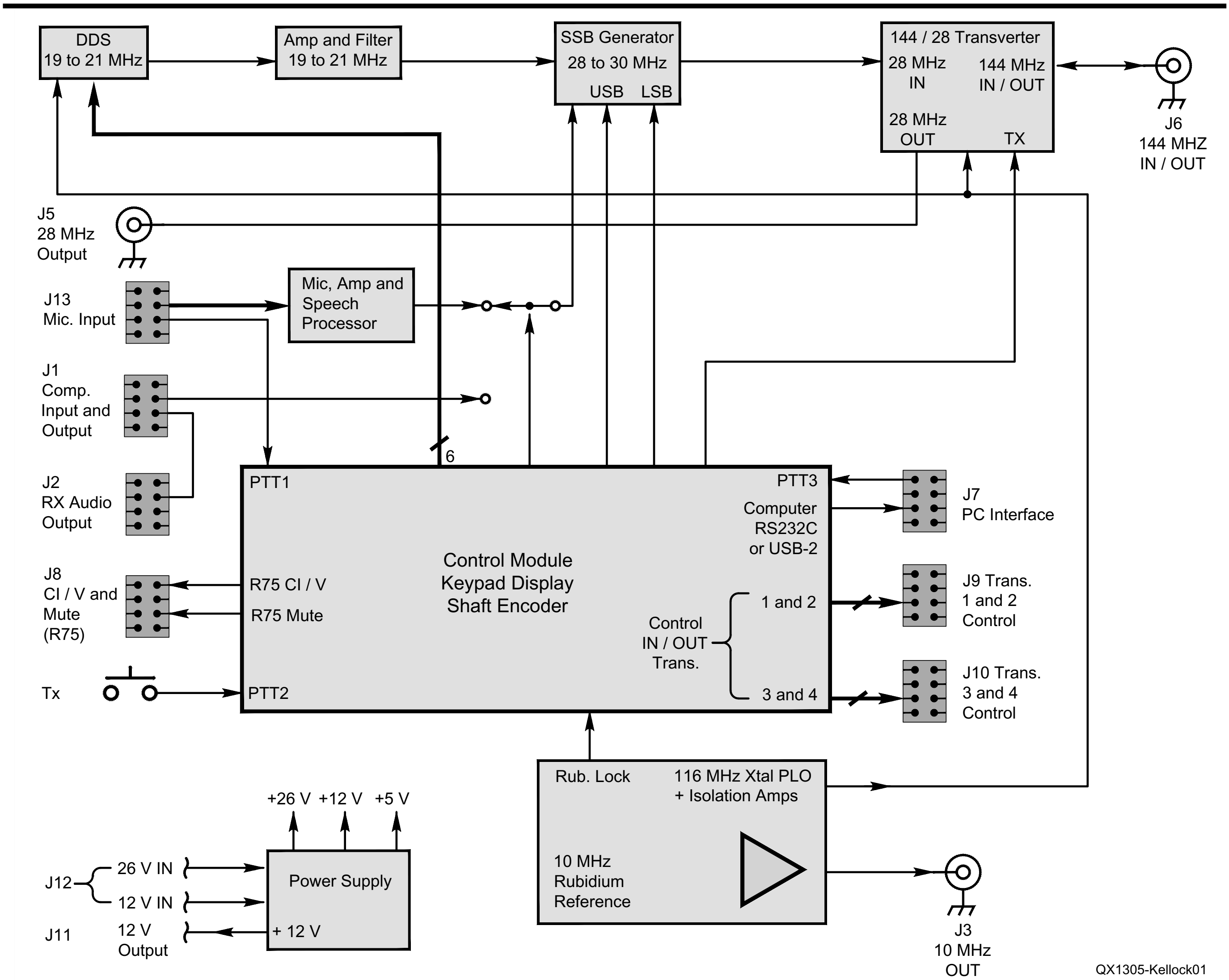



**Figure 1 — Block diagram of the microwave transverter controller showing all the main functional blocks and external interface connectors.**


**Figure 2 — An overall view of the microwave transverter controller.**

was in one of those incredibly small TSSOP packages.

I used a Datum LPRO Rubidium frequency reference. In order to ensure that the reference signal was as clean as possible with reasonably low phase noise, the 24 to 26 V dc power supply should have very low ripple and noise. The external power supply I used is a linear supply with less than 6 mV of ripple and noise. Of course, a GPS disciplined crystal oscillator could also be used, but the Rb reference provides adequate stability, and was available at low cost.

The 10 MHz signal from the reference is passed on to a buffer amp using an LM7171 op amp to drive the remote transverters and a signal conditioner using a 74AC04 CMOS buffer and signal shaper. This provides the input to the crystal PLL oscillator, which in turn provides the internal 116 MHz reference for the DDS and 144 MHz transverter. A simple transformer is used at the input to provide impedance matching and a voltage step-up. Figure 5 shows the schematic of the signal conditioning following the LPRO oscillator. It includes the 116 MHz isolation amplifiers, which are in the same module. A photo of the distribution amplifier module is shown in Figure 6.

The DDS unit uses James (WA1FFL) Hagerty's Advanced Direct Digital VFO circuit board employing the AD9951 DDS chip. (See the Further Reading section at the end of this article.) The reference oscillator is replaced with the 116 MHz from the crystal PLL and the AD9951 is directly controlled by the main controller unit without using the microcontroller on Jim's board. Other functions are used as-is. The filters have been replaced with lower frequency cut-off units since the DDS has to only generate signals from 19 to 21 MHz. This board provided a quick and effective way to get the DDS functionality. The DDS has adequate performance for this application with broadband noise and general spurs being more than 60 dB down. There are a couple of DDS spurs that exceed this level. This board is followed by a band pass filter and amplifier using a 2N5109 transistor to increase the available output to drive the 9 to 28 MHz double balanced mixer in the SSB generator.

I used a Down East Microwave model 144-28INT kit as the 28 to 144 MHz transverter, with the major modification being to supply the 116 MHz LO from the external crystal PLL oscillator unit. The modification can be accommodated on the 144-28INT board quite simply, with only one short wire link being needed.

The 116 MHz crystal PLL (the same circuit with slightly different component values is used in all my crystal PLL applications in various transverters) uses

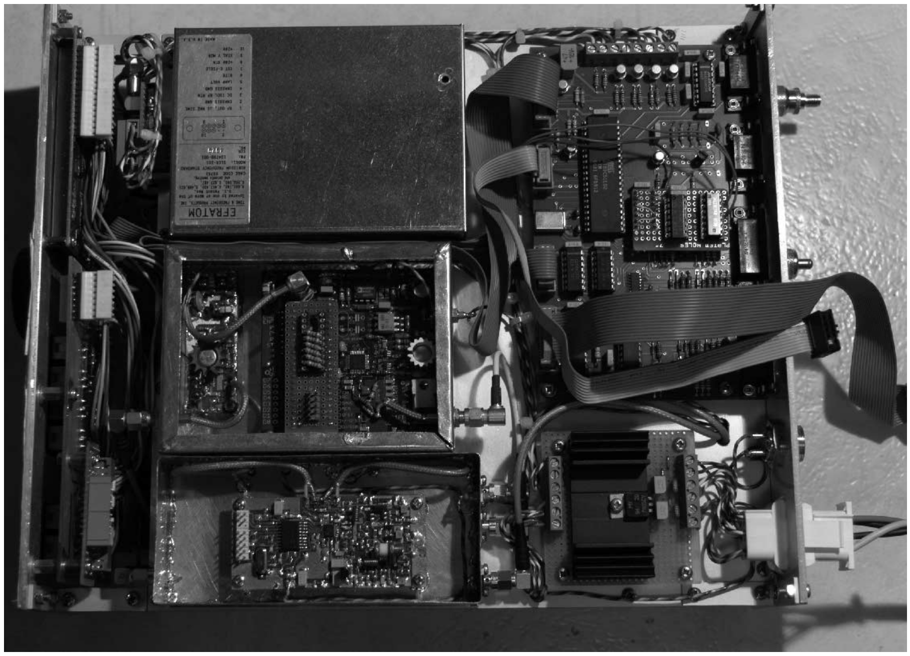


**Figure 3 — Top view of the prototype controller, showing (clockwise from the top left) the 10 MHz Rubidium reference, the controller board with external interfaces, a small power supply, the 116 MHz PLL oscillator and distribution amplifiers and the DDS synthesizer and amplifier. Note that the small protoboard plugged into the main controller board allows programming the processor in-situ. It is not needed for normal operation. Some cables have been unplugged to better show the DDS unit.**

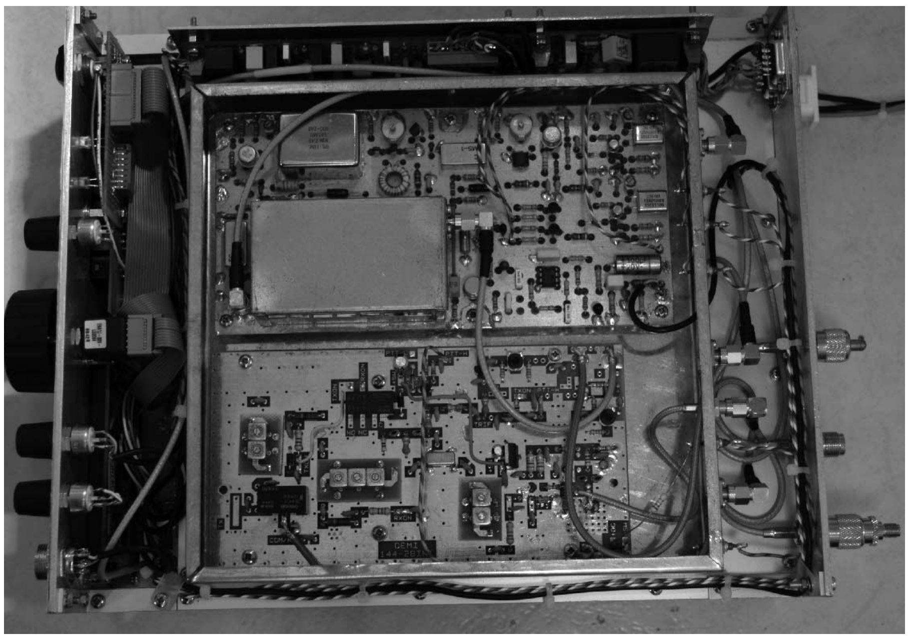


**Figure 4 — Bottom view of the controller, starting from the bottom is the Down East Microwave transverter and the 28 MHz SSB generator, both in a tinplate enclosure. Above them is the audio processing amplifier and computer interface.**

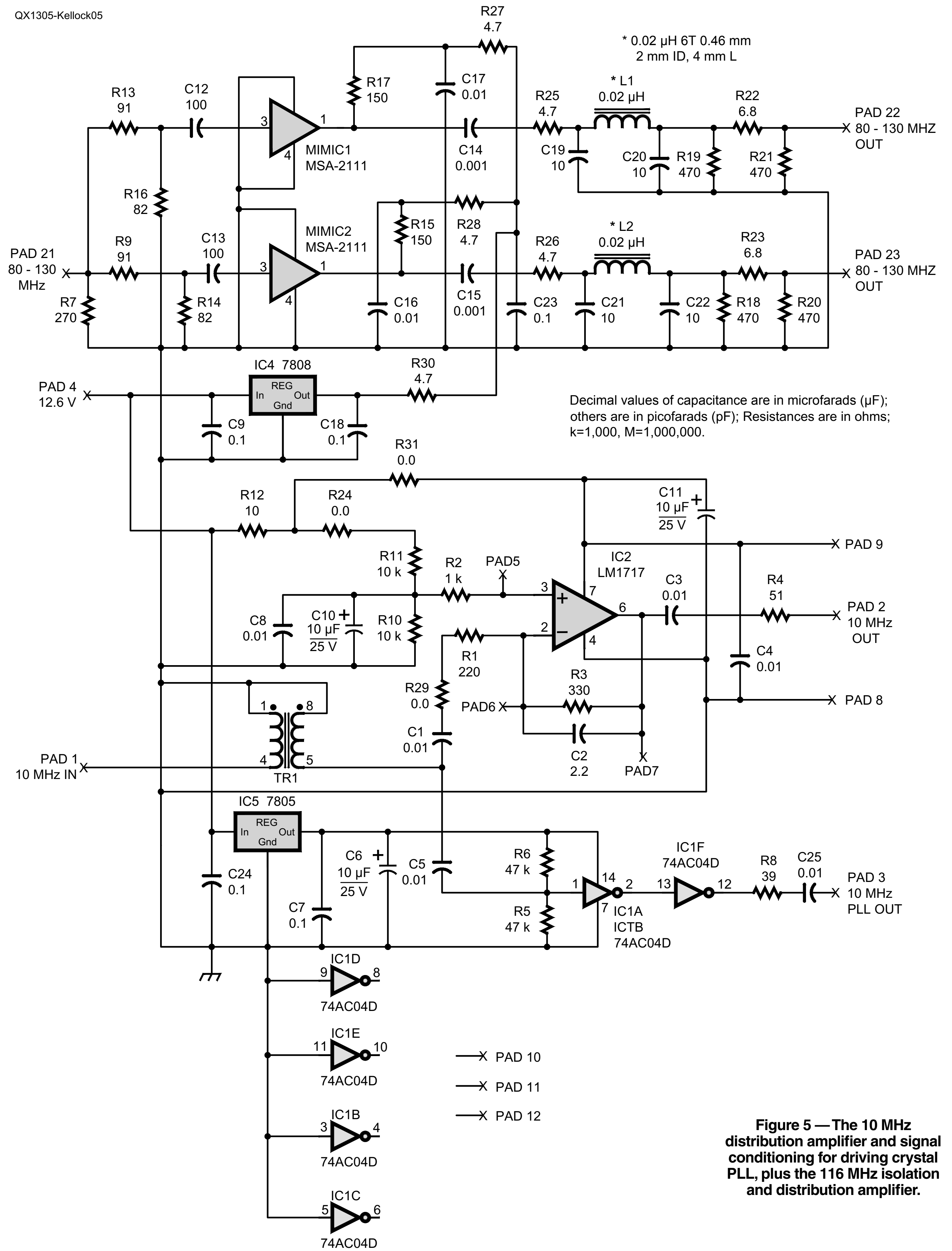



**Figure 5 — The 10 MHz distribution amplifier and signal conditioning for driving crystal PLL, plus the 116 MHz isolation and distribution amplifier.**

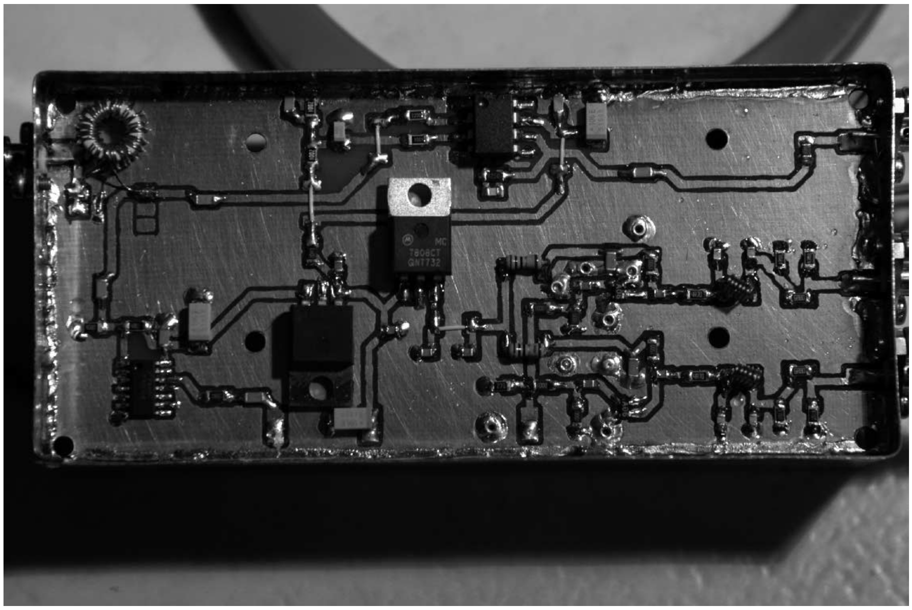


**Figure 6 — The 10 MHz amplifier (top of module), 10 MHz interface for crystal PLL oscillator (lower left of module) and the two 116 MHz isolation amplifiers (lower right).**

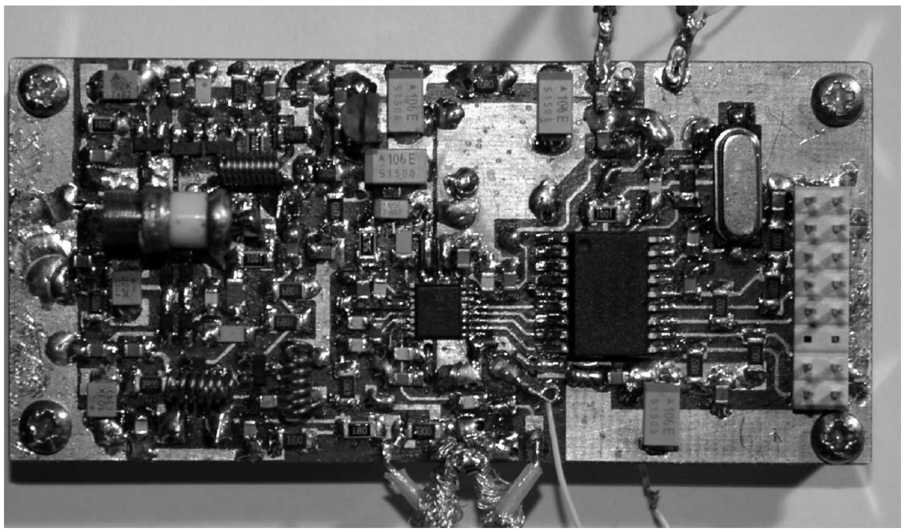


**Figure 7 — The 116 MHz crystal PLL oscillator. The crystal and heater are mounted on the backside of the circuit board. The small HC-49 crystal seen here is for the PIC16F84A microcontroller (the largest chip on the board). The ADF4112 is the small chip almost in the middle of the board. Note the cut in the ground plane which extends under the ADF4112 chip. This separates the digital and analog ground planes.**

the stable and low-noise oscillator circuit developed by John Hazell, G8ACE, which seems to be similar to in approach to the work of John Stephensen, KD6OZH. To phase lock the crystal oscillator, a simple PLL using the ADF4112 has been added and a PIC 16F84A has been used to load the ADF4112 parameters at power up. A 40°C heater (Kuhne QH40A) is used to ensure the crystal temperature is constant. The circuit board is shown in Figure 7.

The circuit board has a solid ground plane on the back side; the crystal with its heater and one power regulator are mounted there. In order to reduce noise in the crystal oscillator, the ground plane on the component side is divided into two parts, with the digital ground being separated from the oscillator and PLL analog grounds in an attempt to reduce noise. There is a pin header on the right side of the board, which is used to program the PIC and later during operation to select which crystal frequency is being used (so a single program can be used for many applications such as LO for 1296 MHz, 2320 MHz, 24048 MHz or other bands). The software for the PIC is developed using Microchip's *MPLAB IDE*, where it is also possible to simulate the software operation and debug it, including the state of the input pins.

After the 116 MHz oscillator, a pair of simple resistive attenuators divides the 116 MHz signal, which is then amplified with a couple of HP MSA2111 MMICs to provide some isolation between the DDS and the 144/28 MHz transverter. The output level for each channel is about +8 dBm. These isolation amps have been combined with the 10 MHz reference distribution as mentioned earlier. The whole sub-system, including the 116 MHz PLL oscillator, is shielded in a small tinplate box.

Now let's have a look at the SSB generation. There are a few small circuit boards used to pre-condition the audio signal from a dynamic microphone. The signal is first amplified, filtered and clipped. Then, a relay is used to select either the microphone-derived audio, or that from a computer sound card (for JT65 or similar operating). Following this, the audio is passed on to the main SSB generator circuit board. Figure 8 is the schematic of the AF Preamp and switching scheme.

The main board for the SSB generator was designed and built many years ago and is a completely conventional 9 MHz filter type SSB generator. Two separate crystal oscillators generate 8.985 and 9.015 MHz carriers, one of which is applied to an SBL-1 mixer depending on whether USB or LSB is desired. The DSB output from the mixer is amplified, filtered and the resulting SSB is amplified before being mixed with the DDS-derived LO to up-convert the 9 MHz signal to 28 to 30 MHz. A band pass filter and amplifier follows the mixer. The resultant 28 to 30 MHz signal is applied to the Down East Microwave 28 to 144 MHz transverter. Figures 9 and 10 show the SSB generator schematic.

The overall performance of the SSB generation system is such that the carrier is suppressed by at least 60 dB and spurious outputs are at least 50 dB below the carrier level when measured at 144.5 MHz.

Miscellaneous analog signal functions like the computer interface are handled by a small unit. In order to keep noise down, isolated transformer coupling has been used between the computer soundcard (a Delta 44 card in my case) and the transverter controller.

The heart of the controller is the microprocessor based control board. A separate file, *kellock.zip*, downloadable from the *QEX* files website (**www.arrl.org/qexfiles**), contains schematics of the control

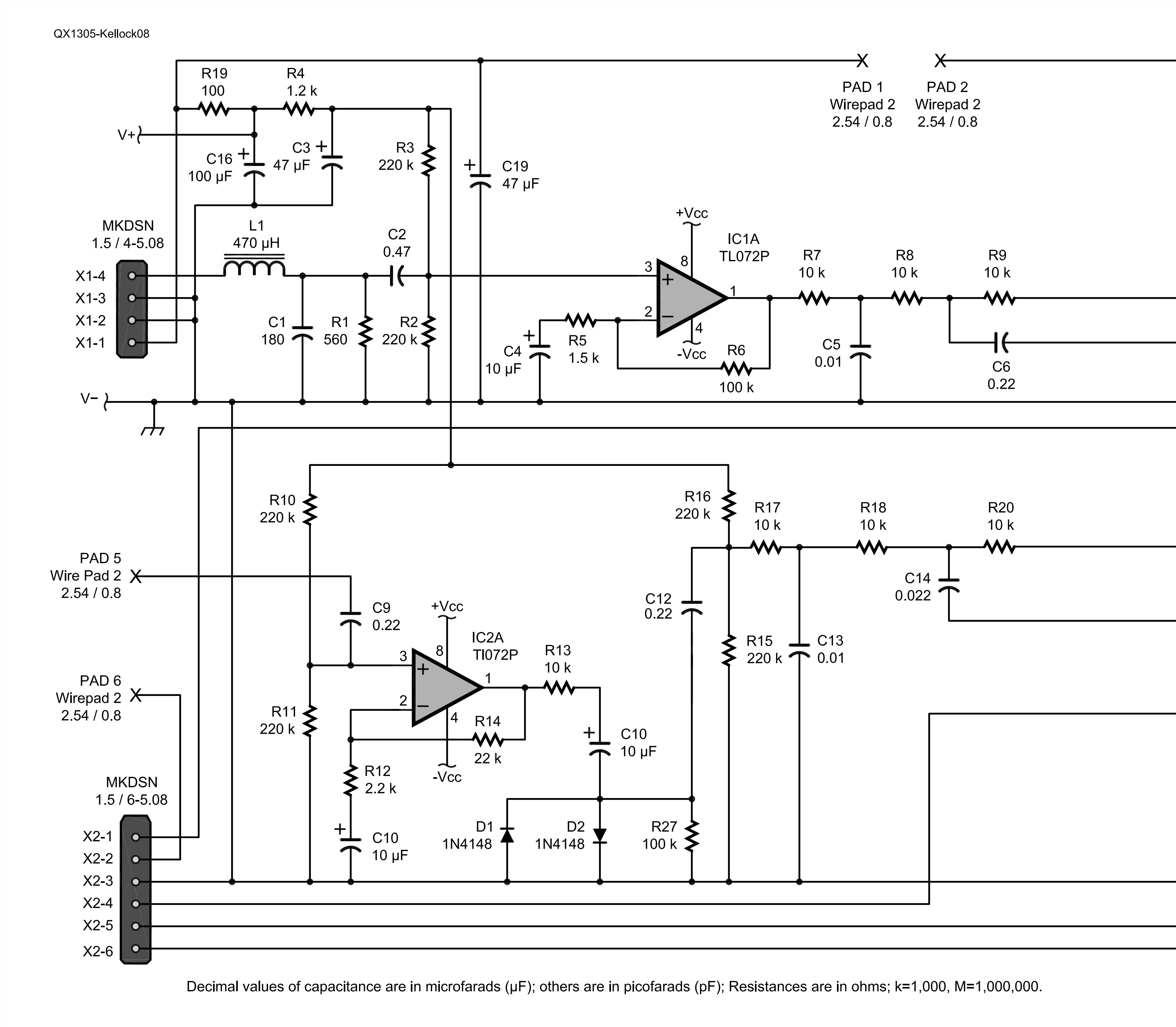
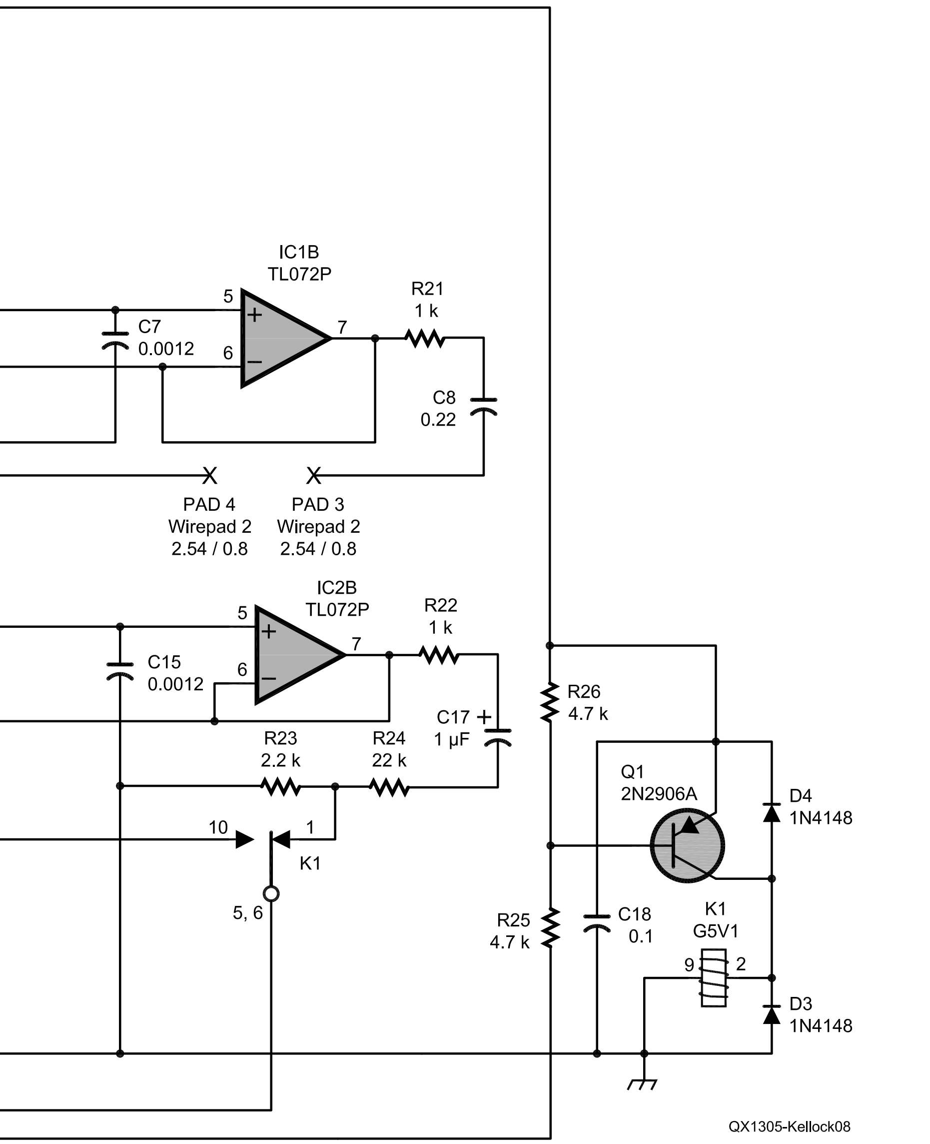



**Figure 8 — Microphone pre-amp, audio clipping and local/remote switching for audio selection. P pads 1, 2 and 3, 4 and 5, 6 are used to place wire bridges, allowing a single sided circuit board. The microphone is connected to X1-4 and 12 V power to X1-1. Gain control (a 10 or 20 kΩ potentiometer) is connected to X2-1, X2-2 and X2-3. A second 10 kΩ potentiometer (for level adjustment) is connected to X2-5 and X2-3; the wiper is connected to the microphone input on the SSB generator in Figure 10.**



IC1B
TL072P
5
6
7
C7
0.0012
R21
1 k
C8
0.22
PAD 4
Wirepad 2
2.54 / 0.8
PAD 3
Wirepad 2
2.54 / 0.8
IC2B
TL072P
5
6
7
R22
1 k
C15
0.0012
C17
1 µF
R23
2.2 k
R24
22 k
10
1
K1
5, 6
R26
4.7 k
Q1
2N2906A
D4
1N4148
R25
4.7 k
C18
0.1
K1
G5V1
9
2
D3
1N4148
QX1305-Kellock08

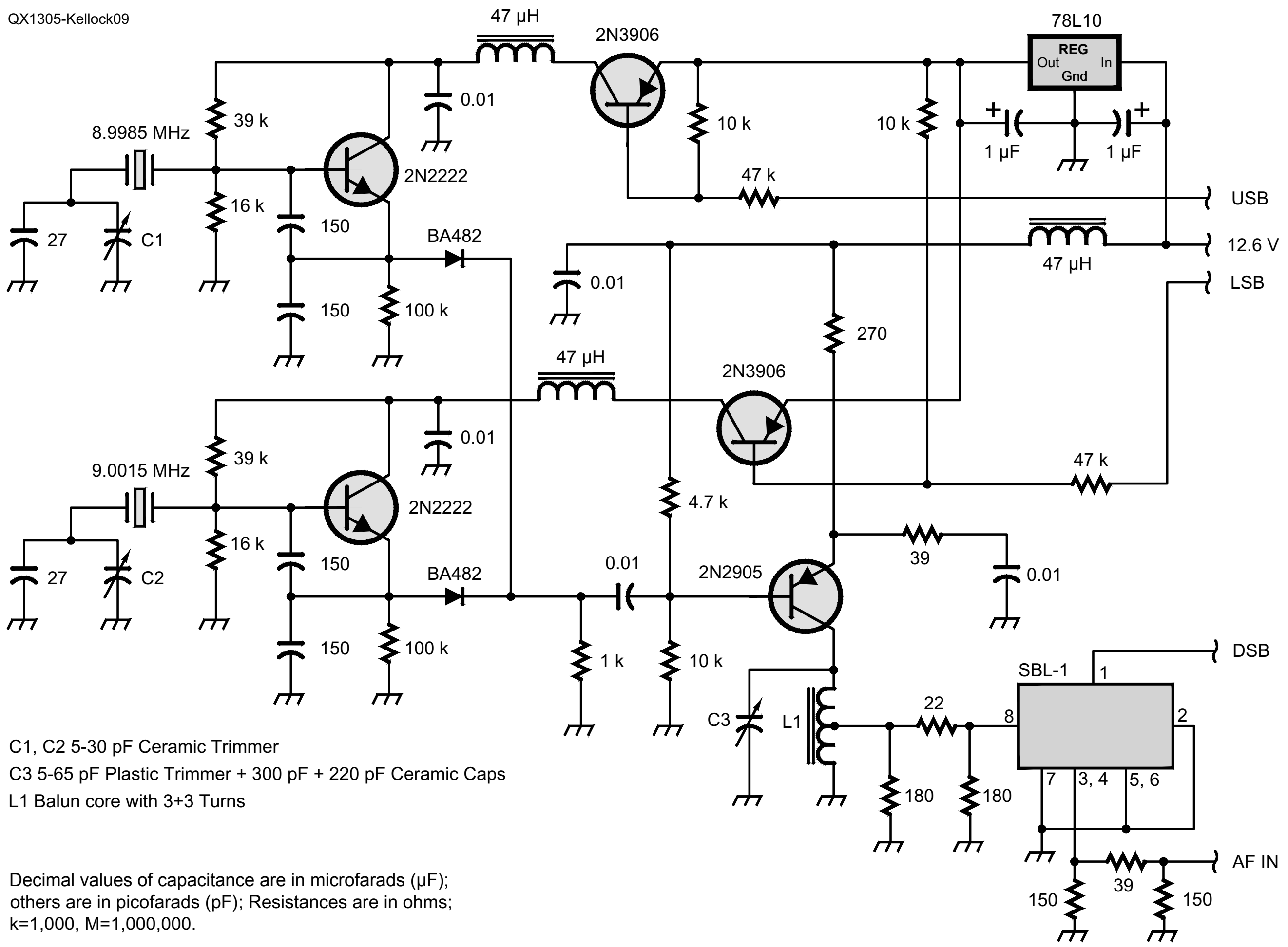



**Figure 9 — The 9 MHz carrier oscillators, switching circuit and DSB modulator.**

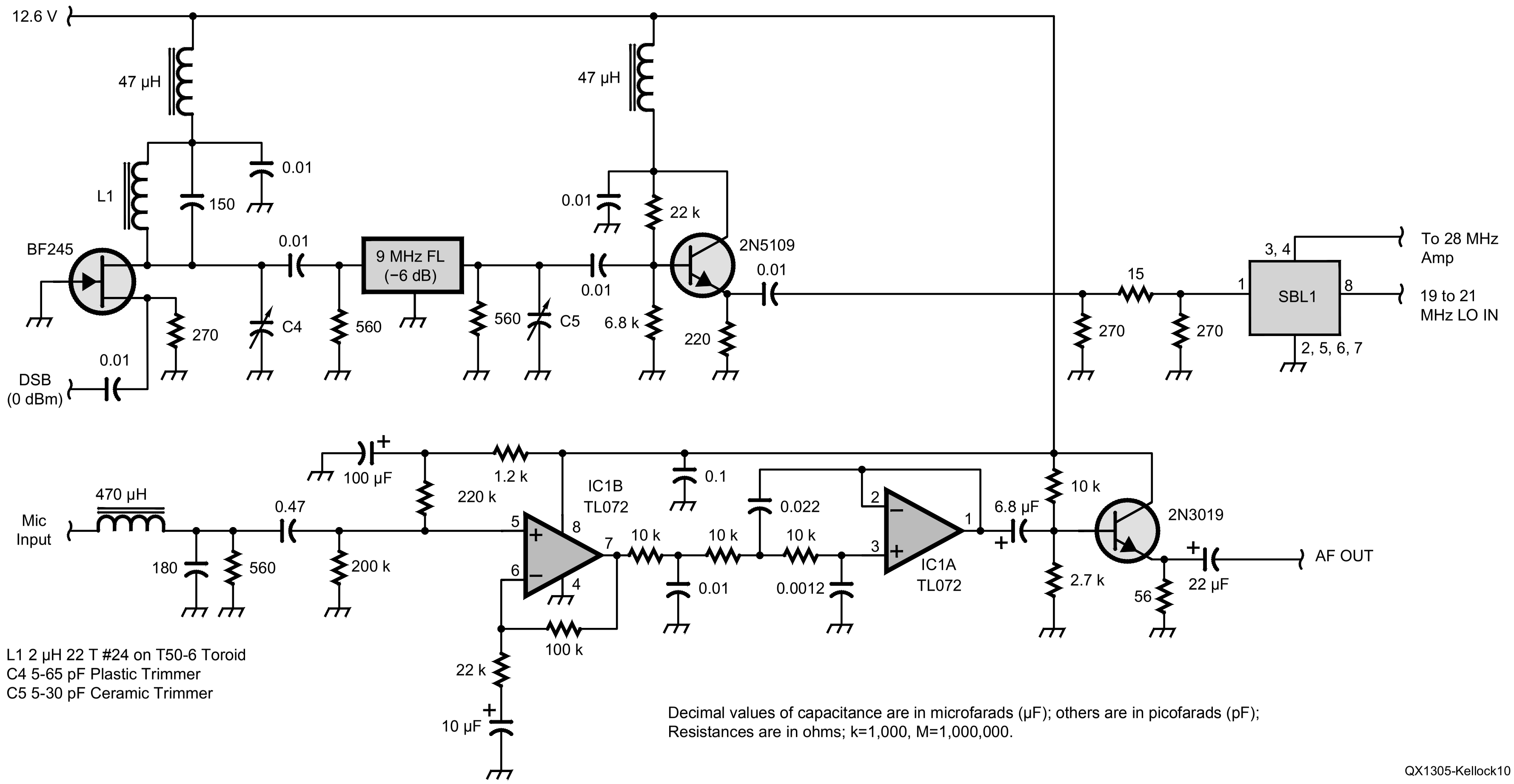



**Figure 10 — The DSB/SSB filter and second mixer, along with the audio amplifier. The microphone input comes from the level control in Figure 8.**

board and the PLL oscillator.[1] The processor used is one of the 8051 derivative processors, an Atmel AT89C51ED2. The circuit board was made for the 40 pin DIP variant of this processor, which is no longer generally available (other package versions are). The processor is augmented by adding a couple of MCP23S17 I/O extenders to give a few more input and output bits, plus an Analog Devices AD7888 8 channel A/D converter. The dial function is implemented by using a Bourns optical encoder, and IC9, IC8 and part of IC7 are used to implement an up/down direction sensing counter, which generates an interrupt to the processor for each count. The actual counting is done in the processor software. The CI/V interface (J8) is implemented using the remainder of IC7s inverters, plus a couple of transistors.

A partial RS232 or USB-2 interface (RXD, TXD and RTS) is implemented using either a MAX232 chip plus a DB9-F connector if RS232 is required, or an FTDI type DB9-USBD5-F module, which replaces the DB9-F connector on the circuit board. In that case, three wire jumpers replace the MAX232 chip, which is not required if a USB-2 interface is provided.

The interface to the external transverters is via J9 (two transverters) and J10 (two transverters). The digital outputs are driven by transistors, and the digital inputs are via transistors with resistor/diode clamping. The idea is that the actual transverters may be remotely located, and this scheme provides some protection and noise immunity for the digital inputs. The analog channels (two per transverter) are diode clamped. The outputs feeding them from each transverter should have a series resistance to limit the clamping current.

## Transverter Interface Operation

Figure 11 shows the generic functions expected to be found in a transverter, which can be controlled by this unit. This is illustrated by the particular example of a 1296 MHz transverter.

First a word about the simple interface signals. I considered using a serial interface between the transverter controller and the transverter, however, I decided that the added complexity and potential reliability issues, versus the better monitoring and control that could be obtained, were not worth the complexity. The main disadvantage of the simple interface in practice is that fault causes are not explicitly shown remotely, and the analog monitoring of the forward and reflected power may be subject to a bit of noise if the cable run is particularly long.

[1]Notes appear on page 19.

The control signals to and from each transverter are:

- To transverter: Transmit Request.
- From transverter: Transmit OK

The transmit command is generated by the controller based on the band selected, and the PTT or remote transmit request. Following application of the transmit command, the controller waits for the transverter to signal TX OK. If this is not received within the specified time interval (set to 400 ms by default), the transmit command is de-activated and the transmit fault indicator is activated. Similarly, if a transmit fault condition occurs in a transverter during a commanded transmission, the same happens. In my transverters all the "fast" protection is self-contained in the transverter itself to ensure that any expensive amplifier transistors are protected and that the protection is not dependent on any remote signals.

The analog monitoring signals from each transverter are:

- From transverter: Forward power (analog voltage)
- From transverter: Reflected power (analog voltage)

The forward power is displayed as a bar graph reading on the bottom line of the 20 × 4 line display used in the controller. The scale factor can be individually set in software for each of the four transverters. Reflected power is also displayed.

## Software Functions Implemented in the Controller

Figure 12 shows the display presently implemented in the controller, while Figure 13 shows the keyboard layout.

The software is implemented using 8051 assembler language compiled by the Systronix 8051 RAD51 IDE environment (which is available as a free download). Extensive use has been made of readily available math libraries for the 8051 (used in the frequency control of the DDS), plus some additional modules developed to handle 64 bit arithmetic. The software is downloaded to the processor flash over a serial line, using a small modification to the processor circuit board (a plug-in board and a couple of jumpers), with the *Atmel FLIP* (version 3.2.0) program.

### User Interface Features

Band selection is done by simply incrementing/decrementing by each push of the **Band Up** and **Band Down** buttons. As there are only four bands it's quite quick. The readout is updated to give the full frequency readout of the selected band.

USB and LSB selection is toggled by successive depressions of the **USB/LSB** button. The current mode is shown on the display.

Local or remote control is selected by successive depressions of the **Remote/Local** button, and the current selection is shown on the display. Remote control is used with JT65, for example.

The receive and transmit frequencies can be separate or locked. The transmit frequency is controlled by the controller DDS. The receive frequency is controlled by the companion receiver, in my case an ICOM R75. This is the state in the "Split" mode. In the "Combined" mode, the controller queries the frequency set on the R75 through the CI/V interface, and sets the transmit frequency to the same value. Therefore, the tuning of the whole system can be done by the R75 tuning dial (and if the R75 frequency is not correct, there will be a small offset between receive and transmit). Successive depressions of the **Split/Comb** button toggle the mode.

The frequency increment represented by each unit of rotation of the tuning knob is selected from 1 Hz, 100 Hz, 1 kHz or 10 kHz. These are presented by successive depressions of the **Resolution Up** or **Resolution Down** buttons, with the presently selected resolution being shown on the display.

The current settings of USB/LSB, Local/Remote, Split/Combined, Tuning Resolution together with the Current Frequency (which also gives the band selected) can be stored into non-volatile memory with the **Save** button, and the last saved set can be recalled by depressing the **Recall** button

The state of the internal Rubidium standard is shown on the display. During the warm-up or if some other fault occurs, it is shown as either NOK or OK.

In addition to these features, the needed transmit and receive change-over functions are carried out by depressing the **Transmit** button on the panel, or by the remote control from the computer interface, if this is enabled. When in transmit mode, transmit frequency changes and USB/LSB mode changes are inhibited.

## Operational Software Functions

The main functionality going on behind the scenes is the monitoring that's taking place in transmit mode. Any faults notified by the attached transverters cause immediate removal of the RF drive at 144 to 146 MHz and the removal of the transmit command from the selected transverter. An alarm condition LED (**TX Fault**) is illuminated. Scanning the KB, updating the display and LED status, updating the DDS frequency and so on also proceeds in the background.

There are many planned additions to the software, but if and when they will be

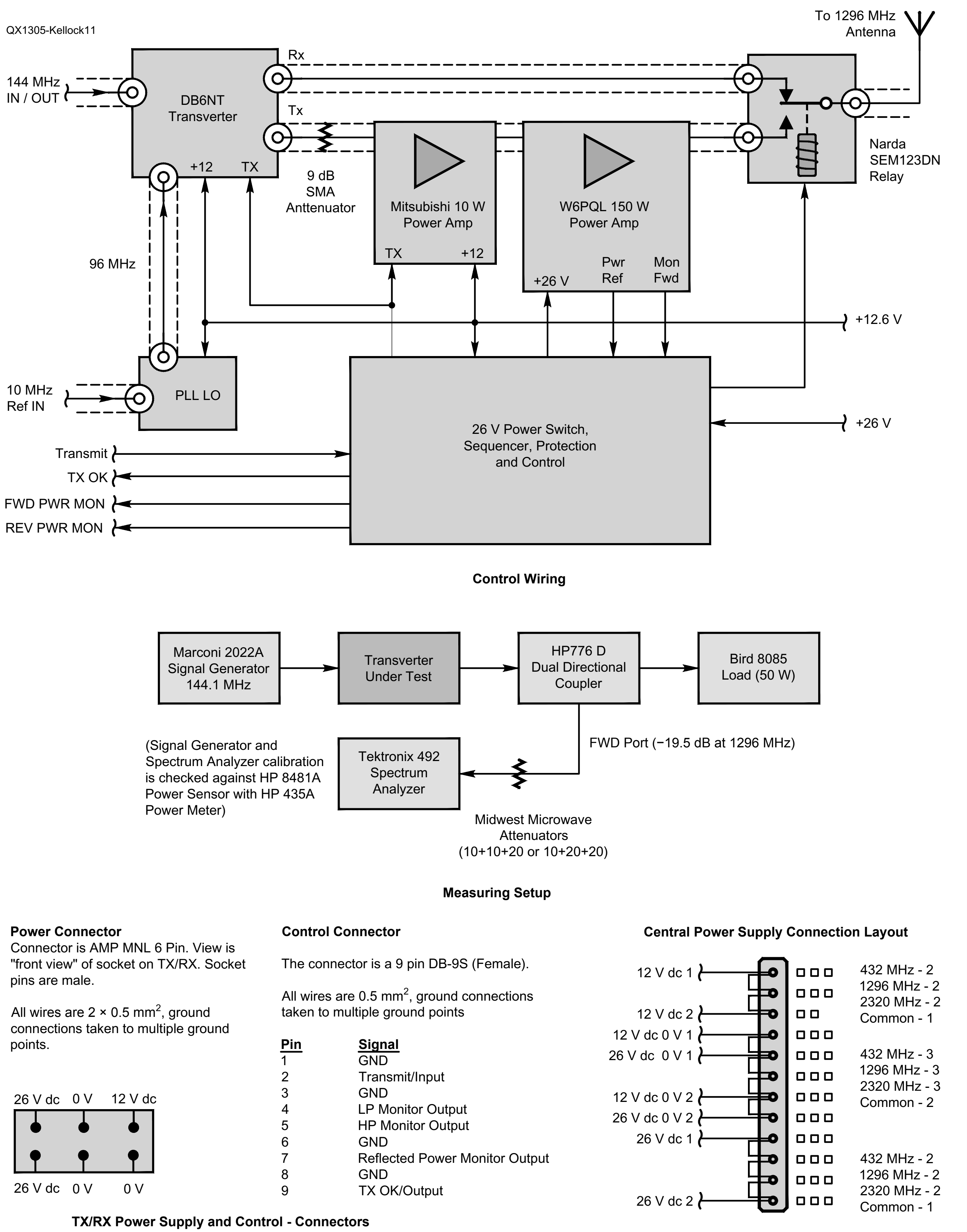



**Figure 11 — A medium power microwave transverter for 1296 MHz, showing the main functional blocks and the control and monitoring signals.**

implemented is another issue. The main future feature is implementation of a small subset of the CI/V commands on the controller so that a common computer can command both the R75 and MTC.

Figure 14 shows a picture of a subrack designed for three high-power transverters with the power supplies in the left hand side (26 V at 10 A and 12 V at 10 A) and fitted with a 1296 MHz transverter. The 1296 MHz transverter is mounted in a disused base station aluminum housing, which provides a good heat sink for the 150 W PEP power amplifier (built using one of Jim (W6PQL) Klitzing's 150 W kits). A DB6NT 1 W transverter drives a 10 W amp using a Mitsubishi MOSFET module, which then drives the 150 W amplifier.

## Acknowledgements and References

There are many hams and others who have, generally unknowingly, contributed to the design and implementation of this system. The many excellent websites maintained by hams who wish to share their ideas and/or kits with others are too numerous to mention. More details of the implementation of some parts of the controller, such as the PLL oscillator, are contained on my website at **http://personal.inet.fi/private/oh2gaq/**. For those who are interested in more exact constructional details of some parts of the system, including *Eagle* design files or software source code, you can contact me at the e-mail address shown at the beginning of this article


**Figure 12 — Display of the MTC with present software. The top line shows the frequency, and implicitly the band in use (in this case 24 GHz). The mode is Combined (common receive and transmit frequency control). The transmit mode is USB. The transmit tuning resolution is 1 kHz (selected from 1 Hz, 100 Hz, 1 kHz and 10 kHz), but this is not relevant in Combined mode. The Rubidium Health is indicating OK. The microphone input is selected and the MTC is under Local control. The bottom line is used for the transmit output display. The 16 leftmost positions show forward power; the four rightmost positions show reflected power.**

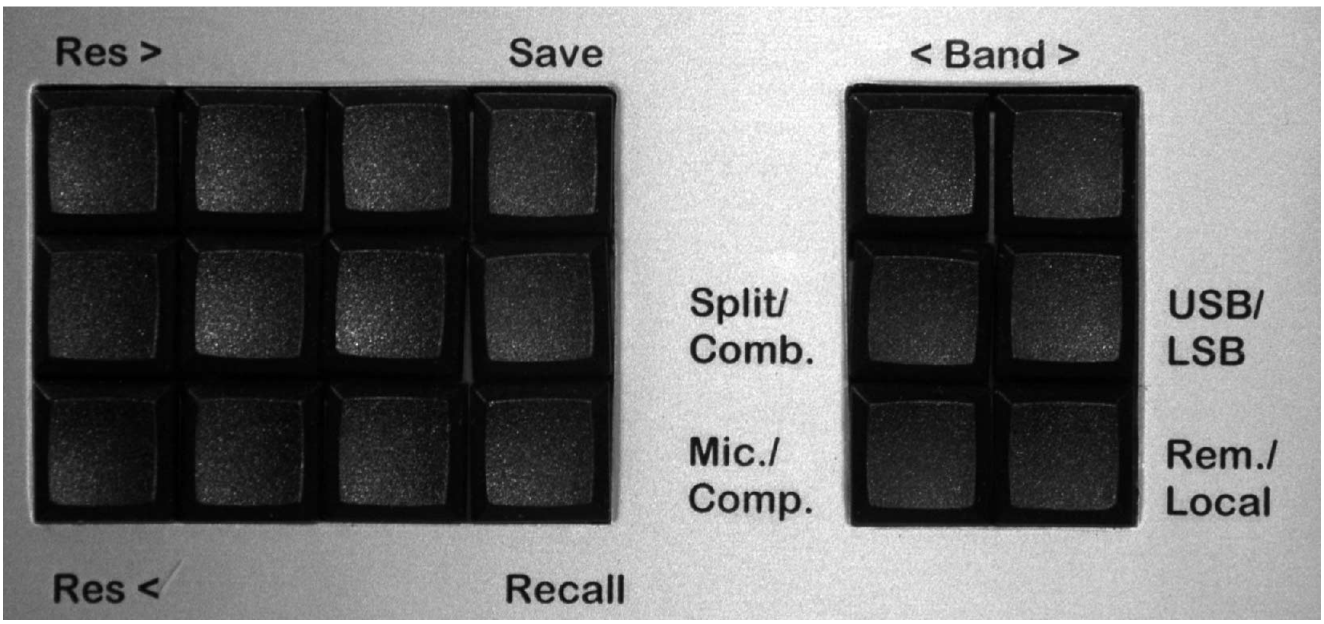



**Figure 13 — The keyboard layout and key functionality with present software version. The main tuning functionality is controlled by the optically encoded main tuning knob when in Split mode**

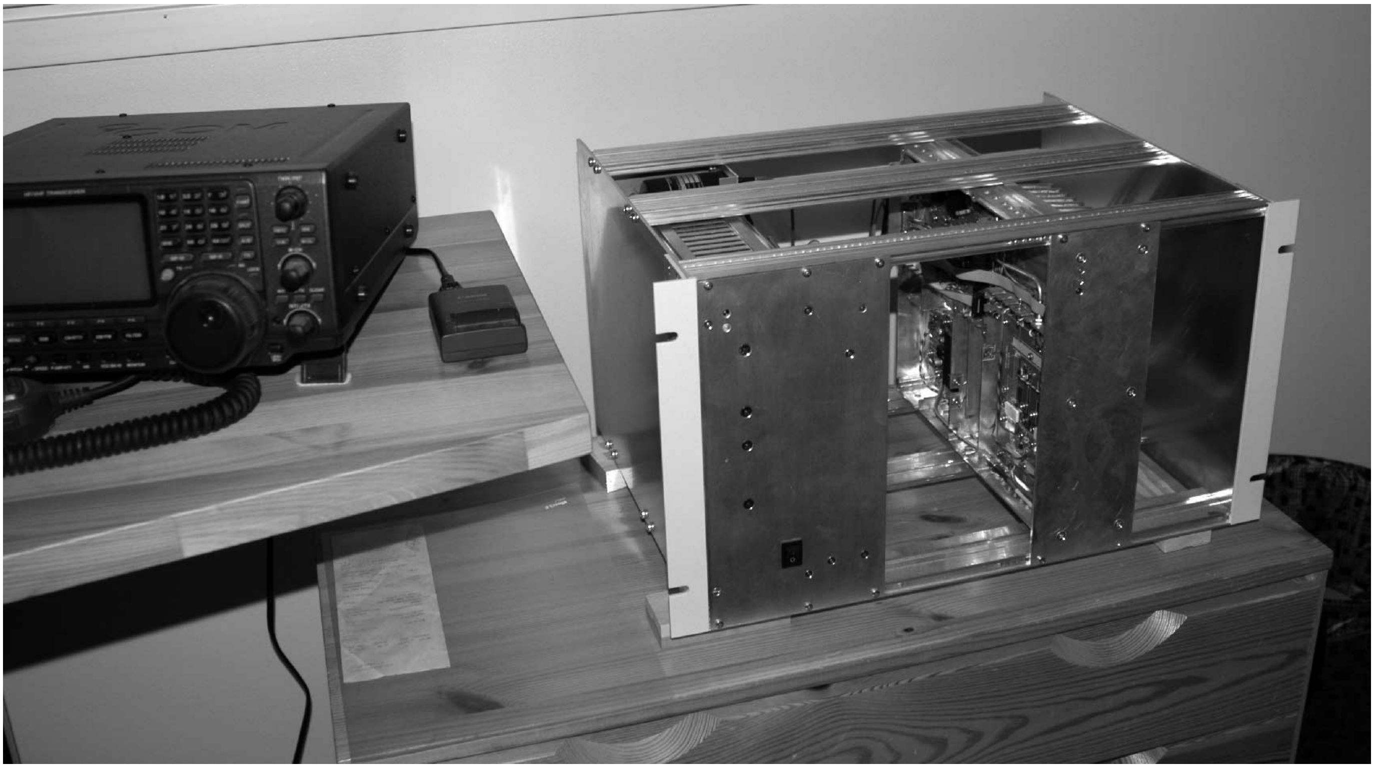


**Figure 14 — Transverter subrack with the 1296 MHz transverter.**

## For Further Reading

I recommend the following articles and websites.

John Stephensen, KD6OZH, "A Stable, Low-Noise Crystal Oscillator for Microwave and Millimeter-Wave Transverters," *QEX*, Nov/Dec 1999.

John Hazel, G8ACE, "Constructional Notes for G8ACE MKII OCXO Sept 2010 V2," available from the G8ACE website at **www.microwaves.dsl.pipex.com/**.

The Analog Devices Data Sheet for ADF411x RF PLL Frequency Synthesizers.

The W6PQL website at **www.w6pql.com**. This site has several excellent articles covering microwave transverters and useful sub-systems, as well as actual kits for many items.

James D. Hagerty, WA1FFL "An Advanced Direct-Digital VFO," *QEX*, May/June 2008. See his website at **www.wa1ffl.com/** for DDS kits using the Analog Devices AD9951 DDS.

KO4BB's website at **www.ko4bb.com** has information about time and frequency control, measuring equipment and generally useful microwave related material.

KE5FX's website at **www.thegleam.com/ke5fx/** also offers time and frequency control information, measuring equipment and other useful microwave related material.

The Down East Microwave website at **http://downeastmicrowave.com/**.

The Kuhne Electronic website at **www.kuhne-electronic.de/en/home.html**.

Systronix RAD51 website at **www.systronix.com/RAD51/RAD51.htm**. This site details the Rapid Application Development Environment for 8051 family processors.

## Note

[1]You can download a zip file of various files related to this article from the ARRL *QEX* files website. Go to **www.arrl.org/qexfiles** and look for the file **7x13_Kellock.zip**.


*Hamish Kellock, OH2GAQ, lives in Espoo, Finland. He has a Diploma in Applied Physics from the Royal Melbourne Institute of Technology (Melbourne, Victoria, Australia). He worked for several years in research associated with lasers and later with computer controlled measurements and instrumentation for RF measurements in Melbourne. For a short time he worked in the mineral processing industry, responsible for the development of computer controlled ore sorting equipment. In 1982 he moved to Finland to work in the telecommunications industry with Nokia. He held several positions over 28 years in the R&D area, covering network management, SDH transmission products, V5.2 multiplexers, microwave radio links and IP DSLAM products. He is now retired. Hamish has published several articles covering work with lasers, and holds patents in the mineral processing field as well as telecommunications.*

*Hamish was first licensed as VK3ZMV in Ballarat, Australia in 1960. Two meters was his main band of interest, followed later by 70 cm. His equipment was all home-built, mainly using surplus World War II parts. When reasonable solid-state devices appeared, he turned his interests to semi-portable operation with home-built rigs, and also published some articles in local newsletters covering TTL logic based frequency synthesizers and 2 meter solid state amplifiers. Hamish was absent from Amateur Radio for a while afterward until the early 2000s, when he took the Finnish Radio Amateurs examination and was licensed as OH2GAQ. He is now gradually putting together equipment for the various microwave bands including, particularly in a portable form, for the SHF bands.*

*Hamish is married and has five children. His wife is a building engineer. Much of his spare time is taken up with building projects for the family, including house renovations for the various grown-up children. During the summer he enjoys boating in the local archipelago in southern Finland, not to mention installing more electronic gadgets in the boat. Of course the next summer house project is always around the corner!*

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.**

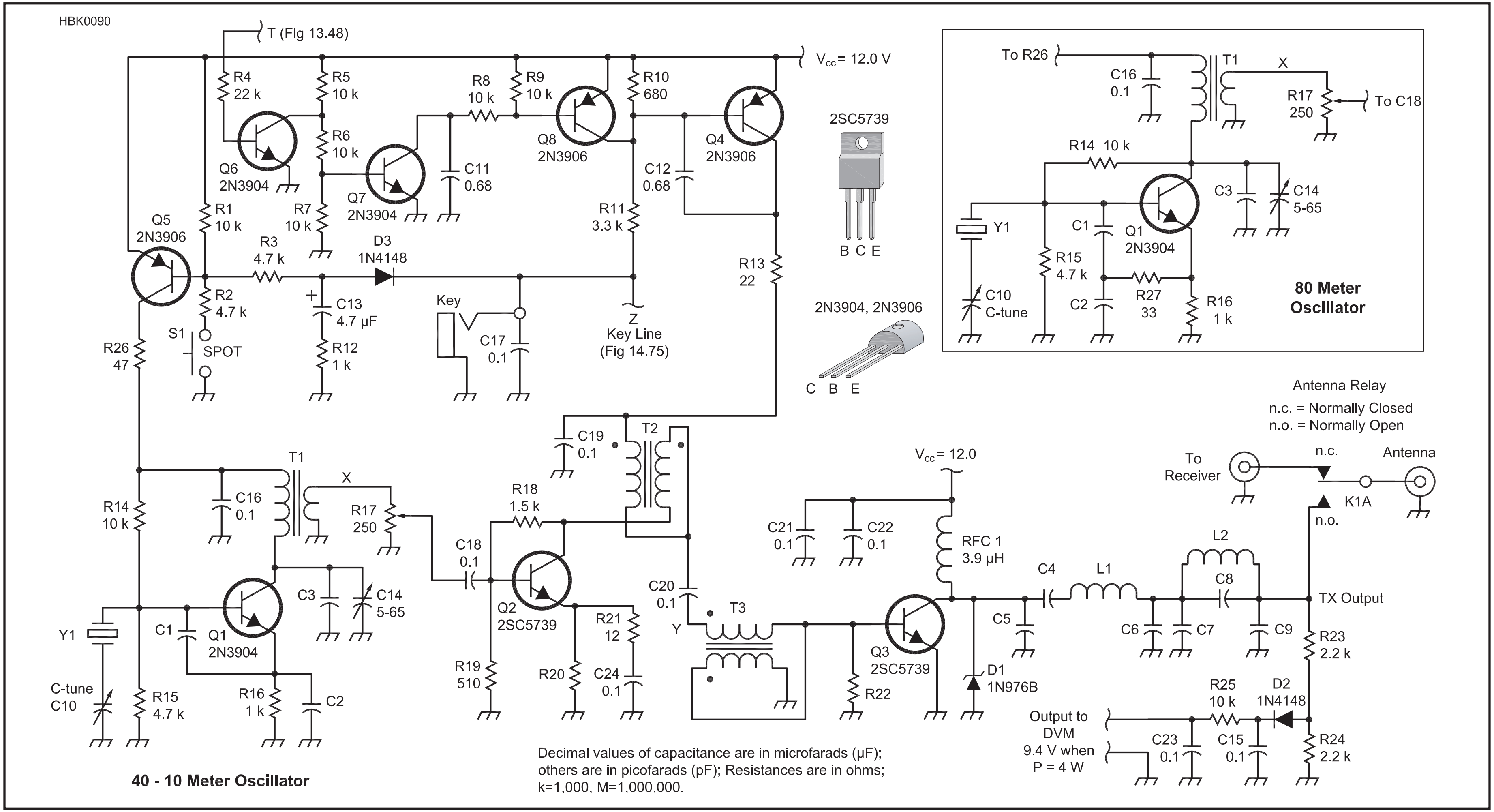



Fig 13.45 — Schematic diagram and parts list for the RF portion of the MKII transmitter. The oscillator (Q1 and associated components) in the main drawing is for the 40-10 m bands, while a modified version for 80 m is shown in the inset (see text). Fixed resistors are ¼ W, 5% carbon film unless otherwise 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 |

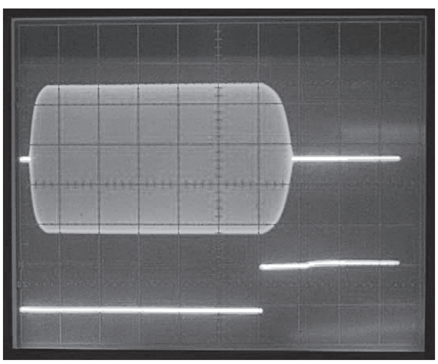


**Fig 13.46 — Keyed waveform. The lower trace is the keyer input, which triggered the oscilloscope in this measurement. The horizontal time scale is 5 ms/div.**

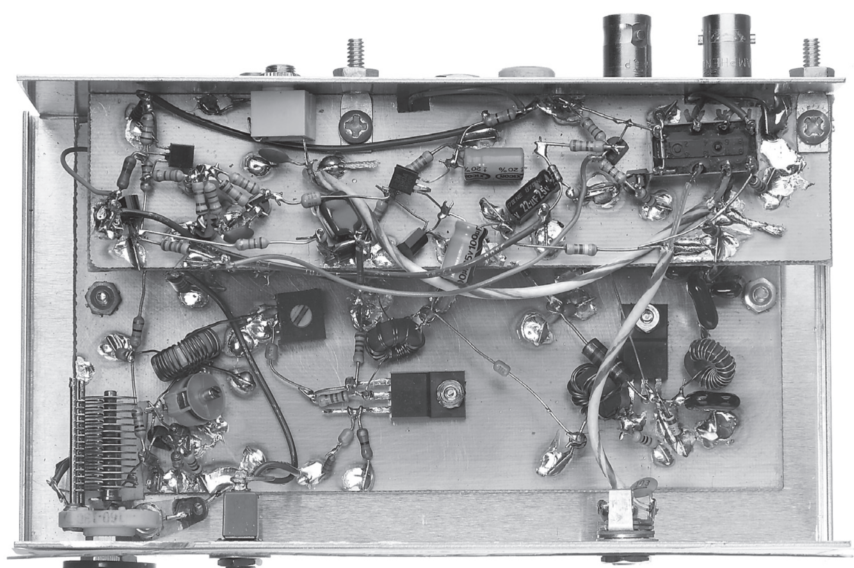


**Fig 13.47 — The transmitter packaged in a 2 × 3 × 6 inch LMB #138 box. The basic RF circuitry is on the larger board. TR control is on the smaller board along the top.**

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**.

### 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-

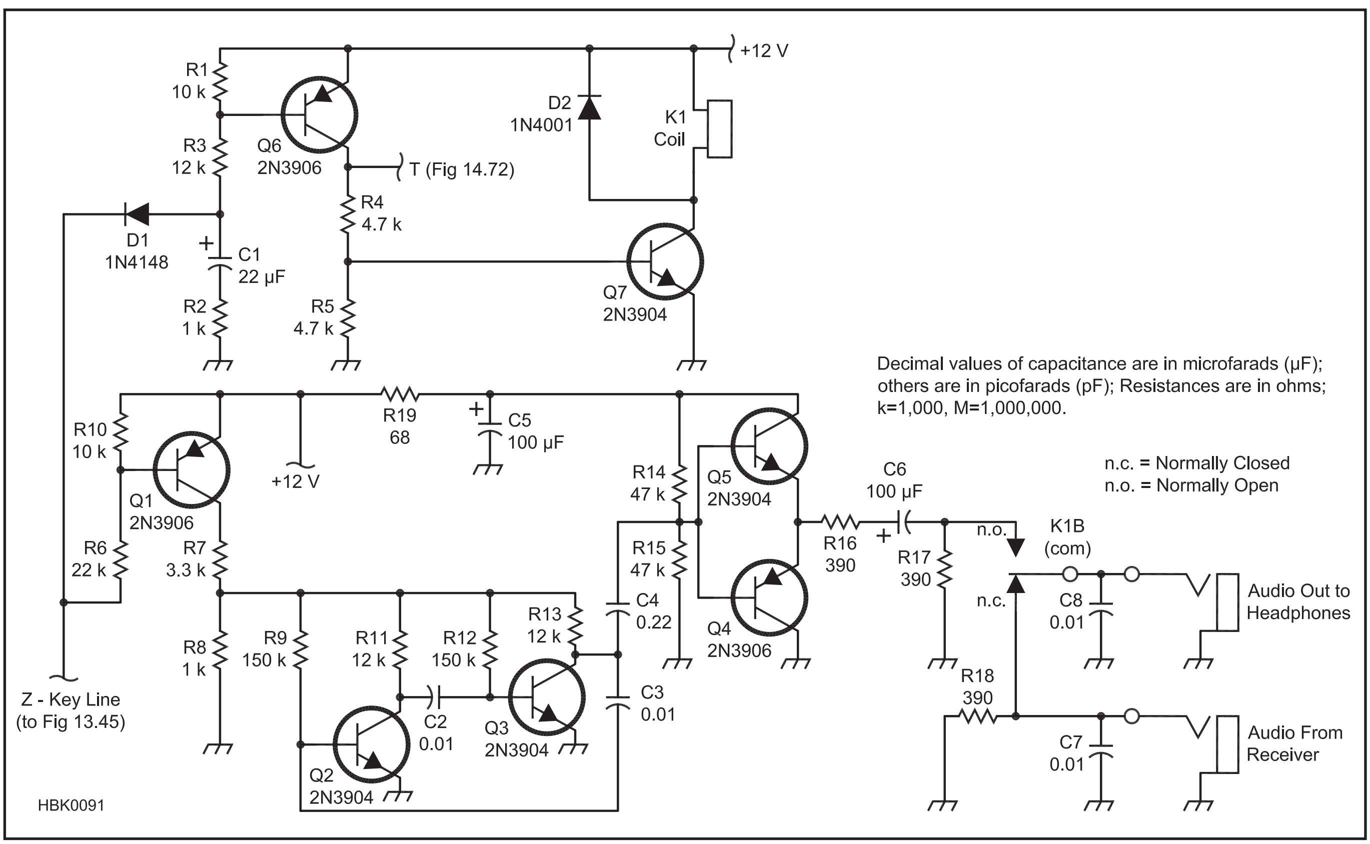



**Fig 13.48 — Detailed schematic diagram and parts list for transmit-receive control section and sidetone generator of the universal QRP transmitter. Resistors are ¼ W, 5% carbon film. A kit of component parts is available from KangaUS (www.kangaus.com).**

**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

**Norcal Sierra From ARRL Handbook** **Sourced March 2008 by Aaron Lyons, N9SKN**

**Parts list complete for both 40 and 30 meters. The 20, 17, 15 meter band module crystals are not included, see notes below**

| QTY | DESCRIPTION | PART NUMBER | SOURCE | URL |
|---|---|---|---|---|
| 1 | Main circuit board + 4 band boards set | none | Far Circuits | http://www.farcircuits.net/ |
| 1 | C54, Main Tune Cap, 5-40 (9-45pF in stk) | junk box | | |
| 1 | Connector, Band Module | S3355-ND | Digi-Key | www.digikey.com |
| | | | | |
| 25 | Abracon MFG +-20PPM | 815-AB-4.9152-B2 | Mouser | www.mouser.com |
| | X1 - X7 4.915 Mhz, HC-49, match 50Hz, 18pF | | | |
| | | | | |
| 1 | X8, 40m, 15.000 Mhz xtal, Citizen | 300-8497-ND | Digi-Key | |
| 1 | X8, 30m, 18.000 Mhz xtal, Citizen | 300-8504-ND | Digi-Key | |
| | X8, 20m, 22.000 Mhz xtal | | See notes below | |
| | X8, 17m, 26.000 Mhz xtal | | See notes below | |
| | X8, 15m, 29.000 Mhz xtal | | See notes below | |
| | | | | |
| 35 | C1,C2, C33, C36, C64, C66, C70, 9-50pF | 24AA024 | Mouser | |
| | Note these are flat trimmers - 7 req per band (Xicon mfg.) | | | |
| | Alternate: Futurlec part no. C50PTC | | | |
| | | | | |
| 2 | C16, C38, flat trimmers 9-50 pF | 24AA024 | Mouser | |
| | Note these are flat trimmers (Xicon mfg.) | | | |
| | | | | |
| 1 | C52, Air Variable trimmer, 2-24 pF | junk box | junk box | |
| 1 | C53, 180pF NPO disc | 140-50N5-181J-RC | Mouser | |
| 1 | C56, 3900pF Poly | 23PS239 | Mouser | |
| 2 | C57, C58 1200pF Poly | 23PS212 | Mouser | |
| 3 | 1 pF disc cap, band module, 100v NPO | 140-100N2-1R0D-RC | Mouser | |
| 5 | 2pF disc cap, band module, sub 2.2pF | 140-100N2-2R2D-RC | Mouser | |
| 2 | 5pF disc cap, band module, sub 4.7pF | 140-100N2-4R7D-RC | Mouser | |
| 2 | 47pF disc cap, band module, 100v NPO | 140-100N5-470J-RC | Mouser | |
| 4 | 150pF disc cap, band module, 50v NPO | 140-50N5-151J | Mouser | |
| 2 | 220 pF disc cap, band module, 50v NPO | 140-50N5-221J-RC | Mouser | |
| 6 | 330 pF disc cap, band module | 140-50S5-331J-RC | Mouser | |
| 1 | 470 pF disc cap, band module | 140-50S5-471J-RC | Mouser | |
| 1 | 560pF disc cap, band module | 140-50S5-561J-RC | Mouser | |
| 1 | 820pF disc cap, band module | 140-50S5-821J | Mouser | |
| 3 | 5pF, disc = 4.7pF sub | 140-50N5-4R7D-RC | Mouser | |

| | | | | |
|---|---|---|---|---|
| 2 | 27pF, disc | 140-50N5-270J-TB-RC | Mouser | |
| 2 | 39pF, disc | 140-50N2-390J-RC | Mouser | |
| 3 | 47pF, disc | 140-50N5-470J-RC | Mouser | |
| 2 | 68pF, disc | 140-50N2-680J-RC | Mouser | |
| 3 | 150pF, disc | 140-50N5-151J-TB-RC | Mouser | |
| 1 | 180pF, NPO disc | 140-50N5-181J-RC | Mouser | |
| 7 | 270pF, disc, MAIN TRX | 140-50N5-271J-TB-RC | Mouser | |
| 2 | 1200pF = 0.0012 uF | 81-RPE5C1H122J2P1A03 | Mouser | |
| 1 | 3900pF = 0.0039 uF, disc | 81-RPE5CH392J2M1D03A | Mouser | |
| 5 | .01uF, multilayer ceramic, MAIN TRX | 80-C315C103J1R-TR | Mouser | |
| 15 | .047uF, multilayer ceramic | 581-SR215C473J | Mouser | |
| 4 | .1uF, multilayer ceramic, MAIN TRX | 581-SR275C104K | Mouser | |
| 1 | .22uF, multilayer ceramic | 80-C322C224J5R | Mouser | |
| 3 | 2.2uF, electrolytic | 140-XRL50V2.2-RC | Mouser | |
| 1 | 2.2uF, electrolytic | 140-NPRL50V2.2-RC | Mouser | |
| 1 | 3.3uF, electrolytic | 140-MLRL50V3.3-RC | Mouser | |
| 1 | 10uF, electrolytic | 140-MLRL50V10-RC | Mouser | |
| 2 | 22uF, electrolytic | 140-XRL50V22-RC | Mouser | |
| 2 | 100uF, electrolytic | 140-XRL50V100-RC | Mouser | |
| | | | | |
| 2 | D6, D10 1N5819 diode | 512-1N5819 | Mouser | |
| 1 | D7, 1N4753A diode | 512-1N4753A | Mouser | |
| 1 | D8, MV2104 equiv = NTE612 | 526-NTE612 | Mouser | |
| 1 | Q5, U310 FET | 781-U310-E3 | Mouser | |
| 8 | 1N914, diode | 512-1N914A | Mouser | |
| 2 | 2N4124 | 512-2N4124BU | Mouser | |
| 1 | 2N4126 | 512-2N4126BU | Mouser | |
| 2 | 2N4416 | 610-2N4416A | Mouser | |
| 1 | 2N2222A, metal can | 511-2N2222A | Mouser | |
| 3 | 2N3553, TO-39 pkg. (NTE341 alternate; check pinout) | 2N3553 | Futurlec.com | www.futurlec.com |
| 1 | Heatsink for 2N3553, TO-39 package | junk box | junk box | |
| 1 | U1, LM358N Dual Op Amp | 512-LM358N | Mouser | |
| 4 | U2, U4, U7, U8, SA602AN mix/osc | 771-SA602AN/01 | Mouser | |
| 1 | U3, LM386N-1 audio amp | LM386N-1-ND | Digi-Key | |
| 1 | U5, MC1350P equiv = NTE746 IF amp | 526-NTE746 | Mouser | |
| 1 | U6, LM393N dual comp | 512-LM393N | Mouser | |
| 1 | U9, AN78L08-ND = Fairchild MC78L08ACP | 512-MC78L08ACP | Mouser | |
| | | | | |
| 2 | R1, R8, PC mt 1k pot | 31CW301 | Mouser | |
| 1 | R8, 1k pot, 16mm, panel mount, RF Gain | 31JN301-F | Mouser | |
| 1 | R1, 1k pot with swx, 16mm, panel mt, AF Gain | 313-1100F-1K | Mouser | |
| 1 | R17, 10k pot, 17mm, panel mt, RIT | 31CN401-F | Mouser | |

| | | | | |
|---|---|---|---|---|
| 3 | R14, R101, S/RFmtr, 500 ohm trimmer | 594-63P501 | Mouser | |
| 1 | 22 ohm fixed 1/4w | 660-CFS1/4CT52R220J | Mouser | |
| 1 | 56 ohm fixed 1/4w | 660-CFS1/4CT52R560J | Mouser | |
| 3 | 100 ohm fixed 1/4w | 660-CFS1/4C101J | Mouser | |
| 1 | 390 ohm fixed 1/4w | 660-CFS1/4CT52R391J | Mouser | |
| 1 | 1K ohm fixed 1/4w | 660-CFS1/4C102J | Mouser | |
| 1 | 1.8K ohm fixed 1/4w | 660-CFS1/4CT52R182J | Mouser | |
| 2 | 3.6K ohm fixed 1/4w | 660-CFS1/4CT52R362J | Mouser | |
| 3 | 5.1K ohm fixed 1/4w | 660-CFS1/4CT52R512J | Mouser | |
| 2 | 12K ohm fixed 1/4w | 660-CFS1/4CT52R123J | Mouser | |
| 7 | 47K ohm fixed 1/4w | 660-CF1/4CT26A473J | Mouser | |
| 2 | 10M ohm fixed 1/4w | R010M14W | Futurlec.com | |
| 1 | 20k pot, S/RF trimmer | 594-63P203 | Mouser | |
| 1 | 5k pot, S/RF trimmer | 594-63P502 | Mouser | |
| | | | | |
| 1 | Ferrite Bead for 2N2222A (See Mod Sheet) | FB-43-201 | Amidon Assoc. | www.amidoncorp.com |
| 1 | RFC1, FT-37-61 core | FT-37-61 | Amidon Assoc. | |
| 2 | RFC2, RFC3, FT-37-43 core | FT-37-43 | Amidon Assoc. | |
| 1 | RFC4, mini choke, 1 mH | 43LS103 | Mouser | |
| 1 | T2, FT-37-43 core | FT-37-43 | Amidon Assoc. | |
| 1 | L2, Mini RFC, 15 uH | 43LS155 | Mouser | |
| 2 | L10, L11, FT-37-61 core | FT-37-61 | Amidon Assoc. | |
| 1 | L7, 19 uH | T68-7 | Amidon Assoc. | |
| 2 | FT-37-61, core, band module | FT-37-61 | Amidon Assoc. | |
| 24 | T-37-2, core, band module | T-37-2 | Amidon Assoc. | |
| 16 | T-37-6, core, band module | T-37-6 | Amidon Assoc. | |
| | | | | |
| | **Optional / Custom / Additional Items** | | | |
| 6 | Small control knobs (Optional) | | | |
| 1 | Main tune knob (Optional) | 450-1755 | Mouser | |
| 1 | Norcal FCC-1 display / counter (Optional) | FCC-1 | Norcal | www.norcalqrp.org |
| 1 | Norcal keyer (Optional) | Norcal Keyer | Norcal | |
| 1 | Meter, for S/RF(Optional) | FS23 | Surplus Sales Nebraska | www.surplussales.com |

**Notes from N9SKN's build:**
Items I had in my modest junk box were not sourced.

Some of the semiconductors may be hard to find.
Some builders have used the NTE341 in place of the 2N3553 for increased power output and better availability. Check the pinout.
The MC1350P may not be readily available. The NTE746 is equivalent.

The optional metering circuitry (S/RF Meter) parts are included in this list
Meter circuit was built "Manhattan Style" using the Handbook circuit rather than the FAR PC board version

R100 and R101 on the FAR band module boards are not called out in the Handbook version and not used

FLAT trimmer caps are only available for band modules - VERTICAL / RIGHT ANGLE type no longer available by the mfg
This should only be a minor inconvenience during alignment.

No ABX on this Norcal / ARRL version

Also needed: Enclosure, switches, connectors, magnet wire, RG-174

I found crystals for 20, 17, 15m band module boards to be expensive from International; check with Wilderness Radio
I did not build the 20, 17 and 15 meter modules but this list includes all other items for those modules for shipping convenience

Filter crystals can be matched with the crystal tester that is part of “HF Test Set” by N6BM; see 4SQRP Club, http://4sqrp.com/kits/
The Norcal FCC-1 frequency display/counter module can be used in direct mode with this tester to match X1-X5 within 50Hz.

# ARRL Handbook CD

## Template File

| | |
|---|---|
| **Title:** | NorCal Sierra |
| **Chapter:** | 14 |
| **Topic:** | The NorCal Sierra: An 80-15 M CW Transceiver |

Template contains:

Note from Wayne Burdick, N6KR.

Sierra drawings.

Band module drawings.

Specifications.

Construction, Alignment and Troubleshooting.

January 16, 1996

Wayne A. Burdick, N6KR
1432 Sixth Avenue
Belmont, California 94002

(415) 592-2700 (home); burdick@interval.com

**To all who are interested in the Sierra QRP Transceiver:**

I designed the Sierra for the Northern California QRP Club (NorCal) back in 1993, and was pleased that the ARRL chose to publish the design in the new *Handbook.* In the intervening years, the Sierra has been field tested by NorCal members, and over 120 of the original Sierras are in use.

The *Handbook* article provides nearly all the information needed to duplicate the NorCal version of the Sierra, but there was no room for the PC board layouts. In this information packet you'll find 1:1 positive masters of the main board and band module. Also included are front- and back-panel layouts and silk screens.

Since the Sierra boards are fairly dense, as well as being double-sided with plated-through holes, not everyone will be able to duplicate them using home PCB etching techniques. In this case, you may actually find it easier to use "ugly" construction (point-to-point wiring using "islands" cut into a copper ground plane). There are also suitable prototyping boards available ("Vector-board" for example). I believe that at least one Sierra has been built in this way.

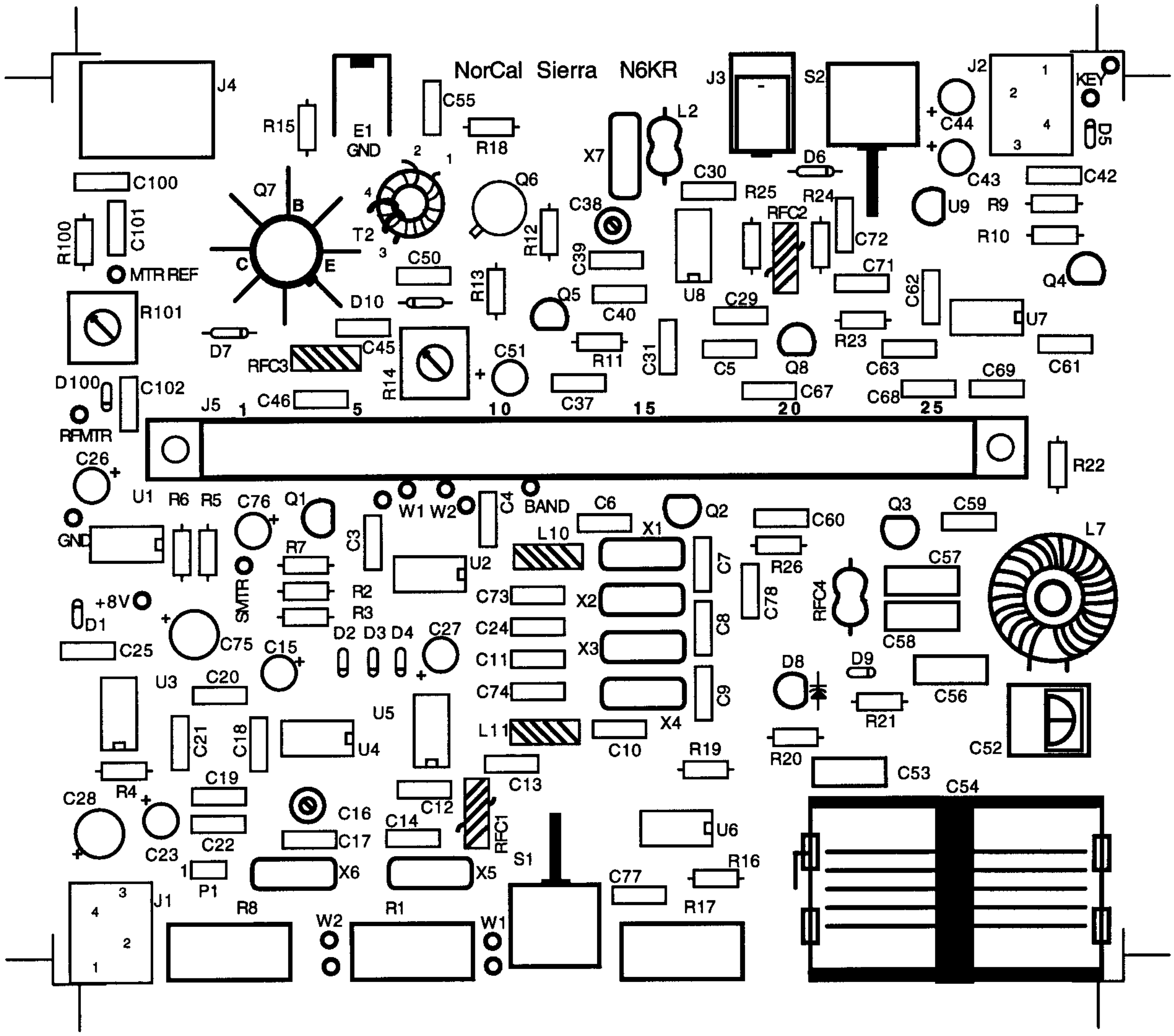
**Sierra Commercial Availability**

Unfortunately, I cannot offer boards or other components for the original Sierra. However, after the first run of Sierras was completed for NorCal, Bob Dyer, KD6VIO, proposed starting his own kit company to sell the Sierra and my other NorCal designs. I agreed to help him get started, and last year I completely upgraded the Sierra design for his new company, Wilderness Radio. Wilderness now has the new Sierra kit in stock. The upgraded rig has many new features, summarized in the attached sheets.

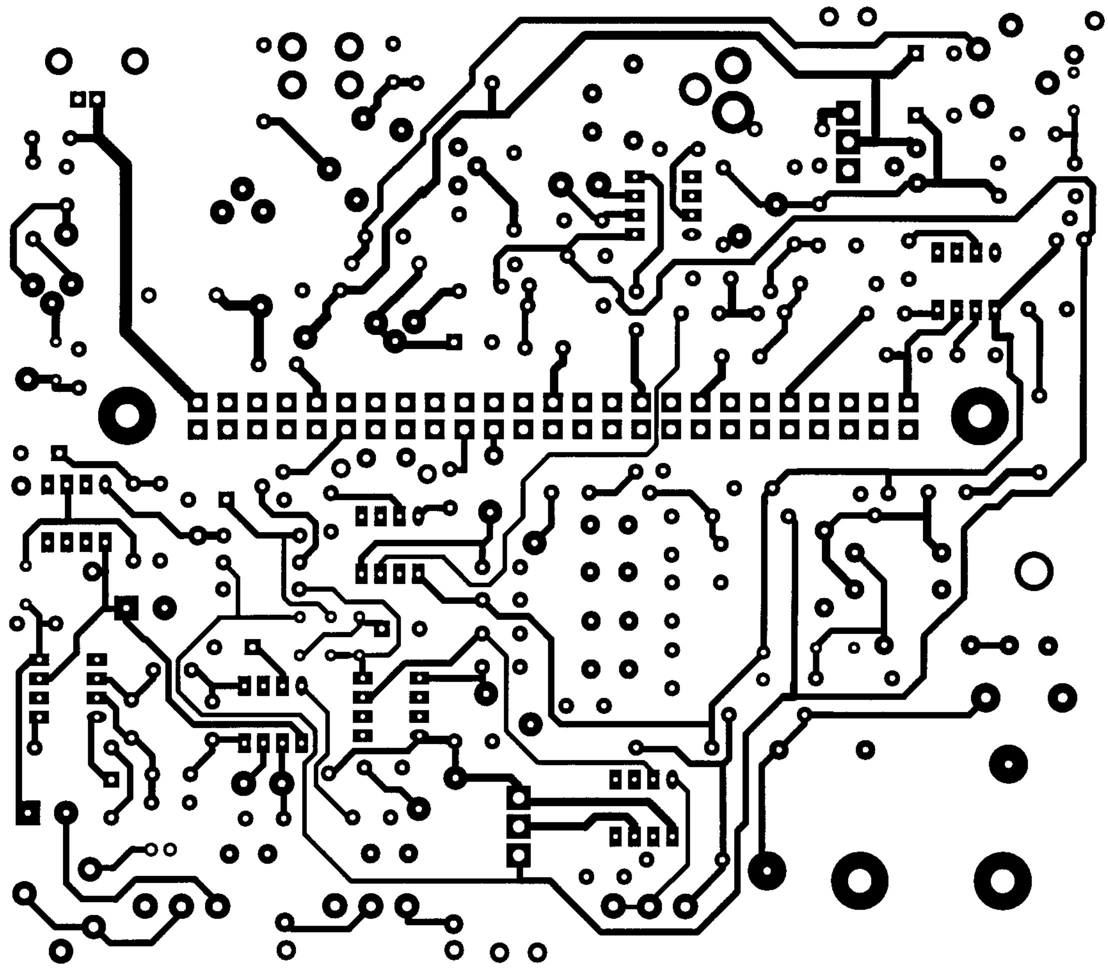
If you have any other questions about either the original or new Sierra transceiver, please write to me at the above address. I can also be reached by phone or e-mail (burdick@interval.com).

Good luck with all of your projects!

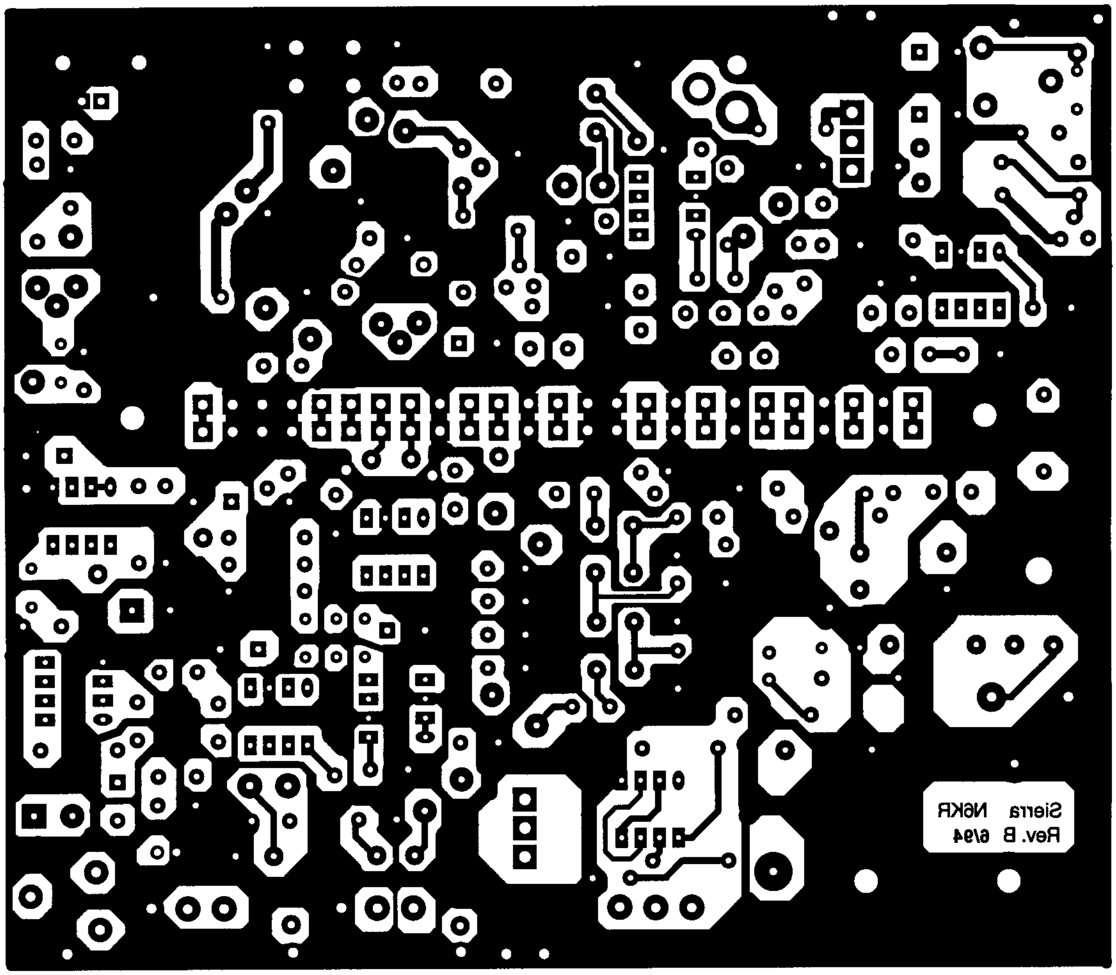
73,
Wayne A. Burdick
N6KR



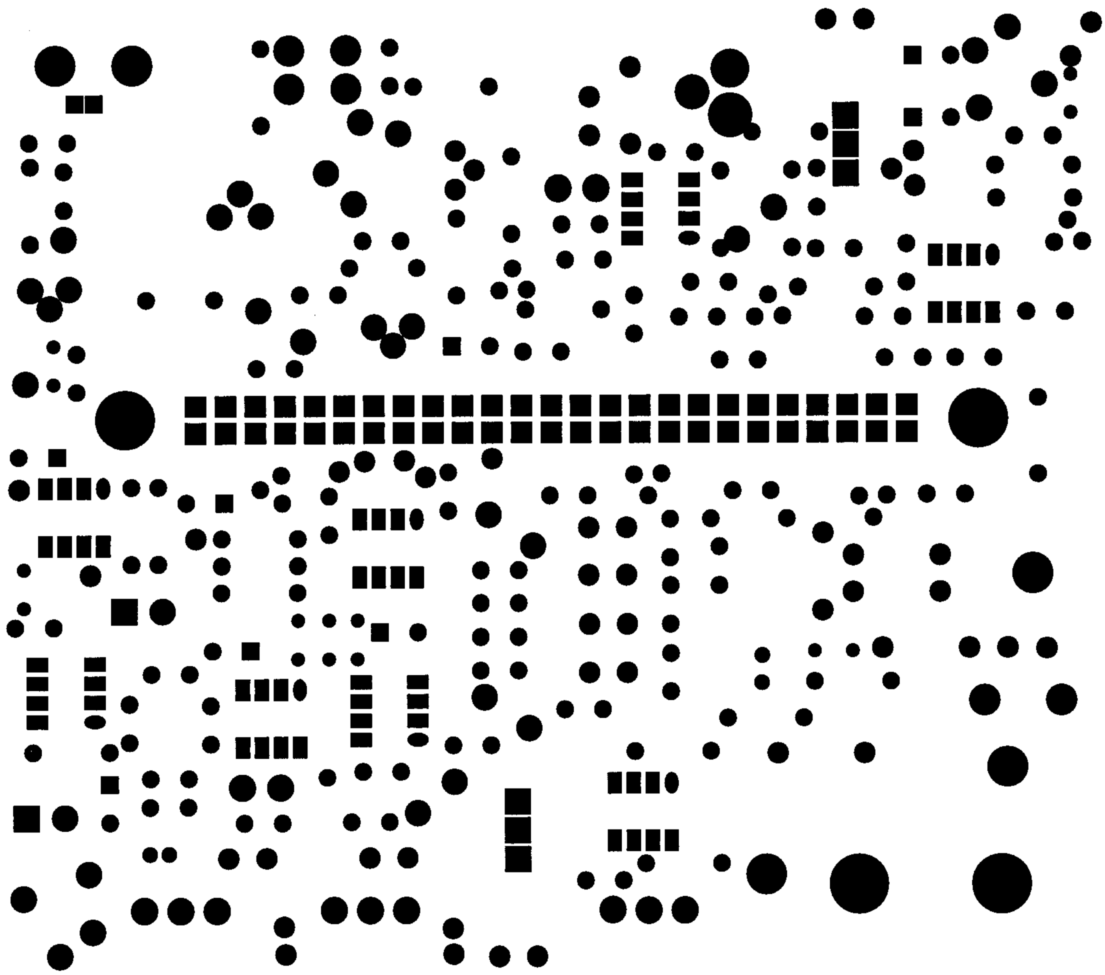

Sierra silkscreen



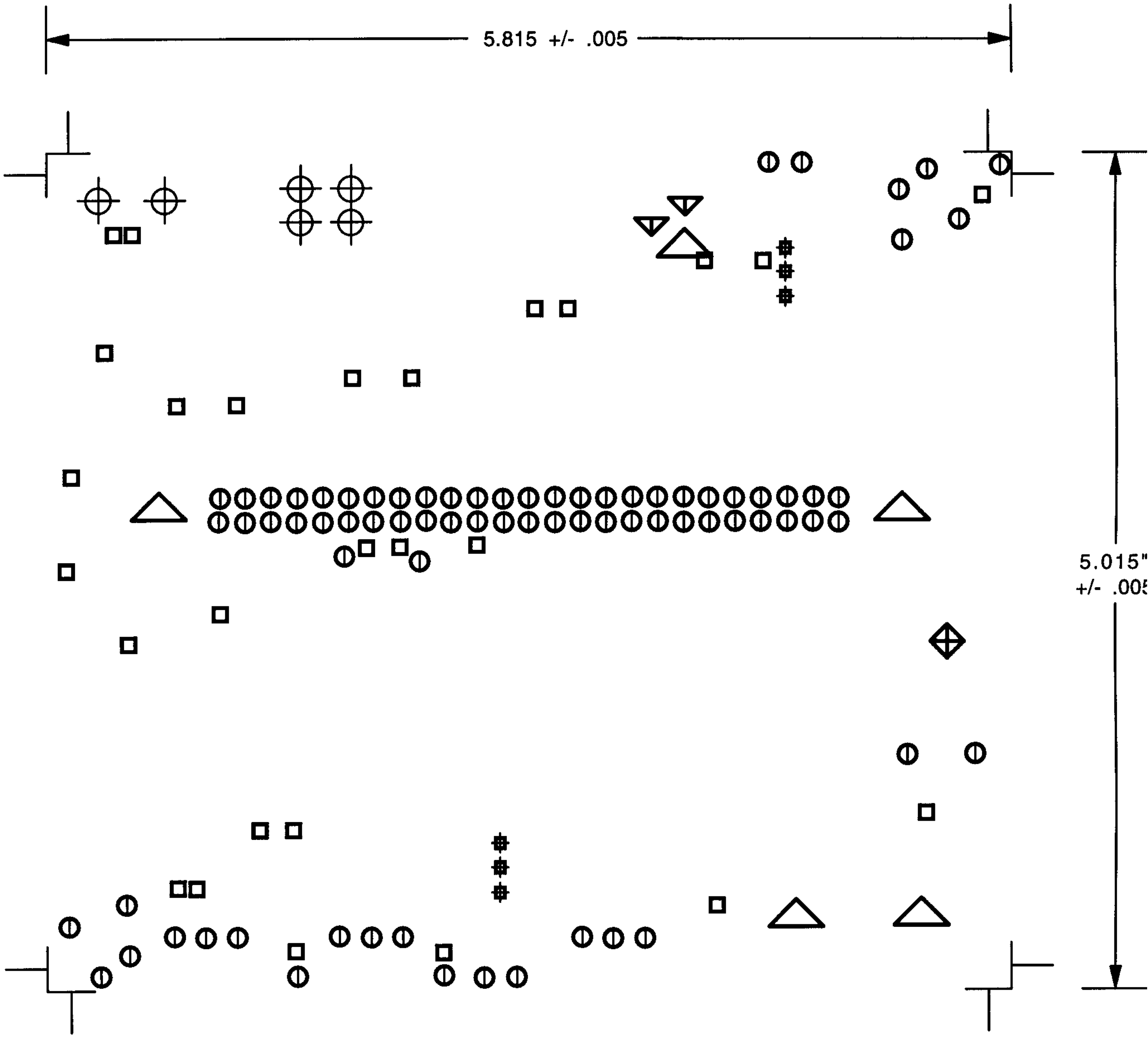
Sierra, component side




Sierra , solder side



Sierra, solder mask (both sides)




Finished Hole Sizes +/- .002"

.140"

.125"

.106"

.082"

.063"

.052"

.042"

ALL OTHERS .031"

All holes are plated through

Solder mask: CLEAR

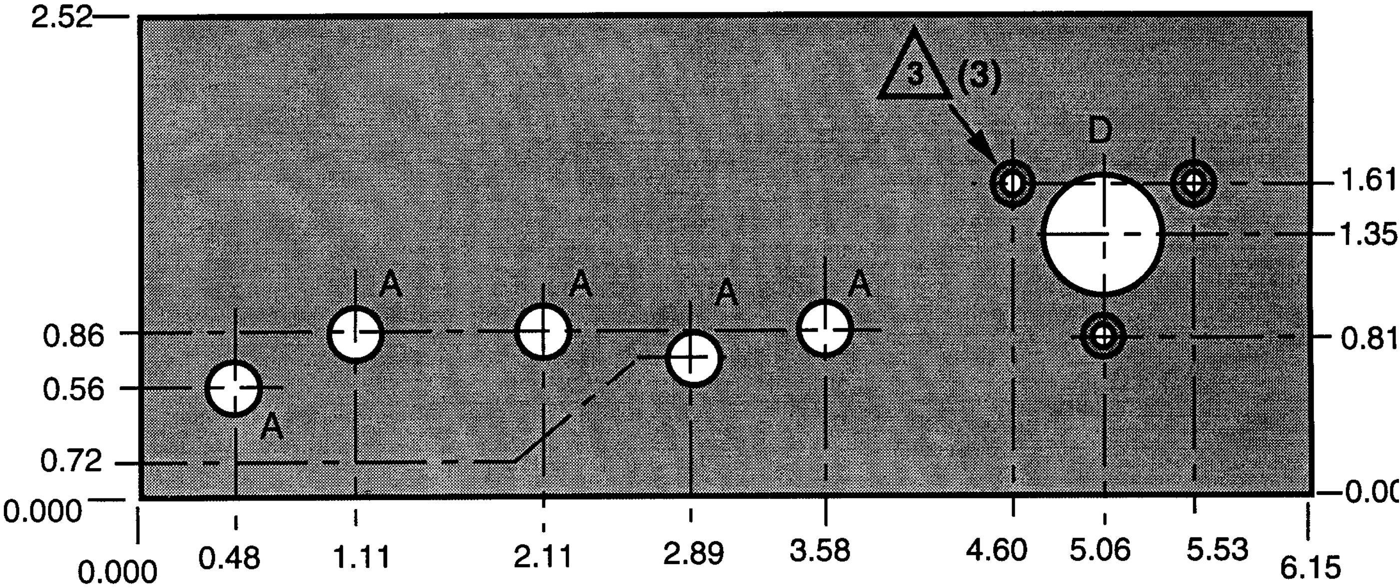
Sierra QRP Transceiver

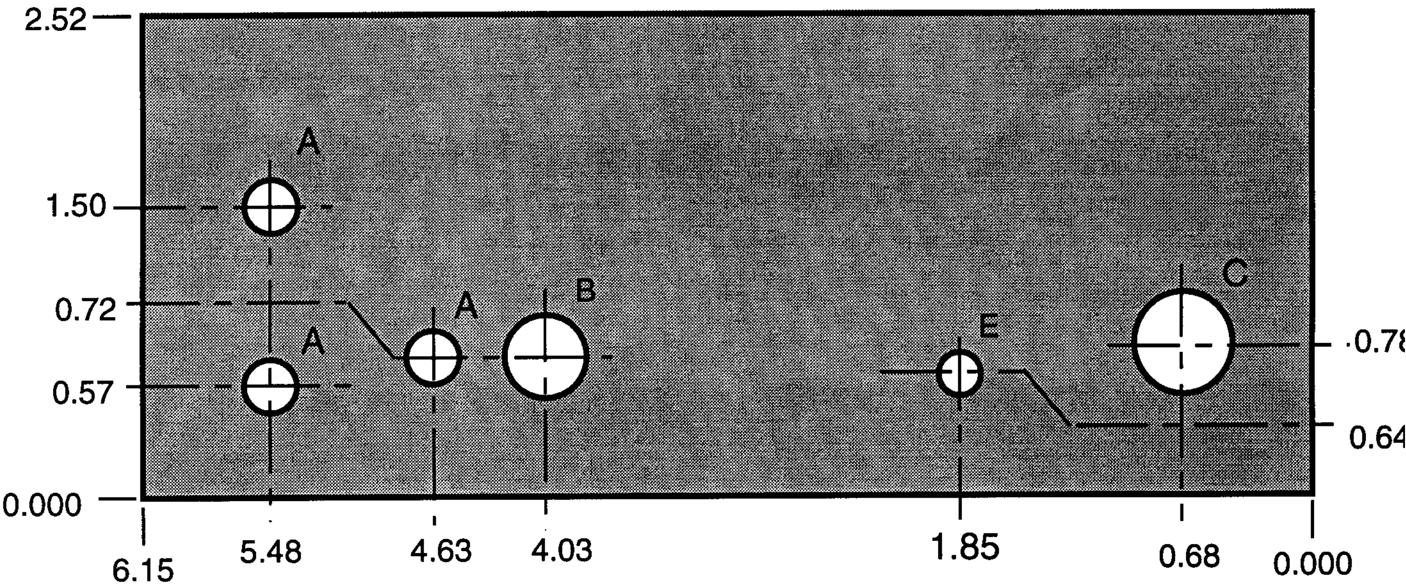
Wayne Burdick 415-354-0928



Rev. B. 7-16-94

# Front




# Back

| Identifier | Hole Dia. |
|---|---|
| A | 0.270 |
| B | 0.430 |
| C | 0.510 |
| D | 0.625 |
| E | 0.220 |

**Notes:** Unless otherwise specified

1. 1 front and 1 back required per unit
2. Mat'l: .060 aluminum; sanded finish
3. Drill and countersink for #4 F.H.M.S.

| TITLE | | | |
|---|---|---|---|
| **Sierra Front and Back Panels** | | | |
| BY Wayne Burdick | | DATE 10-3-94 | |
| REV C | TOL. .005" | SHEET 1 OF 1 | |

# Back Panel

PADDLE

KEY

ON 10 to 15V

POWER

GND

ANTENNA

# Front Panel

AF GAIN

RF GAIN

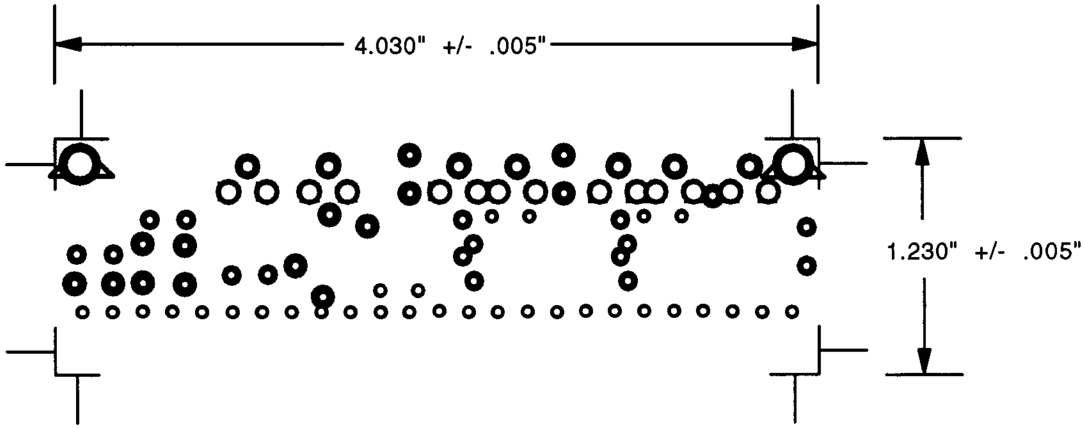
RIT

+ ● -

ON

OFF

**NorCal Sierra CW Transceiver**




Finished Hole Sizes +/- .002"

△ .125"

□ .072"

⦶ .052"

ALL OTHERS .031"

All holes are plated through

Solder mask: CLEAR

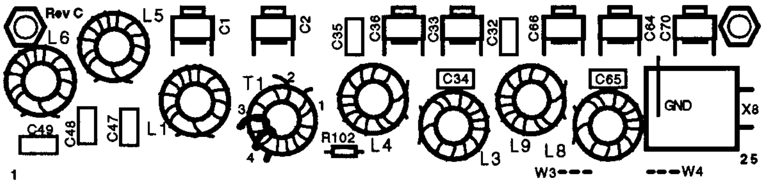
Sierra Band Module

Wayne Burdick 415-354-0928

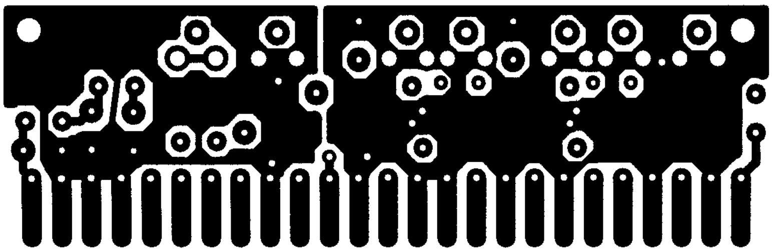


Rev. B. 7-16-94

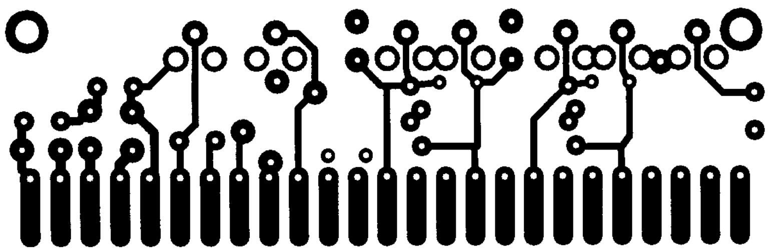
BAND MODULE DIMENSIONS
& DRILL GUIDE



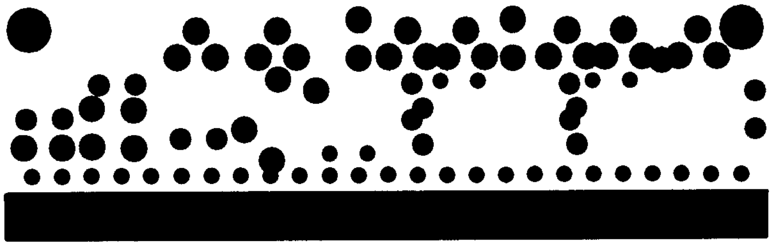

BAND MODULE SILK



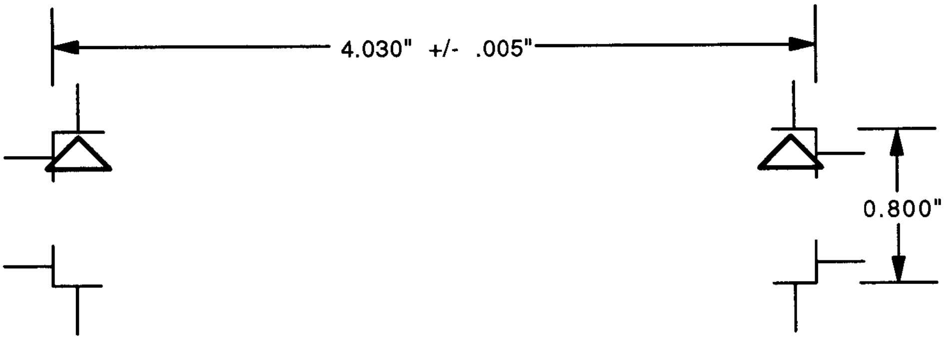
BAND MODULE TOP COPPER
(GOLD PLATED FINGERS)



BAND MODULE BOTTOM COPPER
(GOLD PLATED FINGERS)



BAND MODULE SOLDER MASK




Finished hole sizes, +/- .002

△ .125"

Sierra Band Module Cover

Wayne Burdick 415-354-0928



Rev. B. 7-16-94

No copper required on this board
Silkscreen and (2) holes only

Solder mask: CLEAR,
covering entire board

COVER DIMENSIONS

COVER MOUNTING HOLES

RX TX Pre-mix XTAL

MHz

Sierra Band Module Rev. C 9-20-94

COVER SILK

# Wilderness Sierra QRP Transceiver Specifications

## Physical:

Cabinet: 2.6" (H) x 6.3" (W) x 5.3" (D) , painted and silkscreened
Main PCB: 5.8" (W) x 5" (D)
Band Module: 1.25" (H) x 4.0" (W) x 0.5" (D)
Weight: Approx. 2lb.
All parts including controls and connectors mount directly to PC board--no chassis wiring
Band modules include 4 double-tuned circuits and 1 crystal each
Quick-release latches on either side of the cabinet for changing band modules
Plenty of room inside the box for band module stowage, keyer, batteries, antenna tuner, etc.
Plenty of unused panel space to add a meter, accessory controls, etc.

## DC Power Requirements:

10 to 16VDC; reverse-polarity protection
Receive: 30mA typical with headphones, 30 to 70mA when using speaker (varies with volume)
Transmit: 200-450mA (varies with band and power output setting)

## Frequency Coverage:

3.500-3.650MHz, 7.000-7.150MHz, 10.000-10.150MHz,
14000-14.150MHz, 18.000-18.150MHz, 21.000-21.150MHz
(Note: Manual includes information on building 160, 12, and 10 meter band modules)

## Transmitter:

Power Output: 1.5 to 3.5 watts, depending on band and supply voltage
Spurious products: -40dB or better (typical)
Final Amp efficiency: 60-75% (typical)
Load Tolerance: 1.5:1 or better SWR recommended; will survive brief operation into high SWR
Adjustable sidetone volume level
Transmit-receive delay: 0.2 seconds nominal; can be changed

## Receiver:

Sensitivity: Better than 0.5uV for 10dB S+N/N
Selectivity: Bandwidth is continuously adjustable from approx. 150Hz to 1600Hz wide @ -6dB;
With ABX control at 50%: approx. 400Hz @ -6dB
AGC range: 60 to 80 dB (est.)
I.F.: 4.915MHz; 4-pole Cohn crystal filter plus single-crystal filter following I.F. amp
R.I.T. Range: +/- 2KHz; can be increased (see text)
Audio output: 0.25 watts max into 8 ohm load

## VFO:

VFO operating range: 2.935 to 3.085 MHz (150Khz); 8:1 vernier drive built-in
Calibration: 5KHz increments; typical accuracy, +/- 2KHz
Drift: less than 100 Hz in first 30 minutes from cold start
(RIT off, 25 degrees C, top cover installed)

**Wilderness Radio**

P.O. Box 734, Los Altos, CA 94023-0734 (415) 494-3806

# Sierra Construction, Alignment, and Troubleshooting

Wayne Burdick, N6KR
January 30, 1996

## Main PCB Assembly

*Resistors, Diodes, Miniature RF Chokes*

[ ] Install all of the resistors, double-checking the color code to make sure you're installing the proper value. The resistors should all be oriented in one direction for ease of reading the color codes later--i.e., first band to the left or top, last band to the right or bottom.

[ ] Diodes must be installed with the cathode end--the end with the widest band--oriented in the same direction as the banded end on the PC board outlines. The exception is D8, which has a flat-sided package like a transistor. Install this part as shown on its PC board outline.

[ ] Install the miniature RF chokes (RFC4 and L2) and solder. Note that these chokes look a lot like resistors, only larger.

*Capacitors*

[ ] Install all of the fixed capacitors except the electrolytics; this includes the disc, mica, polystyrene, ceramic, and film types. (Refer to the parts identification drawings.)

[ ] Next, install the electrolytic capacitors. These are polarized; be sure that the (+) lead is installed in the (+) hole in the board. The (+) lead is usually longer than the (-) lead. The (-) lead is usually marked on the body of the capacitor with a black band.

[ ] Next, install all of the variable capacitors *except* C54 (the VFO main tuning capacitor). This includes C16, C38, and C52. (Install C52 backwards from the silkscreen to insure that the rotor is grounded.)

*ICs and Transistors*

[ ] Install all of the transistors except Q7, the final amplifier transistor. Align the tab or flat side of each transistor with its PC board outline.

[ ] Q7 uses a heat sink, which should be pressed carefully onto Q7 before installing it on the board. If you've never used a press-on heat sink before, be forewarned that it's tricky. Don't bend the leads as you're doing it--they may break. Place the heat sink on a hard surface, then press the case of Q7 into the heatsink. It may be helpful to hold the case of Q7 with long-nose pliers until you get it into the heatsink, pressing the bottom of the case with a small screwdriver or awl.

[ ] Install Q7 with its body about 1/16" above the PC board so it doesn't short to its own copper pads. You can optionally use a thin transistor mounting spacer.

[ ] Install all of the ICs. All ICs except U9 are 8-pin DIPs (dual-inline packages). The notched or dimpled end of each IC must be aligned with the notched end of its PC board outline. Also note that the pad for pin 1 of each IC is round, while the other pads are square. U9 is a flat-sided unit like a plastic transistor; install it as indicated on its PC board outline.

*Toroids*

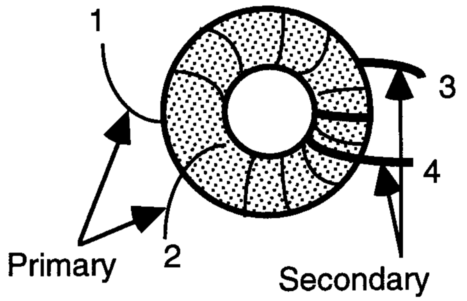
[ ] First, wind the simplest toroids (L10, L11, and RFC1, 2 and 3) as shown in the drawings below, using the cores and number of turns specified in the parts list.

**Note: The FT-37-43 cores and FT-37-61 cores are both <u>black</u>. These cores have completely different characteristics--guaranteed headaches if you get them mixed up!**

[ ] Cut the toroid leads to about 1/2 inch long, then use medium-grit sandpaper to remove the insulation to within about 1/8" of the toroid body. Don't nick the wire or sand it down too thin. The sanding job can be made easier by using a cigarette lighter or wooden match for 5 seconds or so on each lead to burn off most of the insulation.

[ ] Install these toroids (L10, L11, RFC1, 2, and 3) as indicated by the PC board outlines. (All of these toroids mount vertically. )

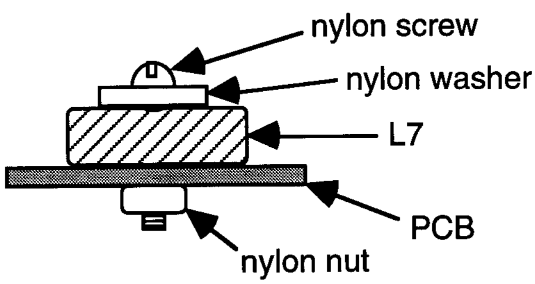
[ ] Next, wind transformer T2. The secondary winding (the one with fewer turns) should be wound on top of the primary winding, resulting in something like the drawing below.




[ ] Remove the insulation from T2's leads as described above, install it on the circuit board, and solder. Make sure that the primary and secondary leads line up with the numbers on the PCB outline.

[ ] Wind L7, the VFO toroid. This toroid has a lot of turns, so be sure to wind the turns as close together as possible without overlapping. Prepare the leads as described previously.

[ ] Insert L7's leads into their correct locations on the board, and secure the toroid to the PC board as shown below using nylon hardware. Do not over tighten--the stress can cause VFO instability. Solder L7.

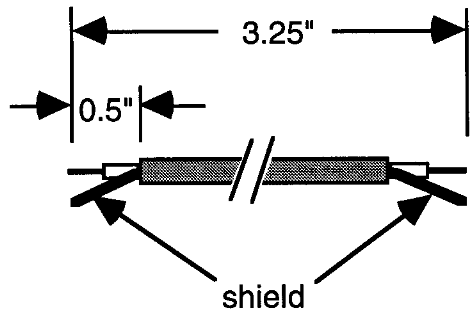



*Miscellaneous Components*

[ ] Install trimmer potentiometer R14 and solder.

[ ] Install all of the 4.915MHz crystals. The crystals are pre-matched, so any four can be used for the crystal filter (X1-X4).

[ ] Prepare two lengths of RG-174 coax for jumpers W1 and W2 as shown below. Use an Exacto knife to remove the outer jacket from each end. De-braid the shield, then twist about 1/3 of the wires back into a bundle to form a stranded wire. Strip about 1/4" of insulation from the center conductor.




[ ] Install W1 and W2. The center conductor at each end of W1 goes to a point labeled "W1," while the shield at each end of W1 goes to the nearest ground point. (Every point intended for a jumper has a white "donut" symbol on the silkscreen.) W2 is installed in a similar fashion. You can install the coax jumpers on either the top or bottom of the board. If you install the jumpers on the bottom of the board, be careful not to let the shield leads short to any other traces.

As a double-check, note that the two coax cables will end up crossed. Be careful not to overheat the center conductor when soldering the braid.

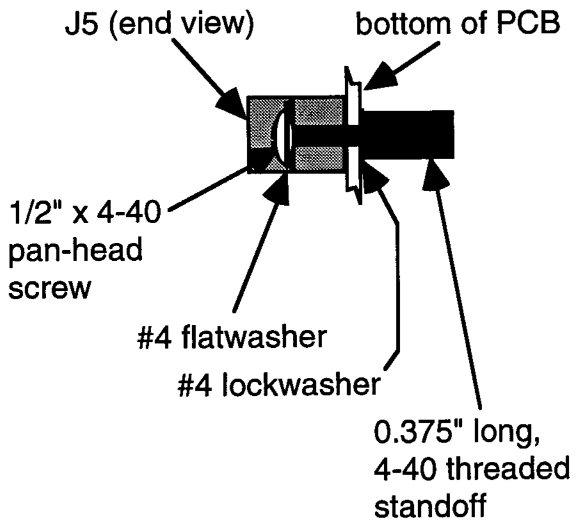
Install the VFO tuning capacitor, C54, as follows:

[ ] Cut a 1" length of solid copper hookup wire, preferably #22 or #24, and solder one end of it to the back-left solder terminal of the capacitor (as viewed from the front).

[ ] The component outline for C54 has a thin white line at the left center showing which hole the 1" wire is inserted into. Insert the wire and place C54 in its proper position on the board.

[ ] On the bottom side of the PC board, use two 4-40 x 1/4" pan head screws and two #4 lock washers to hold C54 in place.
Do not over-tighten these screws, or you'll put stress on the PCB that may cause VFO instability. If the bottom of C54 is warped, be especially careful not to warp the PC board; tighten only one screw if necessary.

[ ] Install the edge connector, J5, using the hardware shown below to hold it firmly against the PC board.




*Controls and Connectors*

Next, you'll install the front and rear panel controls and connectors onto the board. Keep them flush with the PC board, or as close as their leads will allow them to go, to insure good alignment with the panels. (Poor alignment here might cause eventual warping of the PC board.) Leave the finishing nuts and washers on the shafts for now. These will be used later to secure them to the front and rear panels.

[ ] Install J1, J2, J3, and J4. Bend the leads of J1 and J2 slightly to hold them flush against the PC board as you solder.

[ ] Remove the small metal tabs (near the shafts) of potentiometers R1, R8, and R17. Install the pots flush on the PC board. When seated correctly, each pot will sit a bit above the PC board due to the shoulders on the pins. **Double-check the values (stamped on the body of the pot near the threaded part of the shaft),** then solder. Make sure the pots stay flush as you solder.

[ ] Install S1 and S2. Again, it is important to keep the switches flush with the PC board.

## Band Module Assembly

Before you can align and test the Sierra, you'll need to build at least one band module.

*Everything but the toroids first...*

[ ] Install all of the fixed (disc) capacitors (noting the **special cases** below) and solder.

Special cases:

(1) Most band modules do not use C35 and C32.

(2) The 160-meter band module requires two capacitors that are not on the band module layout, C79 and C80. You'll have to mount these near (and electrically parallel with) C1 and C2, respectively, keeping the leads as short as possible.

[ ] Install the seven vertical-mount trimmer capacitors (C1, C2, C36, C33, C66, C64, and C70). All band modules use the same kind of trimmer (9-50pF) **except** 10 meters (5-30pF).

[ ] As you solder the trimmer capacitors, be sure to keep them flush with the PC board.

[ ] Hold the crystal so that you can read the frequency (stamped into the case), then bend the leads on the crystal down at a 90 degree angle, about 1/16" from the body of the crystal.

[ ] Prepare a short (1") piece of bare #24 or #22 solid wire. Insert one end of the wire into the hole just above the crystal and solder it on the bottom of the board. Next, cut the wire off to about 1/2" long on the top of the board, fold it over the crystal, and solder it to the crystal's case, without obscuring the frequency label (this may require that the wire be angled away from the label).

[ ] **Do not install Jumpers W3 and W4.** These are reserved for use with the KC1 keyer/counter to identify which band edge to report (000, 500, etc.). Refer to the KC1 manual for more details.

*...and now, the toroids*

[ ] Wind toroids L5 and L6, making sure that the turns are spaced evenly as described earlier in the manual.

[ ] Prepare the leads as described earlier, and solder L5 and L6 into place.

**Note that the toroids on the band module are very close together due to space constraints. Keep a small space (1/16"-1/8") between adjacent toroids.**

[ ] Wind and install the remaining toroids, except T1.

[ ] Wind T1 in the same manner as described for T2 on the main PC board assembly. The only difference is that pins 3 and 4 are reversed. Orient T1 as shown on the band module silkscreen, then solder.

## Alignment and Test

Rather than require a specific set of test equipment, the Sierra alignment and test procedure given below gives you three alternatives. You can use: (1) standard lab test equipment (oscilloscope, frequency counter, signal generator, multimeter, etc., all with high impedance probes); (2) a general-coverage ham transceiver; or (3) nothing but a DMM (digital multimeter) and a home-made RF probe.

Using real lab test equipment is more precise, and helps a great deal if you need to do some troubleshooting. However, you should be able to align the Sierra using methods 2 or 3. These more primitive techniques will also prove useful in the field, where you seldom have access to good test equipment.

*Smoke Test*

Before turning on power, follow these steps:

[ ] Set both S1 (power) and S2 (RIT) in the OFF position.

[ ] Insert a band module, preferably 40, 30, or 20 meters.

[ ] Connect a 50-ohm, 2-watt (minimum) dummy load to the antenna jack.

[ ] Using a small (1/8") flat-blade screwdriver, turn R14 (drive control) fully counter-clockwise.

[ ] Connect a well-regulated and filtered 11 to 15V DC power supply (or battery) capable of supplying 500mA to J3. The preferred voltage is 13.0 volts.

[ ] Turn on the power supply and S1. If any component is hot to the touch or you see or smell smoke, chances are you have a short or open or bad component--kill the power immediately!

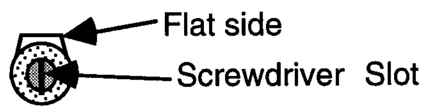
[ ] Connect a milliameter in series with the DC supply and note the current reading, which should be approximately 35mA. If the reading differs by more than about +/- 8 mA from this value, chances are you have a short or open or bad component.

[ ] Using a DMM, verify that the voltage at U1, pin 1, is between 3.5 and 4.0 volts. (This is the no-signal AGC voltage; see **Circuit Details.**) If this voltage is incorrect, refer to **Troubleshooting.**

*Receiver Alignment*

Follow the steps in Table 1 to align the receiver and all signal sources. You'll need to repeat this procedure for each band module (except for the VFO alignment, which is done once). Use a non-metallic or insulated tuning tool for adjusting trimmer capacitors.

**Table 1.** VFO, PMO, and Receiver Alignment.

<table>
<tr><th>Alignment Step</th><th>Using Lab Test Equipment</th><th>Using a Test Receiver and Transmitter</th><th>Using a DMM and RF Probe</th></tr>
<tr><td colspan="4">[ ] Set VFO tuning cap (C54) to its fully-meshed position, then remove the VFO knob.<br><br>[ ] Loosen the set screw on the VFO dial and rotate it until the "150" tic mark is exactly straight up (make a temporary pointer mark on the front panel, if necessary, using a thin slice of electrical tape). Then tighten the set screw and replace the VFO knob.</td></tr>
<tr><td>[ ] With the VFO dial at "150," adjust C52 for a VFO frequency of 2.935 MHz (+/- 1 KHz).</td><td>Connect a hi-Z counter probe to the R22/C59 junction (or, for less loading, R22/C61).</td><td>Connect a 3' long wire antenna to the test receiver. Tune the receiver to 2.935MHz.</td><td>For now, just leave C52 at its midpoint. You can align C54 later using a known on-air signal.</td></tr>
<tr><td colspan="4">[ ] If the VFO can't reach 2.935MHz, remove the nylon screw from L7 and spread out the turns (to go higher) or compress the turns (to go lower). Then repeat the previous step.</td></tr>
<tr><td>[ ] Tune the VFO to the "0" mark on the dial (this is not the end of the VFO's rotation).</td><td>Note the new counter reading.</td><td>Tune the test receiver until you find the Sierra's VFO signal.</td><td>n/a</td></tr>
<tr><td colspan="4">[ ] If the VFO reads above 3.085 MHz, decrease the VFO tuning range by spreading the turns of L7 a bit; if it reads below 3.085 MHz, increase the range by slightly compressing the turns of L7. After adjusting the turns, set the dial to "150" and repeat all VFO alignment steps.<br><br>Note: The worst-case scenario (hopefully rare!) is that, after adjusting the turns of L7, you can't set the VFO's "150" frequency to 2.935 MHz. In this case, you may need to increase or decrease the value of C53. Use only NPO disc, polystyrene, or other stable capacitor types.</td></tr>
<tr><td colspan="4">[ ] Set all trimmer capacitors on both the main board (C16, C38) and the band modules (C1, C2, C36, C33, C66, C64, and C70) to their mid-points as shown:<br></td></tr>
<tr><td>[ ] Align the crystal oscillator using C70 on the band module (labeled "XTAL"). See Table 2 for oscillator freq.</td><td>Connect the counter to pin 6 of U7 (or for less loading, use pin 7).</td><td>Tune the test receiver to the frequency shown in Table 2. Adjust C70 until you hear the oscillator.</td><td>Leave C70 at its midpoint. You'll usually be within about 2 or 3 KHz.</td></tr>
</table>

<table>
<tr><td>[ ] Set the VFO dial to the "0" mark.</td><td>Connect a scope to the junction of R25 and Q8-drain.</td><td>Tune the test receiver to the low end of the PMO range (Table 2), and find the Sierra's PMO signal.</td><td>Connect the RF probe to the junction of R25 and Q8-drain and use E1 for GND.</td></tr>
<tr><td>[ ] Peak the pre-mix band-pass filter with C64 and C66 on the band module (labeled "Pre-mix").</td><td>Adjust C64 and C66 for max signal.<br>Use a counter to verify operation at the right frequency.</td><td>Adjust C64 and C66 for max signal strength by ear, or as indicated on the test receiver's S-meter.</td><td>Adjust C64 and C66 for maximum signal as indicated on the DMM (DC volts scale).</td></tr>
<tr><td colspan="4">NOTE: If you end up with these two capacitors somewhere in mid-range, chances are you've got the PMO filter aligned at the proper frequency. It may be possible to tune to a higher (wrong) output frequency.</td></tr>
<tr><td colspan="4">[ ] Set the RF gain control to its fully clockwise position (max gain).<br><br>[ ] Set the AF gain to about 12 o'clock, and plug in a pair of 8- to 32-ohm stereo headphones.<br><br>[ ] Set the VFO for a dial reading of "50." (This corresponds to 7.050MHz on 40 meters.)</td></tr>
<tr><td>[ ] Set up a signal source at 7.050 MHz (or the corresponding frequency for the band module in use).</td><td>Set a signal generator for 10mV rms output at the desired frequency. Connect it to the Sierra's antenna jack.</td><td>Setup the test transmitter to output a CW signal into a dummy load. Use a 3' wire at the Sierra's antenna input (J4).</td><td>If you don't have any kind of signal source, just connect the best possible antenna to the Sierra (or 33' of wire).</td></tr>
<tr><td>[ ] With the headphones on, vary the frequency of the signal source to find the signal.</td><td>Once you find the signal, reduce the generator output to the point where the signal is quite weak.</td><td>Key the test transmitter, and tune its VFO until you hear the signal in the Sierra's headphones.</td><td>You may hear some background noise; if not, try to locate a signal using the VFO knob.</td></tr>
<tr><td>[ ] Peak the receiver front-end filter using C1 and C2 on the band module (labeled "RX").</td><td>Adjust C1 and C2 for maximum signal strength by ear, or with a scope at U3-5.</td><td>Adjust C1 and C2 for maximum signal strength.</td><td>Tune C1 and C2 for max increase in noise or for loudest signal.</td></tr>
<tr><td colspan="4">[ ] Set the BFO trimmer, C16, for the desired audio pitch. This moves the BFO in relation to the center frequency of the crystal filter, sortof like "IF Shift" on a commercial rig.</td></tr>
</table>

### *Crystal Oscillator and PMO Frequency Chart*

Table 2 lists the crystal oscillator and PMO frequencies used on each band. If you're using a frequency counter or general-coverage receiver during alignment, you can use this table to determine what frequencies to look for.

Note that the crystal oscillator and PMO frequencies are *above* the RF range on all bands except 10 and 12 meters (shown in bold). We use frequencies *below* the RF range on 10 and 12 meters because it is nearly impossible to buy a fundamental-mode crystal above 30 MHz, and not a good idea even if you could. Table 2 also shows how the IF (intermediate frequency) of 4.915 MHz is obtained by the receive mixer on each band. Since the sign of the subtraction is reversed on 10 and 12 meters, the signal you listen to is on the other side of zero beat on the VFO dial. However, the same dial calibration still applies; only the sideband gets inverted.

**Table 2.** Crystal Oscillator and PMO frequencies.

| RF Range | Crystal Oscillator | PMO Range | RX Mixer Formula (see text) |
|---|---|---|---|
| 1.800-1.950 | 9.800 | 6.715-6.865 | IF = PMO - RF (USB) |
| 3.500-3.650 | 11.500 | 8.415-8.565 | IF = PMO - RF (USB) |
| 7.000-7.150 | 15.000 | 11.915-12.065 | IF = PMO - RF (USB) |
| 10.000-10.150 | 18.000 | 14.915-15.065 | IF = PMO - RF (USB) |
| 14.000-14.150 | 22.000 | 18.915-19.065 | IF = PMO - RF (USB) |
| 18.000-18.150 | 26.000 | 22.915-23.065 | IF = PMO - RF (USB) |
| 21.000-21.150 | 29.000 | 25.915-26.065 | IF = PMO - RF (USB) |
| **24.800-24.950** | **22.970** | **19.885-20.035** | **IF = RF - PMO (LSB)** |
| **28.000-28.150** | **26.170** | **23.085-23.235** | **IF = RF - PMO (LSB)** |

*Transmitter Alignment*

Table 3 lists the steps required to align the transmitter. The receiver alignment must be completed first to insure that the VFO and PMO are operating properly.

**Table 3.** Transmitter Alignment.

| Alignment Step | Using Lab Test Equipment | Using a Test Receiver | Using a DMM and RF Probe |
|---|---|---|---|
| [ ] Connect a 50-ohm dummy load to the Sierra's antenna jack.<br>[ ] Plug in a hand key at J2. Avoid using a keyer in "tune" mode.<br>[ ] Plug in a band module; start with 40, 30, or 20 meters if possible. Set the Sierra VFO for a dial reading of "050" (i.e., 7.050 MHz if you're using the 40-meter band module). | | | |
| [ ] Prepare to monitor the Sierra's RF output. | Connect a scope to the antenna jack, J4. Also connect a counter --**if it can handle 40V p-p or more.** Use high impedance probes. | Connect a 3' wire antenna to the test receiver's antenna input. Tune the test receiver to 7.050 (or the equivalent for the band in use). | Connect the RF probe to the antenna jack. Set the DMM to its 30V range. You can also use an SWR bridge or wattmeter. |
| [ ] Set the drive control for maximum (fully clockwise), then **back it down by about 1/8 turn.** | | | |
| [ ] Key the Sierra and peak the transmit band-pass filter using C33 and C36 on the band module (labeled "TX").<br><br>**Do not key the transmitter for over 3 seconds at a time; allow plenty of cool-down time.** | Start with the scope at 1 volt/division and work up to 5 volt/division as you peak the filter. | Find the Sierra's output signal on the test receiver. As you peak the filter, try to keep the signal around S6 to S9 on the test receiver's S-meter using its RF attenuators and/or gain control. | Peak the filter trimmers carefully and watch for an increase in the DMM reading. Eventually you should hit somewhere in the 5 to 10 volt range. |

| | | |
|---|---|---|
| [ ] Set the power output to the desired level using R14. (See **Operation.**) | Power = $(Vp\text{-}p/2.8)^2$ / 50Ω) | Using a DMM and RF probe: Power = $Vrms^2$/ 50Ω |
| [ ] Listening in the Sierra's headphones, set the TX offset adjustment, C38, for the desired TX monitor pitch. If the TX monitor tone seems weak, you may have set C38 near its minimum, which would put the TX offset on the wrong side of zero beat. | | |

## Troubleshooting

**1. If you have a problem that you can *see* or *smell*, turn off power immediately.**

2. Inspect the PC board for solder bridges, cold or non-existent solder joints, incorrectly-installed parts (backwards or wrong part), broken parts, and open circuit traces.

3. Double-check your setup. Often you can trace a problem to a bad scope probe, intermittent clip lead, incorrect power supply voltage, idle chit-chat from passers-by, weak coffee, etc. Try the alignment procedure again if it seems safe to do so.

4. Try signal tracing to locate where the signal is getting lost. A general signal tracing procedure is given below. Unless otherwise noted, measurements were taken with a high-impedance DMM set to DC V and an RF probe.

*Low-level Signal Sources:*

a. VFO output at the junction of R22 and C59: 640mV rms
b. BFO at U4, pin 6: 230mV rms
c. Crystal oscillator output at U7, pin 6: 250mV rms
d. PMO buffer output at the drain of Q8: 270mV rms

*Receiver (with a 10 mV rms signal at J4):*

a. RX Mixer output, U2, pin 5: 200mV rms
b. IF amp input, U5, pin 4: 200mV rms
c. Product detector output, U4, pin 5: 12 mVrms (DMM only; AC V)
d. AF amp out, U3, pin 5: 1.47Vrms (DMM only; AC V)
e. AGC voltage, U1, pin 1: 5.6 VDC (DMM only; DC V)

*Transmitter (measured on keydown with drive set to minimum):*

a. TX mixer oscillator at U8, pin 6: 140mV rms
b. TX mixer PMO injection at U8, pin 1: 89mV rms
c. Buffer output at Q5 source: 400mV rms
d. Driver output at Q6 collector (case): 400mV rms

*Transmitter (keydown with drive set to 90% of maximum):*

a. Driver output at Q7 base: 1.2Vrms
b. Power Amp output at Q7 collector: 13.9Vrms
c. Output at antenna jack: 9.5V rms.
(Low efficiency? Try reversing T2's secondary leads.)

5. Check all DC voltages using Table 3 (next page). Also, be suspicious of electrolytic caps: if they have high leakage, they can act like they're in parallel with a resistor. This is especially true of C26. If you see a different voltage at C26(+) than you do at pin 3 of U1 with the RF gain control at minimum, toss C26 in the round file.

6. If you still have difficulties, seek help from another NorCal member nearby. Jim, Doug, or Wayne may be able to point you in the right direction.

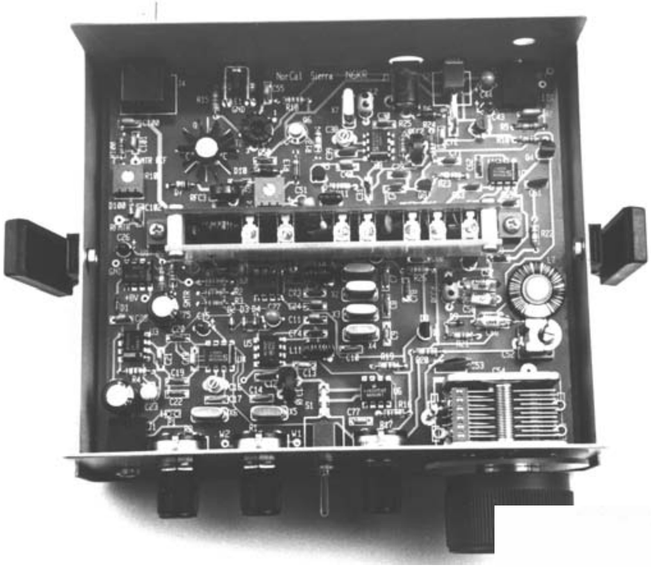
*DC Voltage Chart*

These readings were taken with a DMM (30V scale), under the following conditions: power supply = 12.96 (rcv), 12.83 (xmit); regulated supply (output of U9) @ 7.93 volts; dummy load at J4; transmit output 2 watts ("Xmit" readings); headphones plugged in and AF gain at 2 o'clock; RF gain: max; RIT: OFF.

In general, you should expect your readings to be within about 5 to 10% of these. Voltages in **bold** are unstable due to the effect of the DMM probe; use an oscilloscope if possible at these points. Voltages listed as "n/a" either can't be measured or are irrelevant.

**Table 3.** Sierra DC Voltages, All Active Devices

| Device/Pin# | Rcv | Xmit | Device/Pin# | Rcv | Xmit | Device/Pin# | Rcv | Xmit |
|---|---|---|---|---|---|---|---|---|
| U1, pin 1 | 3.69 | 4.40 | U5, pin 1 | 7.94 | 7.93 | U9, IN | 12.68 | 12.49 |
| U1, pin 2 | 3.69 | 4.40 | U5, pin 2 | 7.94 | 7.93 | U9, OUT | 7.94 | 7.93 |
| U1, pin 3 | 3.69 | 4.42 | U5, pin 3 | 0.00 | 0.00 | U9, GND | 0.00 | 0.00 |
| U1, pin 4 | 0.00 | 0.00 | U5, pin 4 | 2.54 | 2.55 | Q1, emitter | 0.00 | 0.00 |
| U1, pin 5 | n/a | n/a | U5, pin 5 | 3.80 | 6.69 | Q1, base | 0.00 | 0.71 |
| U1, pin 6 | n/a | n/a | U5, pin 6 | 2.54 | 2.55 | Q1, coll. | 0.00 | 0.00 |
| U1, pin 7 | n/a | n/a | U5, pin 7 | 0.00 | 0.00 | Q2, emitter | 0.00 | 0.00 |
| U1, pin 8 | 7.94 | 7.93 | U5, pin 8 | 7.94 | 7.93 | Q2, base | 0.00 | 0.69 |
| U2, pin 1 | 1.44 | 1.44 | U6, pin 1 | 0.78 | 0.78 | Q2, coll. | 0.00 | 0.00 |
| U2, pin 2 | 1.44 | 1.44 | U6, pin 2 | 2.54 | 2.55 | Q3, gate | 0.03 | 0.03 |
| U2, pin 3 | 0.00 | 0.00 | U6, pin 3 | 7.94 | 7.93 | Q3, source | 0.03 | 0.03 |
| U2, pin 4 | 6.68 | 6.59 | U6, pin 4 | 0.00 | 0.00 | Q3, drain | 7.94 | 7.93 |
| U2, pin 5 | 6.75 | 6.63 | U6, pin 5 | 2.54 | 2.55 | Q4, emitter | 7.94 | 7.93 |
| U2, pin 6 | 7.88 | 7.88 | U6, pin 6 | 7.94 | 7.93 | Q4, base | 7.83 | 7.19 |
| U2, pin 7 | 7.41 | 7.41 | U6, pin 7 | 0.01 | 0.01 | Q4, coll. | 0.00 | 7.74 |
| U2, pin 8 | 7.94 | 7.93 | U6, pin 8 | 7.94 | 7.93 | Q5, gate | 0.00 | 0.00 |
| U3, pin 1 | 1.30 | 1.30 | U7, pin 1 | 1.42 | 1.42 | Q5, source | 0.00 | 2.00 |
| U3, pin 2 | 0.01 | 0.01 | U7, pin 2 | 1.42 | 1.42 | Q5, drain | 0.00 | 7.74 |
| U3, pin 3 | 0.01 | 0.01 | U7, pin 3 | 0.00 | 0.00 | Q6, emitter | **n/a** | 1.31 |
| U3, pin 4 | 0.00 | 0.00 | U7, pin 4 | 6.72 | 6.72 | Q6, base | 0.00 | 2.01 |
| U3, pin 5 | 3.92 | 3.92 | U7, pin 5 | 6.73 | 6.73 | Q6, coll. | 12.68 | 9.54 |
| U3, pin 6 | 7.94 | 7.93 | U7, pin 6 | 7.86 | 7.86 | Q7, emitter | 0.00 | 0.00 |
| U3, pin 7 | 3.96 | 3.96 | U7, pin 7 | 7.14 | 7.14 | Q7, base | 0.00 | **0.00** |
| U3, pin 8 | 1.31 | 1.30 | U7, pin 8 | 7.94 | 7.93 | Q7, coll. | 12.68 | **12.89** |
| U4, pin 1 | 1.42 | 1.42 | U8, pin 1 | 0.00 | 1.42 | Q8, gate | 0.00 | 0.00 |
| U4, pin 2 | 1.42 | 1.42 | U8, pin 2 | 0.00 | 1.42 | Q8, source | 0.68 | 0.68 |
| U4, pin 3 | 0.00 | 0.00 | U8, pin 3 | 0.00 | 0.00 | Q8, drain | 7.94 | 7.93 |
| U4, pin 4 | 6.74 | 6.74 | U8, pin 4 | 0.00 | 6.43 | | | |
| U4, pin 5 | 6.76 | 6.76 | U8, pin 5 | 0.00 | 6.44 | | | |
| U4, pin 6 | 7.85 | 7.85 | U8, pin 6 | 0.00 | 7.66 | | | |
| U4, pin 7 | 7.60 | 7.60 | U8, pin 7 | 0.00 | 7.39 | | | |
| U4, pin 8 | 7.94 | 7.93 | U8, pin 8 | 0.00 | 7.74 | | | |



## THE NORCAL SIERRA: AN 80-15 M CW TRANSCEIVER

Most home-built QRP transceivers cover a single band, for good reason: complexity of the circuit and physical layout can increase dramatically when two or more bands are covered. This holds for most approaches to multiband design, including the use of multipole switches, transverters and various forms of electronic switching.[1]

If the designer is willing to give up instant band switching, then plug-in band modules can be used. Band modules are especially appropriate for a transceiver that will be used for extended portable operation, for example: back-packing. The reduced circuit complexity improves reliability, and the extra time it takes to change bands usually isn't a problem. Also, the operator need take only the modules needed for a particular outing.

The Sierra transceiver shown in **Fig 15.8** uses this technique, providing coverage of all bands from 80 through 15 m with good performance and relative simplicity.[2] The name Sierra was inspired by the mountain range of the same name — a common hiking

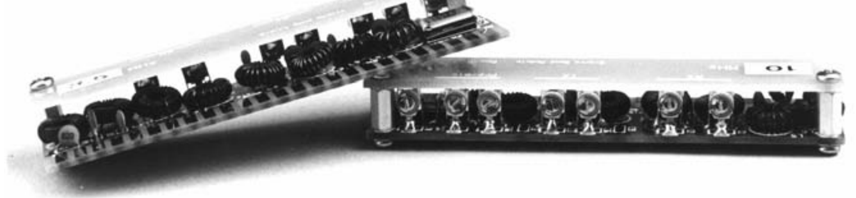


**Fig 15.8 — The Sierra transceiver. One band module is plugged into the center of the main PC board; the remaining boards are shown below the rig. Quick-release latches on the top cover of the enclosure make it easy to change bands.**

destination for West Coast QRPers. The transceiver was designed and built by Wayne Burdick, N6KR, and field tested by members of NorCal, the Northern California QRP Club.[3]

## FEATURES

One of the most important features of the Sierra for the portable QRP operator is its low current drain. Because it has no relays, switching diodes or other active band-switching circuitry, the Sierra draws only 30 mA on receive.[4] Another asset for field operation is the Sierra's low-frequency VFO and premixing scheme, which provides 150 kHz of coverage and good frequency stability on all bands.

The receiver is a single-conversion superhet with audio-derived AGC and RIT. It has excellent sensitivity and selectivity, and will comfortably drive a speaker. Transmit features include full break-in keying, shaped keying and power output averaging 2 W, with direct monitoring of the transmitted signal in lieu of sidetone. Optional circuitry allows monitoring of relative power output and received signal strength.

**Table 15.1**
**Crystal Oscillator and Premix (PMO) Frequencies in MHz**

The premixer (U7) subtracts the VFO (2.935 to 3.085 MHz) from the crystal oscillator to obtain the PMO range shown. The receive mixer (U2) subtracts the RF input from the PMO signal, yielding 4.915 MHz. The transmit mixer (U8) subtracts 4.915 MHz from the PMO signal to produce an output in the RF range.

| *RF Range* | *Crystal Oscillator* | *PMO Range* |
|---|---|---|
| 3.500-3.650 | 11.500 | 8.415-8.565 |
| 7.000-7.150 | 15.000 | 11.915-12.065 |
| 10.000-10.150 | 18.000 | 14.915-15.065 |
| 14.000-14.150 | 22.000 | 18.915-19.065 |
| 18.000-18.150 | 26.000 | 22.915-23.065 |
| 21.000-21.150 | 29.000 | 25.915-26.065 |

Physically, the Sierra is quite compact — the enclosure is 2.7 × 6.2 × 5.3 inches (HWD) — yet there is a large amount of unused space both inside and on the front and rear panels. This results from the use of PC board-mounted controls and connectors. The top cover is secured by quick-release plastic latches, which provide easy access to the inside of the enclosure. Band changes take only a few seconds.

## CIRCUIT DESCRIPTION

**Fig 15.9** is a block diagram of the Sierra. The diagram shows specific signal frequencies for operation on 40 m. **Table 15.1** provides a summary of crystal oscillator and premix frequencies for all bands.

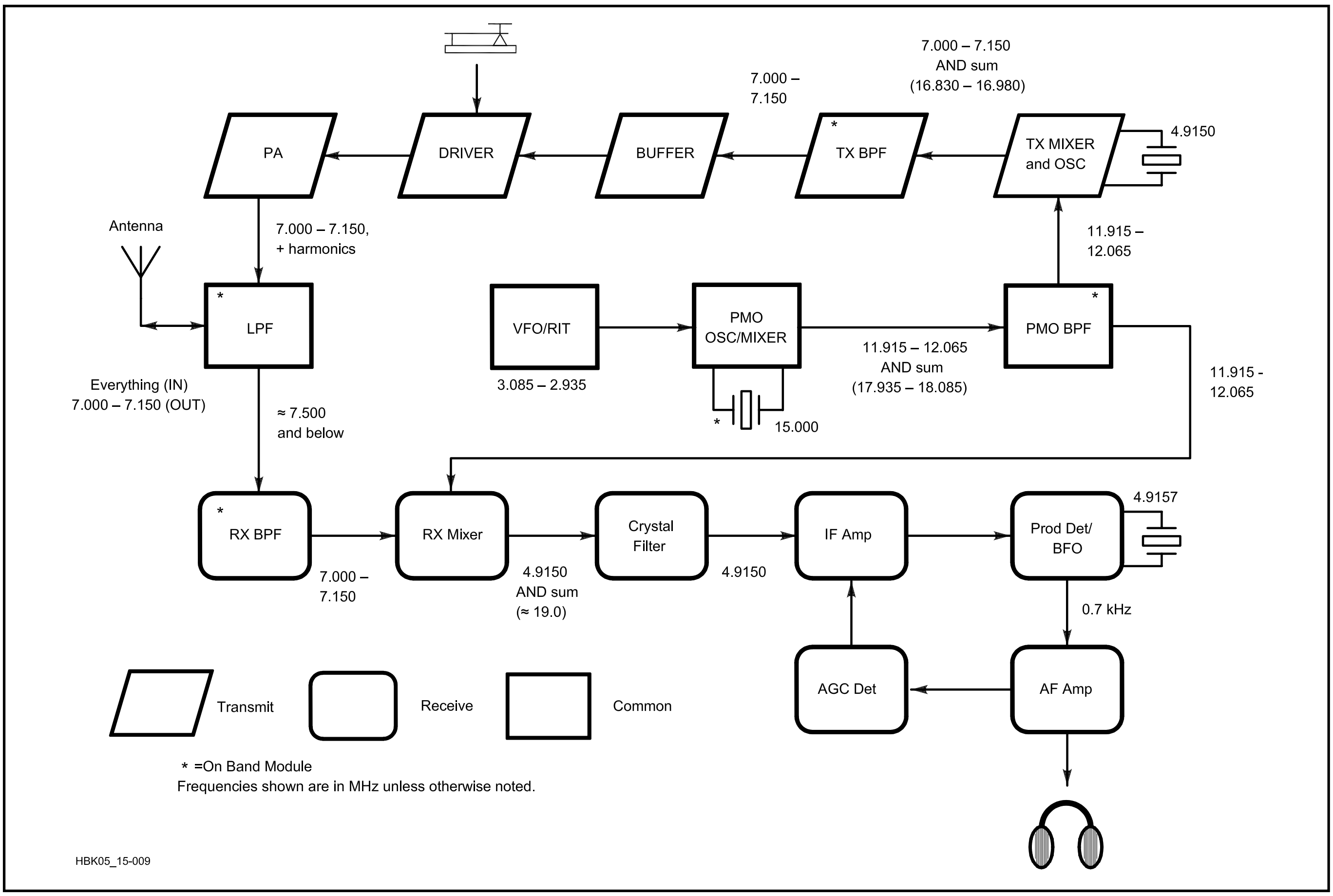



**Fig 15.9 — Block diagram of the Sierra transceiver. Three different-shaped symbols are used to show transmit, receive and common blocks. Those blocks with an asterisk (*) are part of the band module. Signal frequencies shown are for 40 m; see Table 15.1 for a list of crystal oscillator and premix frequencies for all bands.**

**Table 15.2**
**Band Module Components**

All crystals are fundamental, 15-pF load capacitance, 0.005% frequency tolerance, in HC-49 holders. Fixed capacitors over 5 pF are 5% tolerance. All coils are wound with enameled wire.

| | Band | | | | | |
|---|---|---|---|---|---|---|
| *Part* | *80 m* | *40 m* | *30 m* | *20 m* | *17 m* | *15 m* |
| C32, C35 | 33 pF, 5% | 47 pF, 5% | not used | not used | not used | not used |
| C34 | 5 pF, 5% | 5 pF, 5% | 2 pF, 5% | 2 pF, 5% | 2 pF, 5% | 2 pF, 5% |
| C47, C49 | 820 pF, 5% | 330 pF, 5% | 330 pF, 5% | 220 pF, 5% | 150 pF, 5% | 150 pF, 5% |
| C48 | 1800 pF, 5% | 820 pF, 5% | 560 pF, 5% | 470 pF, 5% | 330 pF, 5% | 330 pF, 5% |
| C65 | 5 pF, 5% | 5 pF, 5% | 2 pF, 5% | 1 pF, 5% | 1 pF, 5% | 1 pF, 5% |
| L1 | 50 µH, 30 t #28 on FT-37-61 | 14 µH, 16 t #26 on FT-37-61 | 5.2 µH, 36 t #28 on T-37-2 | 2.9 µH, 27 t #28 on T-37-2 | 1.7 µH, 24 t #28 on T-37-6 | 1.9 µH, 25 t #28 on T-37-6 |
| L3, L4 | 32 µH, 24 t #26 on FT-37-61 | 5.2 µH, 36 t #28 on T-37-2 | 4.4 µH, 33 t #28 on T-37-2 | 2.9 µH, 27 t #28 on T-37-2 | 1.7 µH, 24 t #28 on T-37-6 | 1.9 µH, 25 t #28 on T-37-6 |
| L5, L6 | 2.1 µH, 23 t #26 on T-37-2 | 1.3 µH, 18 t #26 on T-37-2 | 1.0 µH, 16 t #26 on T-37-2 | 0.58 µH, 12 t #26 on T-37-2 | 0.43 µH, 12 t #26 on T-37-6 | 0.36 µH, 11 t #26 on T-37-6 |
| L8, L9 | 8.0 µH, 12 t #26 on FT-37-61 | 2.5 µH, 25 t #28 on T-37-2 | 1.6 µH, 20 t #28 on T-37-2 | 1.3 µH, 18 t #26 on T-37-2 | 0.97 µH, 18 t #26 on T-37-6 | 0.87 µH, 17 t #28 on T-37-6 |
| T1 (Sec same as L1) | Pri: 2 t #26 on FT-37-61 | Pri: 1 t #26 on FT-37-61 | Pri: 3 t #26 on T-37-2 | Pri: 2 t #26 on T-37-2 | Pri: 2 t #26 on T-37-6 | Pri: 2 t #26 on T-37-6 |
| X8 | 11.500 MHz (ICM 434162) | 15.000 MHz (ICM 434162) | 18.000 MHz (ICM 434162) | 22.000 MHz (ICM 435162) | 26.000 MHz (ICM 436162) | 29.000 MHz (ICM 436162) |

The schematic is shown in **Fig 15.10**. See **Table 15.2** for band-module component values.

On all bands, the VFO range is 2.935 MHz to 3.085 MHz. The VFO tunes "backwards": At the low end of each band, the VFO frequency is 3.085 MHz. U7 is the premixer and crystal oscillator, while Q8 buffers the premix signal prior to injection into the receive mixer (U2) and transmit mixer (U8).

A low-pass filter, three band-pass filters and a premix crystal make up each band module. To make the schematic easier to follow, this circuitry is integrated into Fig 15.10, rather than drawn separately. J5 is the band module connector (see the note on the schematic).

The receive mixer is an NE602, which draws only 2.5 mA and requires only about 0.6 V (P-P) of oscillator injection at pin 6. An L network is used to match the receive mixer to the first crystal filter (X1-X4). This filter has a bandwidth of less than 400 Hz. The single-crystal second filter (X5) removes some of the noise generated by the IF amplifier (U7), a technique W7ZOI described.[5] This second filter also introduces enough loss to prevent the IF amplifier from overdriving the product detector (U4).

The output of the AF amplifier (U3) is dc-coupled to the AGC detector. U3's output floats at $V_{cc}/2$, about 4 V, which happens to be the appropriate no-signal AGC voltage for the IF amplifier when it is operated at 8 V. C26, R5, R6, C76 and R7 provide AGC loop filtering. Like all audio-derived AGC schemes, this circuit suffers from pops or clicks at times.

Transmit signal monitoring is achieved by means of a separate 4.915 MHz oscillator for the transmitter; the difference between this oscillator and the BFO determines the AF pitch. Keying is exponentially shaped, with the rise time set by the turn-on delay of transmit mixer U8 and the fall time determined by C51, in the emitter of driver Q6.

## CONSTRUCTION

The Sierra's physical layout and packaging make it relatively easy to build and align, although this isn't a project for the first-time builder. The boards and custom enclosure described here are included as part of an available kit.[6] Alternative construction methods are discussed below.

With the exception of the components on the band module, all of the circuitry for the Sierra is mounted on a single 5 × 6 inch PC board. This board contains not only the components, but all of the controls and connectors as well. The board is double-sided with plated-through holes, which permits flexible arrangement of the circuitry while eliminating nearly all hand-wiring. The only two jumpers on the board, W1 and W2, are short coaxial cables between the RF GAIN control and the receiver input filters.

A dual-row edge connector (J5) provides the interface between the main board and the band module. The 50 pins of J5 are used in pairs, so there are actually only 25 circuits (over half of which are ground connections).

The band module boards are 1.25 × 4 inches (HW). They, too, are double-sided, maximizing the amount of ground plane. Because the band modules might be inserted and removed hundreds of times over the life of the rig, the etched fingers that mate with J5 are gold-plated. Each etched finger on the front is connected to the corresponding finger on the back by a plated through hole, which greatly improves reliability over that of a single finger contact.

Each band module requires eight toroids: two for the low-pass filter, and two each for the receive, transmit and premix band-pass filters. The builder can secure the toroids to the band module with silicone adhesive or Q-dope. Right-angle-mount trimmer capacitors allow alignment from above the module. Each band module has a top cover made of PC board material. The cover protects the components during insertion, removal and storage.

The VFO capacitor is a 5-40 pF unit with a built-in 8:1 vernier drive. The operating frequency is read from a custom dial fabricated from 0.060-inch Lexan. The dial mounts on a hub that comes with the capacitor.

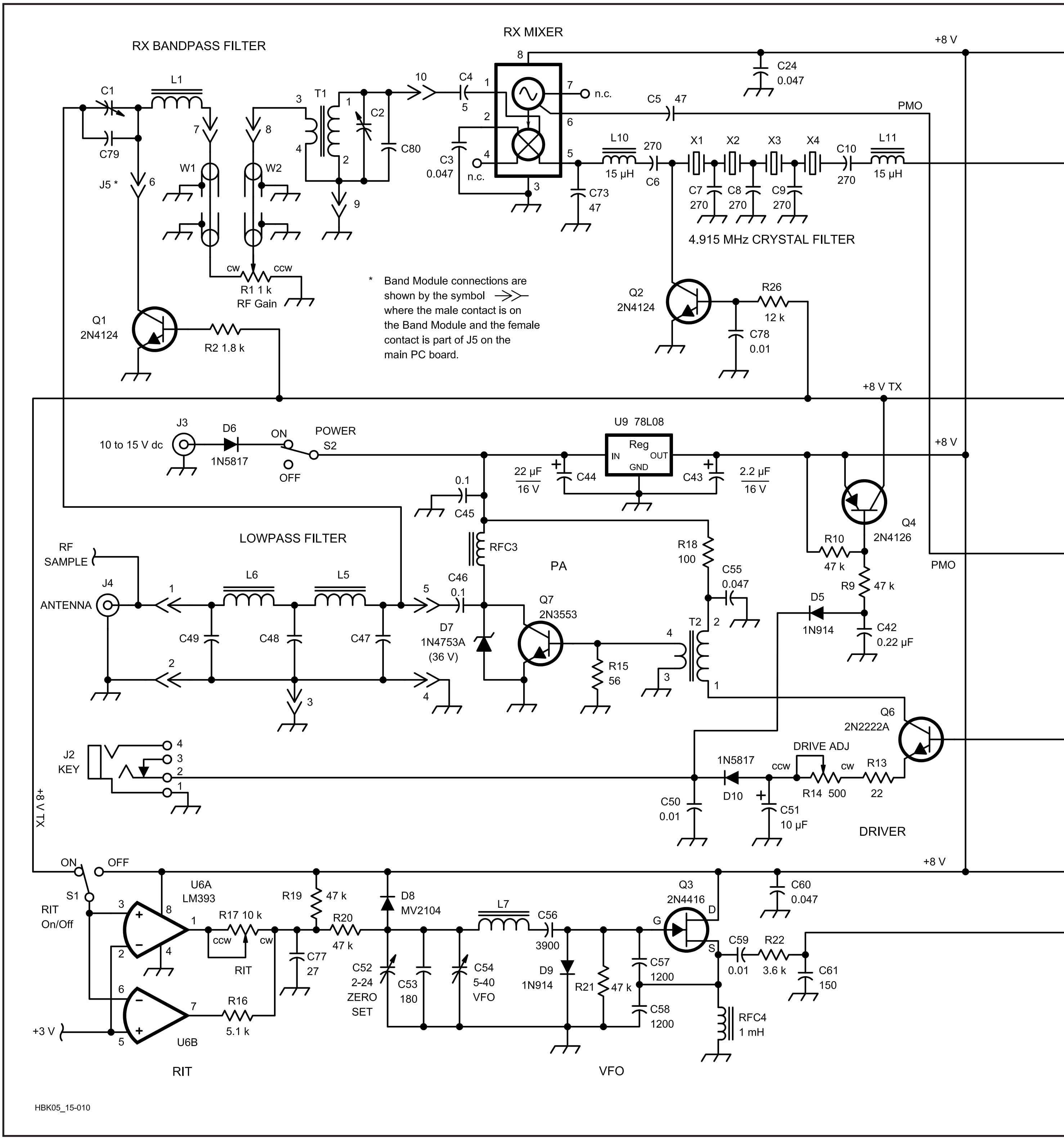
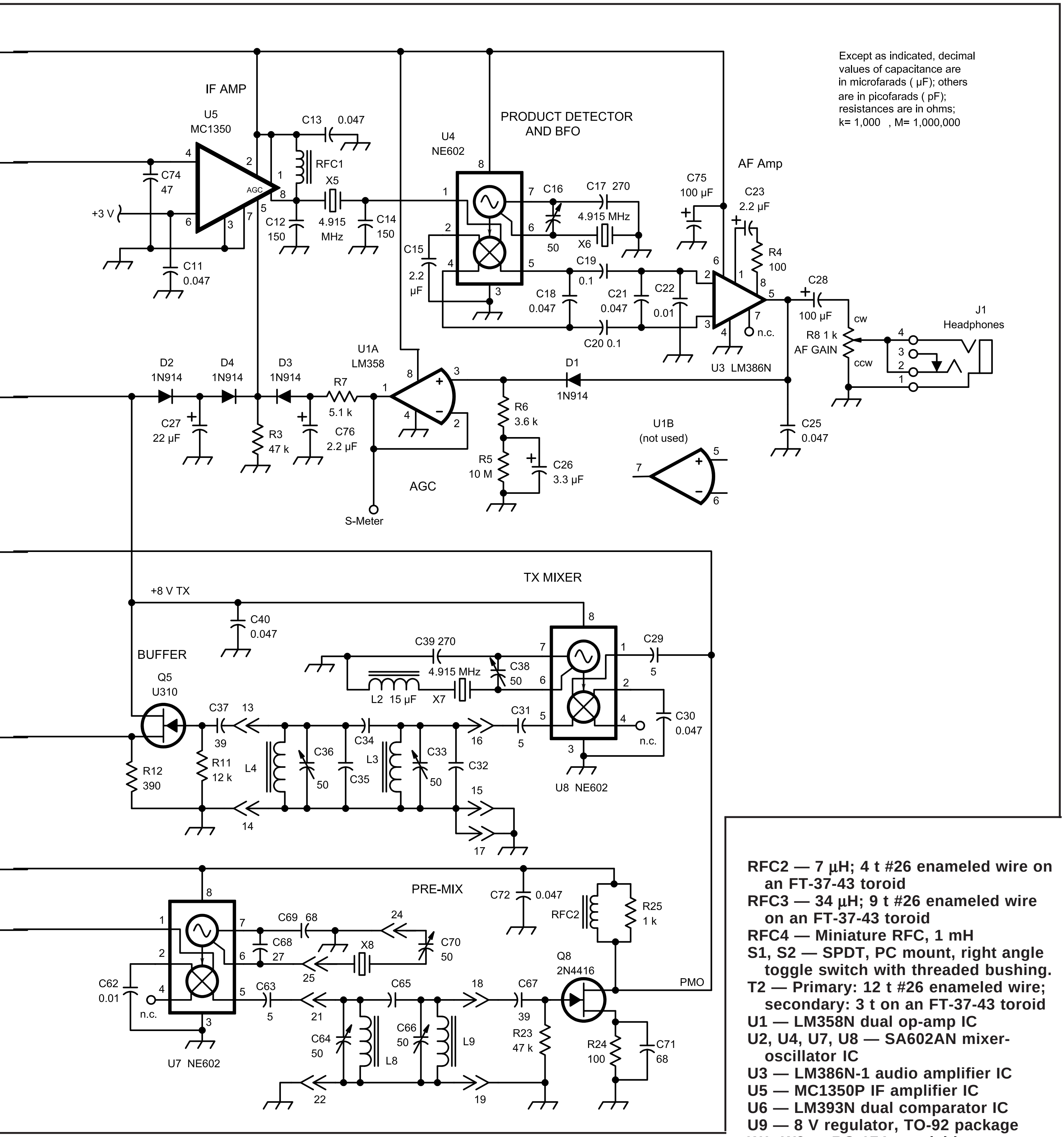



Fig 15.10 — Schematic of the Sierra transceiver. Parts that change for each band are shown in Table 15.2. See the Templates Section on the ARRL Handbook CD-ROM for more information on parts for this project.

**C1, C2, C33, C36, C64, C66, C70 — 9-50 pF right-angle-mount ceramic trimmer (same for all band modules)**
**C16, C38 — Ceramic trimmer, 8-50 pF**
**C52 — Air variable, 2-24 pF**
**C53 — Disc, 180 pF, 5%, NP0**
**C54 — 5-40 pF air variable with 8:1 vernier drive**
**C56 — Polystyrene, 3900 pF, 5%**
**C57, C58 — Polystyrene, 1200 pF, 5%**
**D6, D10 — 1N5817, 1N5819 or similar**
**D7 — 36 V, 1 W Zener diode (1N4753A)**
**D8 — MV2104 varactor diode, or equivalent**
**J1, J2 — PC-mount 3.5-mm stereo jack with switch**
**J3 — 2.1-mm dc power jack**
**J4 — PC-mount BNC jack**




J5 — 50 pin, dual-row edgeboard connector with 0.156-inch spacing
L10, L11 — 18 µH; 18 t #28 enameled wire on an FT-37-61 toroid
L2 — Miniature RFC, 15 µH
L7 — 19 µH; 58 t #28 enameled wire on a T-68-7 toroid
Q5 — U310, J310, 2N4416 or other high-transconductance device
R1, R8 — PC-mount 1-kΩ pot
R14, R101 — 500 Ω trimmer
R17 — PC-mount 10-kΩ pot
RFC1 — 3.5 µH; 8 t #26 enameled wire on an FT-37-61 toroid
RFC2 — 7 µH; 4 t #26 enameled wire on an FT-37-43 toroid
RFC3 — 34 µH; 9 t #26 enameled wire on an FT-37-43 toroid
RFC4 — Miniature RFC, 1 mH
S1, S2 — SPDT, PC mount, right angle toggle switch with threaded bushing.
T2 — Primary: 12 t #26 enameled wire; secondary: 3 t on an FT-37-43 toroid
U1 — LM358N dual op-amp IC
U2, U4, U7, U8 — SA602AN mixer-oscillator IC
U3 — LM386N-1 audio amplifier IC
U5 — MC1350P IF amplifier IC
U6 — LM393N dual comparator IC
U9 — 8 V regulator, TO-92 package
W1, W2 — RG-174 coaxial jumper, about 3 inches long (see text)
X1-X7 — 4.915 MHz, HC-49. X1 through X5 should be matched (their series-resonant frequencies within 50 Hz)

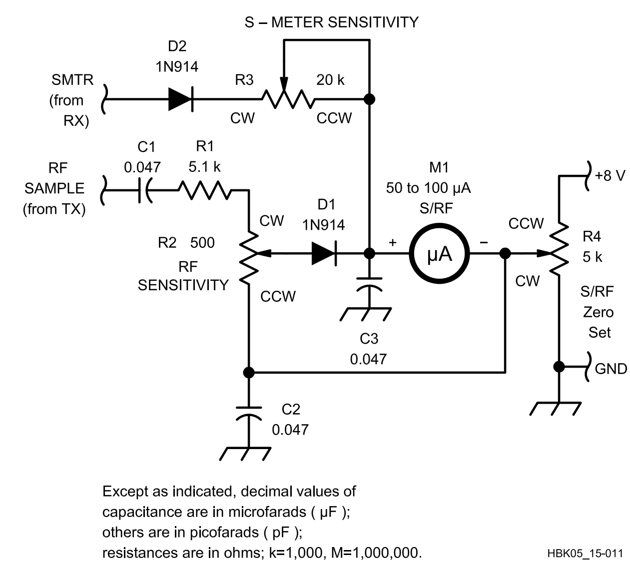



**Fig 15.11 — Metering circuitry for the Sierra transceiver.**

The Sierra's custom 0.060-inch aluminum enclosure offers several benefits in both construction and operation. Its top and bottom covers are identical U-shaped pieces. The bottom is secured to the main board by two 0.375-inch standoffs, while the top is secured to the bottom by two long-life, quick-release plastic latches. As a result, the builder can easily remove both covers to make "live" adjustments or signal measurements without removing any controls, connectors or wires. The front and rear panels attach directly to the controls and connectors on the main board. This keeps the panels rigid and properly oriented.

As can be seen in the photograph, the interior of the rig is uncluttered. NorCal QRP Club members have taken advantage of this, building in keyers, frequency counters and other accessories — and even storing up to four band modules in the top cover. One popular addition is an S/RF meter, the circuit shown in **Fig 15.11**.

The construction techniques described above represent only one way to build the Sierra; other physical layouts may better suit your needs. For example: If no built-ins are needed, the rig could be built in a smaller enclosure. You could replace the VFO capacitor with a small 10-turn pot and a varactor diode. If necessary, eliminate RIT and metering.

If a different physical layout is required, determine the orientation and mounts for the band module connector first, and then arrange the various circuit blocks around it. Use short leads and good ground-plane techniques to avoid instability, especially on the band modules. Point-to-point or "dead-bug" construction are possible, but in some cases shields and additional decoupling may be required. Use a reliable connector if band modules will be repeatedly inserted and removed.

## ALIGNMENT

The minimum recommended equipment for aligning the rig is a DMM with home-made RF probe and a ham-band transceiver. Better still is a general-coverage receiver or frequency counter.[7] Start with a 40- or 20-m module; these are usually the easiest to align.

First, set the VFO to the desired band edge by adjusting C52. If exactly 150 kHz of range is desired, squeeze or spread the windings of L7 and readjust C52 iteratively until this range is obtained. RIT operation can also be checked at this time. Reduce the value of R19 if more RIT range is desired.

Prepare each band module for alignment by setting all of its trim caps to midrange. (The final settings will be close to midpoint in most cases.)

Receiver alignment is straightforward. Set BFO trimmer C16 to midrange, RF GAIN (R1) to maximum and AF GAIN (R8) so that noise can be heard on the phones or speaker. On the band module, peak the premix trimmers (C64 and C66) for maximum signal level measured at Q8's drain. Set the fine frequency adjustment (C70) by lightly coupling a frequency counter to U7, pin 7. Next, connect an antenna to J4 and adjust the receiver filter trimmers (C1 and C2) for maximum signal. The AGC circuitry normally requires no adjustment, but the no-signal gain of the IF amplifier can be increased by decreasing the value of R3.

Before beginning transmitter alignment, set the drive-level control, R14, to minimum. Key the rig while monitoring the transmitted signal on a separate receiver and peak the transmit band-pass filter using C33 and C36. Then, with a dummy load or well-matched antenna connected to J4, set R14 to about 90% of maximum and check the output power level. It may be necessary to stagger-tune C33 and C36 on the lower bands in order to obtain constant output power across the desired tuning range. On 80 m the –3 dB transmit bandwidth will probably be less than 150 kHz.

Typically, output on 80, 40 and 20 m is 2.0-2.5 W, and on the higher bands 1.0-2.0 W. Some builders have obtained higher outputs on all bands by modifying the band-pass filters. However, filter modification may compromise spectral purity of the output, so the results should be checked with a spectrum analyzer. Also, note that the Sierra was designed to be a 2-W rig: additional RF shielding and decoupling may be required if the rig is operated at higher power levels.

## PERFORMANCE

The Sierra design uses a carefully selected set of compromises to keep complexity low and battery life long. An example is the use of NE602 mixers, which affects both receive and transmit performance. On receive, the RF gain will occasionally need reduction when strong signals overload the receive mixer. On transmit, ARRL Lab tests show that the rig complies with FCC regulations for its power and frequency ranges.

Aside from the weak receive mixer, receiver performance is very good. There are no spurious signals (birdies) audible on any band. ARRL Lab tests show that the Sierra's receiver has a typical MDS of about –139 dBm, blocking dynamic range of up to 112 dB and two-tone dynamic range of up to 90 dB. AGC range is about 70 dB.

The Sierra's transmitter offers smooth break-in keying, along with direct transmit signal monitoring. There are two benefits to direct monitoring:

- the clean sinusoidal tone is easier on the ears than most sidetone oscillators and
- the pitch of the monitor tone is the correct receive-signal pitch to listen for when calling other stations.

The TR mute delay capacitor, C27, can be reduced to as low as 4.7 μF to provide faster break-in keying if needed.

The prototype Sierra survived its christening at Field Day, 1994, where members of the Zuni Loop Expeditionary Force used it on 80, 40, 20 and 15 m. There, Sierra compared favorably to the Heath HW-9 and several older Ten-Tec rigs, having as good or better sensitivity and selectivity — and in most cases better-sounding sidetone and break-in keying. While the other rigs had higher output power, they couldn't touch the Sierra's small size, light weight and low power consumption. The Sierra has consistently received high marks from stations worked too, with reports of excellent keying and stability.

## CONCLUSION

At the time this article was written, over 100 Sierras had been built. Many have been used extensively in the field, where the rig's unique features are an asset. For some builders, the Sierra has become the primary home station rig.

The success of the Sierra is due, in large part, to the energy and enthusiasm of the members of NorCal, who helped test and refine early prototypes, procured parts for the field-test units and suggested future modifications.[8] This project should serve as a model for other clubs who see a need for an entirely new kind of equipment, perhaps something that is not available commercially.

### Notes

[1]One of N6KR's previous designs, the Safari-4, is a good example of how complex a band-switched rig can get. See "The Safari-4...." Oct through Dec 1990 *QEX*.

[2]Band modules for 160, 12 and 10 m have also been built and are available for the kit (see note 6). PC board patterns, construction hints, alignment and troubleshooting tips, and other information about the Sierra is included in the Template Packages section of the CD-ROM bundled with this *Handbook*.

[3]For information about NorCal, visit **www.norcalqrp.org**.

[4]Most multiband rigs draw from 150 to 500 mA on receive, necessitating the use of a larger battery. A discussion of battery life considerations can be found in "A Solar-Powered Field Day," May 1995 *QST*.

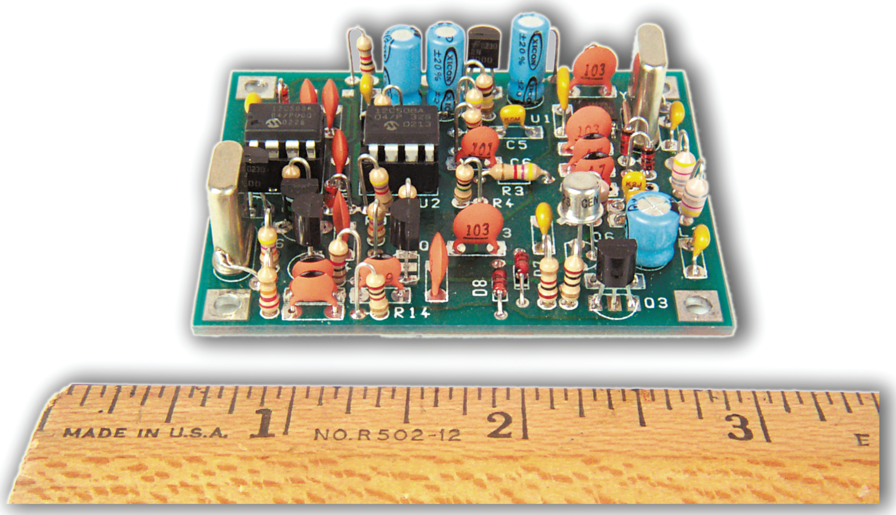
[5]*Solid-State Design*, p 87. This book is out of print but may be available used.

[6]Full and partial kits are available. The full kit comes with all components, controls, connectors, and a detailed assembly manual. Complete band modules kits are available for 80, 40, 30, 20, 17 and 15 m. For information, contact Wilderness Radio, PO Box 3422, Joplin, MO 64803, tel 417-782-1397; **www.fix.net/~jparker/wilderness/sierra.htm**.

[7]The alignment procedure given here is necessarily brief. More complete instructions are provided with the ARRL Template Package on the accompanying *Handbook CD* and the kit instructions.

[8]The author would like to acknowledge the contributions of several NorCal members: Doug Hendricks, KI6DS; Jim Cates, WA6GER; Bob Dyer, KD6VIO; Dave Meacham, W6EMD; Eric Swartz, WA6HHQ, Bob Warmke, W6CYX; Stan Cooper, K4DRD; Vic Black, AB6SO; and Bob Korte, KD6KYT.

# THE ROCKMITE — A SIMPLE SINGLE-BAND CW TRANSCEIVER




Dave Benson, K1SWL, first described the simple 1/2 W RockMite CW transceiver for 40 or 20 meters in April 2003 *QST*. The *RockMite* — named for its crystal control and its small size — has attracted an enthusiastic following, with thousands of the transceivers in circulation. This project builds on the original and adds versions for 80 and 30 meters. Changing the RockMite frequency is a matter of replacing the two (identical) crystals with frequencies of your choosing. If you change bands, however, the output harmonic filter and several capacitor values must be scaled accordingly, and the value of several Zener diodes may change. Details are shown in **Table 15.3**.

## Overview

The RockMite printed-circuit board measures 2.0 × 2.5 inches and fits in the Altoids tin that is beloved by the QRP community as an enclosure. Kits are available.[1] A custom made aluminum enclosure is available from **www.americanmorse.com**.

The RockMite uses the familiar direct conversion (D-C) receiver scheme shown in **Fig 15.12**. There isn't much to it — an oscillator and a mixer convert received signals directly to audio and an amplifier boosts that audio to usable levels. On transmit, the same oscillator serves as the transmitter frequency source, and only gain and keying stages are needed to bring the oscillator signal up to levels usable for making CW contacts.

Several crucial details are missing from this oversimplified picture, however. The operator who calls "CQ" with a crystal-controlled D-C rig will most likely get replies on zero-beat with his signal and without some means of shifting frequency (offset) between transmit and receive, will copy only low-frequency thumps. Additionally, the joy of sending CW will be somewhat tempered by the lack of a sidetone circuit to monitor your own sending.

By using an 8-pin PIC microcontroller, it becomes possible to add an iambic keyer along with other functions. This can be done with minimum cost and with little printed circuit board acreage. Having made the decision to use a controller chip, a spare pin on that IC was dedicated to providing a 700 Hz sidetone during key-down conditions. The controller also supplies a TR control signal and a shift signal. This shift signal merely provides a dc voltage level to a varicap (tuning) diode to pull the crystal oscillator frequency between transmit and receive. The TR offset is reversible, as described later, so that the RockMite offers two possible oper-

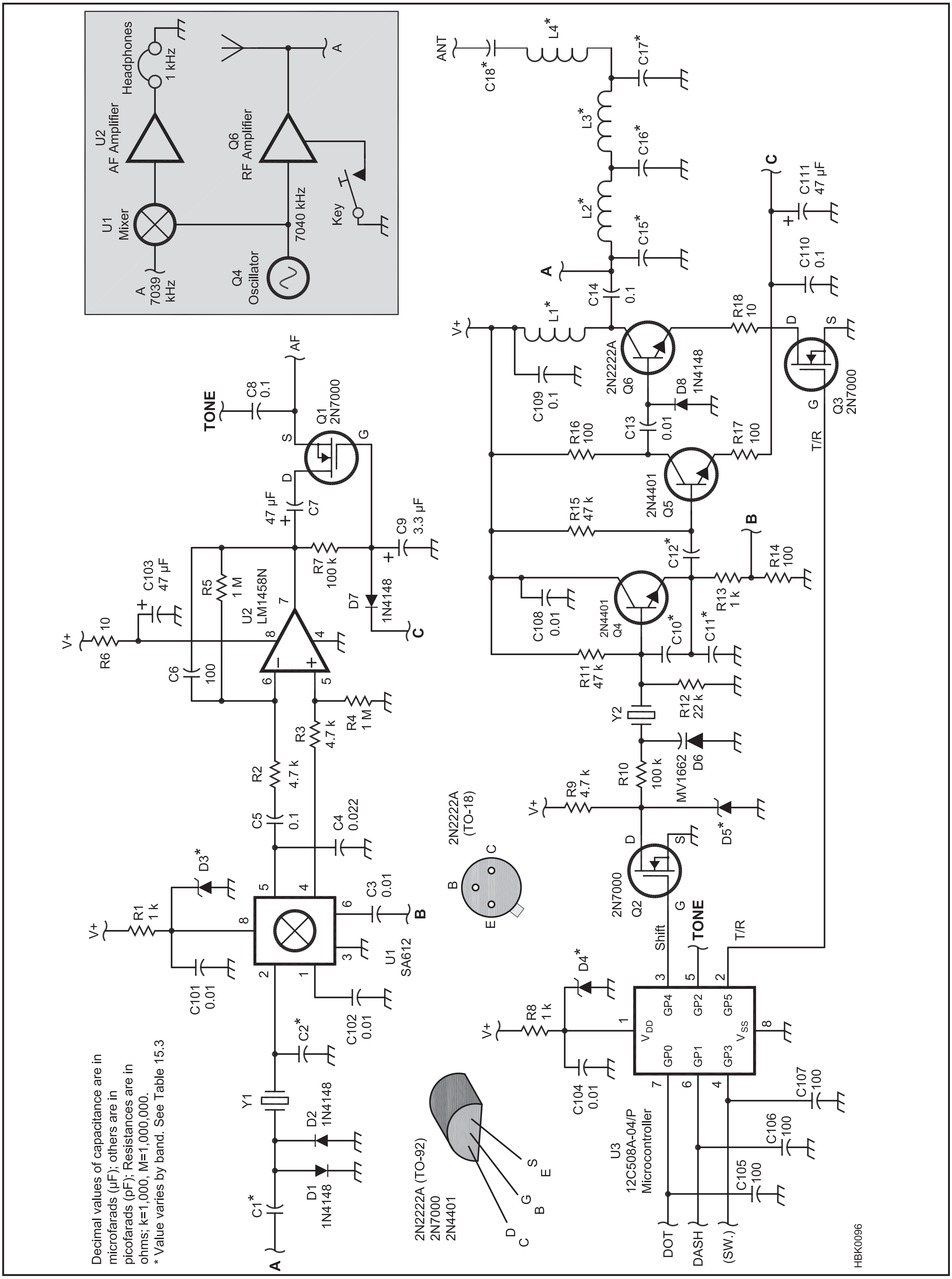

Decimal values of capacitance are in microfarads (µF); others are in picofarads (pF); Resistances are in ohms; k=1,000, M=1,000,000.
* Value varies by band. See Table 15.3
U1 Mixer
U2 AF Amplifier
Headphones
1 kHz
A 7039 kHz
Q4 Oscillator
7040 kHz
Q6 RF Amplifier
Key
U1 SA612
U2 LM1458N
Q1 2N7000
Q2 2N7000
Q3 2N7000
Q4 2N4401
Q5 2N4401
Q6 2N2222A
U3 12C508A-04/P Microcontroller
2N2222A (TO-18)
2N2222A (TO-92) 2N7000 2N4401
TONE
AF
ANT
DOT
DASH
(SW.)
T/R
Shift
MV1662
HBK0096

**Fig 15.12 — The RockMite transceiver simplified block diagram (inset) and schematic. Most components are stocked by major distributors such as Digi-Key, Mouser and Ocean State Electronics (see the *TISFind* database at www.arrl.org/tis). Resistors are 5% 1/4 W.**

**C1, C2, C10, C11, C12, C18 — NP0 disk capacitor, 5%. See Table 15.3 for values.**
**C3, C13, C101, C102, C108 — 0.01 µF disk capacitor.**
**C4 — 0.022 µF monolithic capacitor.**
**C5, C8, C14, C104, C109, C110 — 0.1 µF monolithic capacitor.**
**C6, C105-107 — 100 pF disk capacitor.**
**C7, C103, C111 — 47 µF, 25 V electrolytic capacitor.**
**C9 — 3.3 µF, 50 V electrolytic capacitor.**
**C15, C17 — Disk capacitor, 5%. See Table 15.3 for values.**
**C16 — C0G monolithic capacitor 5%. See Table 15.3 for values.**
**D1, D2, D7, D8 — 1N4148 diode.**
**D3, D4, D5 — Zener diode, 0.5 W. See Table 15.3 for values.**
**D6 — MV1662 varicap diode.**
**L1, L2, L3, L4 — Molded RF choke, 10% tolerance. See Table 15.3 for values.**
**Q1, Q2, Q3 — 2N7000 FET.**
**Q4, Q5 — 2N4401 transistor.**
**Q6 — 2N2222A transistor.**
**U1 — SA612AD mixer/oscillator IC. (Surface mount part is used on the kit PC board. If building from scratch, consider the SA612AN in a DIP package.)**
**U2 — LM1458N dual op-amp IC.**
**U3 — 12C508A-04/P microcontroller. (Must be programmed before use. See Note 1.)**
**Y1, Y2 — HC49/U crystal (20 pF load) for operating frequency of interest. Crystals for popular QRP frequencies, including those shown in Table 15.3, are available from expandedspectrumsystems.com or AF4K.com.**

**Table 15.3**
**RockMite Component Values by Band**

| *Band* | *80 m* | *40 m* | *30 m* | *20 m* |
|---|---|---|---|---|
| *Freq (MHz)* | *3.560* | *7.030* | *10.106* | *14.060* |
| C1 | 47 pF | 47 pF | 47 pF | 47 pF |
| C2 | 33 pF | 47 pF | 47 pF | 47 pF |
| C10, C11 | 68 pF | 68 pF | 33 pF | 39 pF |
| C12 | 47 pF | 47 pF | 33 pF | 39 pF |
| C15, C17 | 560 pF | 470 pF | 330 pF | 220 pF |
| C16 | 1200 pF | 1000 pF | 680 pF | 470 pF |
| C18 | 330 pF | 150 pF | 82 pF | 82 pF |
| D3 | 1N5231B (5.1 V Zener) | 1N5231B (5.1 V Zener) | 1N5231B (5.1 V Zener) | 1N5233B (6.0 V Zener) |
| D4 | 1N5231B (5.1 V Zener) | 1N5231B (5.1 V Zener) | 1N5231B (5.1 V Zener) | 1N5230B (4.7 V Zener) |
| D5 | Omitted | 1N5236B (7.5 V Zener) | 1N5231B (5.1 V Zener) | 1N5230B (4.7 V Zener) |
| L1 | 15 µH | 10 µH | 6.8 µH | 4.7 µH |
| L2, L3 | 2.2 µH | 1 µH | 0.68 µH | 0.47 µH |
| L4 | 5.6 µH | 3.3 µH | 3.3 µH | 1.5 µH |

ating frequencies. This function has traditionally been done with a double-pole switch, but it's easier and cheaper to perform that function in firmware.

There is one other noteworthy trick employed in the RockMite. Builders of simple receivers for 40 meters have all experienced the joys of listening to shortwave broadcasts mixed in with their CW. For most simple gear, the high levels of broadcast RF cause intermodulation distortion (IMD). This can be mitigated by the use of more robust (higher-current consumption and complexity) receiver front ends. Another approach is to ensure that the broadcast signal levels reaching the receiver mixer are attenuated enough to avoid their IMD effects. If you're interested in only a small segment of an amateur band, a sharply tuned (narrow) band-pass filter may be used to good effect to accomplish that. The RockMite uses this approach by utilizing a second crystal at the operating frequency at the receiver front end. The performance improvement with the added crystal is significant.

### Circuit Description

The RockMite schematic is shown in Fig 15.12. Local oscillator Q4 is a crystal- controlled Colpitts oscillator and runs continuously. Its operating frequency is determined by crystal Y2 and the surrounding components. Diode D6 is a varicap (tuning) diode and it furnishes a voltage-dependent capacitance. This effect is used to pull the crystal oscillator frequency about 700 Hz between transmit and receive to provide a beat-frequency offset. The voltage applied to D6 through resistor R10 is 0 V with Q2 turned on (conducting) or it is the rated Zener voltage of D5 with Q2 off.

A sample of the local oscillator signal is coupled to the base of Q5. Q5 provides no voltage gain but instead serves to improve key-up isolation between the local oscillator and the antenna. This ensures that the key-up energy to the antenna (back-wave) is negligible. Equally important, the lowered signal level at the antenna terminal prevents blocking effects from desensitizing the receiver.

The output of the buffer stage is coupled via C13 to the power amplifier stage, Q6. Diode D8 provides a clamp function, making it easier to drive the base of Q6. Transistor Q6 runs Class C, is driven hard and, in theory, has only conducting and nonconducting states for high efficiency. The waveform at Q6's collector would ideally be a square wave. In practice, there's considerable waveform distortion at that signal point and, in any case, it's nothing you'd want to apply directly to an antenna.

Capacitor C14 couples this waveform to the output harmonic filter, which comprises L2 and L3 and C15, C16 and C17. Since the original RockMite article was published, FCC requirements for spectral purity changed from –30 dBc to –43 dBc. A series L-C circuit (L4 and C18) between the output of the low pass filter and the antenna provides the needed additional harmonic attenuation. In an effort to save space and reduce construction complexity, subminiature epoxy-molded RF chokes were used instead of the traditional toroids. For the frequencies and power levels encountered in the RockMite, performance appears adequate – – loss and self-heating were not significant. Power output is about 500 mW with a 13 V dc supply and it will work at lower supply voltages.

The receiver is continuously connected to the antenna through coupling capacitor C1. Diodes D1 and D2 limit the key-down voltage swing appearing at the receiver front-end to safe values. The presence of Y1 at the receiver front-end may seem somewhat startling, but it serves as a narrow band-pass filter to keep RF energy from frequencies far removed from the operating frequency to a minimum. The SA612 mixer, which does the conversion from RF to audio, needs all the help it can get.

Readers may recognize the circuit as an adaptation of a Roy Lewallen, W7EL, circuit — a widely used series-LC TR switch. The inductance in this circuit is being furnished by crystal Y1 at a frequency slightly off its series-resonant point. Perhaps less obviously, capacitor C2 forms an L network in combination with a portion of the crystal motional inductance. It's impedance step-up; there's about 10 dB of voltage gain prior to the mixer input (U1, pin 2). The values of

C1 and C2 were twiddled empirically to yield a 6 dB bandwidth of about 2 kHz and to straddle the two operating frequencies fairly evenly. For the 40 meter version, receiver filter response is –35 dB at 7100 kHz and up. Although this value of ultimate rejection is unacceptably poor for typical crystal filters, here it needs to be only good enough to yield significant improvement in IMD performance.

The mixer IC, U1, converts the received signal from the operating frequency to audio; that signal appears at pins 4 and 5 of U1. C4 provides some low-pass filtering to cut unwanted audio hiss. U2 is a garden-variety dual op-amp (one-half is unused) configured for a gain of about 200 (46 dB). This boosts the mixer's output audio to headphone-usable levels. Capacitor C6 provides an additional pole of audio low-pass filtering.

Transistor Q1 provides a simple mute function to reduce the amount of keydown thump. It disconnects the audio amplifier from the headphones whenever the rig is keyed. The large (transmitted) signal appearing at the receiver during key-down yields a dc offset at the mixer output, which is amplified to a large transient by the audio amplifier. The muting isn't perfect but it's a lot less fatiguing than none at all. Key-up recovery time is set by C9 — this value may be reduced if you prefer quicker QSK (break-in). U3 is a 12C508A microcontroller device and has been custom programmed to provide iambic keyer (Mode B) and frequency shift functions. U3 pins 6 and 7 are typically connected to a pair of paddle inputs to provide the keyer functions. Ground one of those two inputs during rig power up and the RockMite will use the other input for the straight key or more capable external keyer.

There are two operator controls on the RockMite and they're both implemented via a push-button switch closure, in order to ground controller pin 4. The two functions are discriminated by the duration of the switch closure.

A brief (< 250 ms) closure on the switch reverses the offset to provide a second operating frequency. When you wish to work another station, use this function to select the higher of the two pitches on a received signal. Note that the pitch at the converse setting is a measure of how close to zero-beat you are; ideally it would be just a low-frequency thump. If the two selections yield a high pitch and a still higher pitch, you probably won't be able to work the other station.

A longer closure on the switch input puts the keyer in a speed-adjustment mode. The RockMite outputs a Morse code S to acknowledge entry into this mode. Tapping (or holding) the dot paddle speeds up the keyer; the same operation on the dash paddle slows it down. The default (power-up) speed is approximately 16 WPM and the speed range is about 5 to 40 WPM. If no dot/dash inputs are received after about 1 second, the RockMite outputs a lower frequency tone and reverts to normal operation. The Morse S and subsequent tones are not transmitted on the air.

## Modifications

The idea of a transceiver whose only control is a pushbutton switch probably flies in the face of recent trends in transceiver design. If you feel the need to "manage" your radio, resistor R5 may be replaced with a 1 MΩ audio taper potentiometer (wiper and one end-terminal used) to serve as a volume control. Keep the leads short.

Sidetone level can be altered by changing the value of C8. Note: the "raspy" nature of the RockMite sidetone is caused by the square-wave nature of the signal. One or more R-C networks (series-R, shunt-C to ground) in the path from U3 pin 5 to C8 will soften the tone. A good starting point for this filter is 10 Ω/10 µF.

Adding a 1N4001 diode in series with the power supply (V+) feed will preclude reverse-polarity mishaps. (The banded end goes toward the RockMite board.) Or better yet, use a 1N5818 Schottky diode for lower voltage drop. Any of the diodes 1N4001-1N4007 or 1N5818-1N5820 series is fine. They're noncritical and all overkill for this application.

The RockMite will run on a 9 V battery if R1 and R8 are changed from 1 kΩ to 470 Ω. This change increases receiver current consumption from 25 mA to 40 mA when using a 12-14 V supply.

## Troubleshooting

Detailed troubleshooting information can be found in the file RMhelps.pdf, available for download from the Small Wonder Labs Web site (see note 1). Here are some of the more common problems.

*AC hum:* Make sure Y2's case is grounded. The RockMite has a lot of audio gain. You may experience difficulty when using an unregulated power supply or wall transformer to power the rig. A regulated supply will help considerably in this regard. If in doubt, try a battery supply. You may use a 9 V battery temporarily to check out the difference.

*Howl in headphones:* (Make sure you're not in straight-key mode with the key down. That's the sidetone.) The combination of high audio gain and wire lead treatments can yield an audio oscillation or "howl," although this has not been reported often. Here are some things to try.

- If using a battery supply, make sure it's reasonably well charged. A nearly-exhausted battery may cause howl or motorboating.
- Provide separation between wires run to and from the RockMite board and the board components. Close lead proximity affords more chances for unwanted signal crosstalk. Where wires do need to cross, keep them at right angles to one another to minimize the coupling.
- Don't count on the enclosure itself to provide ground return continuity. It may be helpful to run a ground return wire from the board to the headphone jack ground lug and from there to the dc power return. If you do this, continue to use a wire from board ground to the main dc power return. You want to avoid conditions where one circuit path is carrying both audio and dc ground currents, and for that matter, RF as well.
- Ensure that the ground braid is used on the coax connecting the PC board to the antenna jack. Connect the rig end to a convenient ground point near the antenna pad and be sure the other end makes connection to the antenna jack ground lug.

*Broadcast pickup:* There are two potential issues with the RockMite. Shortwave broadcast (SWBC) will be more likely during the evening hours. Despite the presence of the front-end crystal filter, some SWBC may occasionally be heard. A fix involves reducing the signal levels getting to U1, which can be accomplished by changing R5 to a 1 MΩ variable volume control as described in the previous section. The use of an antenna tuner will also assist in reducing the out-of-band RF energy getting to U1.

Local AM broadcast interference is more likely during daylight hours when local AM stations are on the air. Install a 1 kΩ resistor at the two unused pads immediately below D1/D2. Note that this fix does not help with shortwave broadcast. The fix was tested successfully at the ARRL lab, located within two miles of several 5 kW AM broadcast stations.

*Very low volume:* This is a minimalist transceiver, so it won't provide ear-splitting volume. Even so, with a good antenna and headphones you should have little trouble hearing signals. If everything else checks out, consider the following. Use a resonant antenna, 50 Ω nominal, such as a dipole. If the antenna is nonresonant (random wire, etc), use a tuner to make the antenna look like 50 Ω at the rig. SWR is not especially critical here. The worst that could happen is the loss of an inexpensive transistor (Q6).

Headphones should be a low-impedance stereo type, such as those used for personal MP3 or CD players. If there are specifications on the package, look for a sensitivity spec of 104 dB/mW or better. And a final caution related to audio output: You'd be surprised how often reports of very low audio are traced to use of incorrect audio jack or plug types. You won't hear much with the audio output shorted to ground!

## Does It Really Work?

The receiver is direct-conversion, so the audio you hear is busier than what's typically found in a big rig. There's some audio low-pass filtering, but it still doesn't have the sharp roll-off characteristics prevalent with crystal IF filtering. Because the D-C receiver receives both sidebands equally well, there are twice as many signals as you'd expect of a more capable receiver. Once you get the hang of selecting which of the two operating frequencies to call someone on, the operation is pretty straightforward.

## A Thriving Community

This project started out as a party favor and indeed, it was initially dubbed "a wireless code practice oscillator" — somewhat tongue-in-cheek. Once the first samples were available, it became clear that the RockMite was a usable radio. Much of this success can be attributed to the QRP community's use of watering holes. Many QRPers monitor those frequencies when they're in the shack and your chances of success with a "CQ" are surprisingly good.

A gallery of construction pictures, modification information, links and related topics may be found at **www.qsl.net/n0rc/rm/**. There's also a very active user's group on-line at **groups.yahoo.com/group/Rock-Mite_Group/**.

A special thanks to Doug Hendricks, KI6DS, for his material support with this project and to Rod Cerkoney, NØRC, for his enthusiastic Web site support. Thanks also to Steve Weber, KD1JV, for design suggestions during the development phase.

[1]Complete parts kits for the RockMite, including PC board, all on-board parts, a programmed microcontroller and instructions, are available from Small Wonder Labs (**www.smallwonderlabs.com**). Programmed microcontroller ICs alone are also available. RockMite object code (.hex file) may be found in the Templates section of the *Handbook* CD-ROM.

# Designing and Building Transistor Linear Power Amplifiers

*Part 1 — Designing an experimental one transistor amplifier.*

**Rick Campbell, KK7B**

This two part article describes a procedure to design and build a simple transistor linear amplifier. The examples presented in Part 2 are single band HF and VHF amplifiers at the 5 W level — a particularly enjoyable and educational class of amplifiers for the experimenter.

The working amplifier will have the block diagram shown in Figure 1. Here is a step-by-step procedure to do an experimental, measurement-based design:

- Select a device and note its breakdown voltage, maximum current and thermal resistance.
- Turn it on with dc.
- Connect the RF drive and RF load.
- Measure gain, output power and linearity and adjust dc, RF drive and RF load for optimum performance.

After the amplifier is finished, it will need RF and dc switching and an output low-pass filter.

Switching and filtering needs are different for each application. Part 2 will have a few practical examples currently on the air. Note that the step-by-step procedure makes no mention of frequency, efficiency, bandwidth or even the type of device. Each of these will be dealt with in the following sections, but it is useful to remember that the basic procedure is the same whether we are building a 400 W amplifier for 500 kHz or a 100 mW amplifier for 200 GHz.

Most linear amplifier designs are optimized for a particular parameter. It is useful to remember that optimizing for one parameter always involves compromise in others. The design procedure here is optimized to get you on the air with skill, understanding and any available device. The most clever and creative radio designers often have external or self-imposed spending limits on projects — in the absence of fiscal constraints, a person could simply pick an amplifier out of a catalog without learning a thing.

## Select a Device

Let's assume that we are not designing a radio for mass production. As amateurs, scientists and research engineers, we are free use whatever device is available. The best transistor for our project might be something from the junk box, an experimental device that hasn't yet been released to manufacturing, or something inexpensive from RadioShack or Digi-Key. It is important to have either a data sheet for the transistor, or a small quantity on hand so that you can destroy a few while discovering breakdown voltages and thermal limits.

We are also free to select the operating voltage. The standard voltage for amateur portable equipment is 12 V, and a selection of well-designed, conservative and useful amplifier designs are available as kits and semi-kits. If you want medium power, a 12 V power supply and wideband operation, that is a good approach. But if you are interested in doing a few experiments and a little design work, the first assumption to throw out is the 12 V supply.

Many inexpensive new devices have been designed for use in switching power supplies, and are not characterized for RF at all. Some of these make excellent linear amplifiers with higher operating voltage. Devices that operate at 60 V are common, and much higher voltage devices are available. RF transistors are now available with a 1000 V breakdown voltage. In a linear amplifier, the output waveform is supposed to be a function of the input waveform, not the supply voltage, as long as the supply voltage is greater than needed. This allows us to use simple unregulated power supplies with a large capacitor on the output instead of more complex regulated supplies.

A simple unregulated power supply is shown in Figure 2. The output voltage may be varied during experiments with a small Variac type variable autotransformer or a

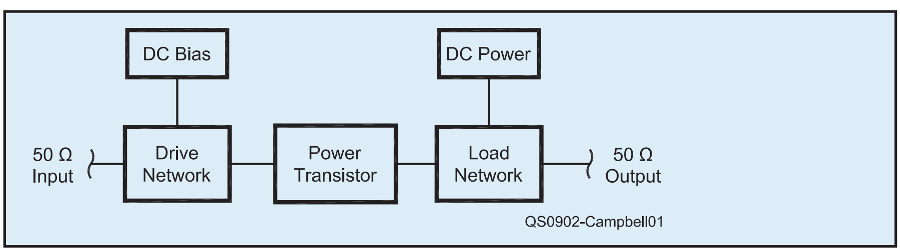



**Figure 1 — Block diagram of typical solid state power amplifier.**

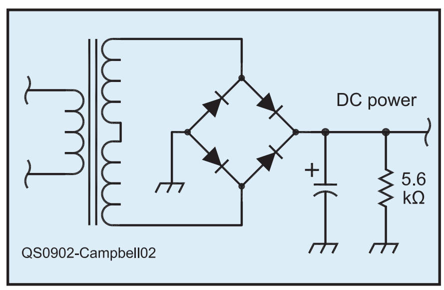



**Figure 2 — Collector or drain supply for amplifier experiments.**

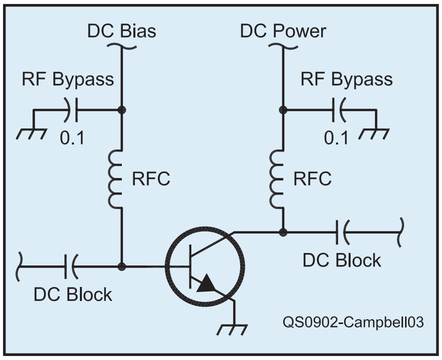



**Figure 3 — Arrangement to turn on the transistor for static measurements.**

junk box transformer with the windings all connected in series to serve as a tapped auto-transformer .

After looking at breakdown voltages and pondering power supplies, we need to look at how much current the device can handle. A transistor rated at 1 A and 120 V could control 120 W — if it could dissipate the heat. Thermal conductivity is the last parameter we need, and a quick look at the dissipation in watts will tell us whether the device is suitable for our power level.

The power dissipation is determined by the device package and how it is connected to the heat sink. One other criterion for an experimental linear PA device is that it be cheap! When I design and build an experimental amplifier, I expect to burn out a few transistors in the process. As the old blues song goes: *A man should never gamble more than he can stand to lose*.

## Turn It On with DC

A linear amplifier transistor needs a collector (drain, if an FET) power supply and a base (gate) bias supply. The basic circuit is shown in Figure 3. If the transistor dc is fed through an RF choke or RF transformer winding, then the no-signal resting voltage on the collector (drain) equals the dc supply voltage. Assuming a symmetrical output waveform, the collector voltage can drop down to near 0 V on the negative peaks, and up to near twice the dc supply voltage on positive peaks. That means we should pick a dc power supply voltage comfortably less than half the rated breakdown voltage of the transistor.

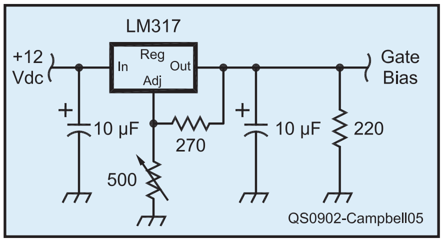



**Figure 5 — Simple gate bias supply for FET power amplifiers.**

How do we define *comfortably less*? That all depends on how expensive the device is, and how annoying it is to replace! I believe it is both necessary and desirable to burn out a few transistors while experimenting with a new design. Maybe that's why I quit rock climbing and started windsurfing — the splash is the best part! It is also part of the reason why it is more fun to experiment at the 5 W level than at 1500 W.

Once the collector supply is connected, turn the device on with a little base current (or gate voltage for an FET). The current mirror in Figure 3 is a generic circuit I use for base bias, and Figure 4 is what I use for gate voltage if the amplifier device is an enhancement mode FET. These are variable supplies that have a knob to adjust bias while you are watching the collector (drain) current on a meter. Note that the bias supplies in Figures 4 and 5 have very low impedance — they can supply considerable current.

I usually design my base supplies to supply about the same current as the collector. That is called a *stiff* bias supply, and it needs to be stiff at audio frequencies, so that the dc bias doesn't change with variations in the driving waveform. That statement raises the question of the operating class of the amplifier. I prefer to run my amplifiers with enough resting current to operate in pure class A during the pauses and subtle nuances of speech, and then carefully adjust them on the bench for an acceptable level of distortion on the voice peaks.

A good linear amplifier will dissipate about half of the dc power as heat. Professional linear amplifier designers devote entire careers to improving from 45% efficiency to 55% efficiency, but we can do more to save the planet by turning off the overhead when we leave the room — so *about half* is close enough for our estimates. A 10 W linear amplifier needs to be capable of comfortably dissipating 10 W as heat. Turn up the bias until the amplifier is dissipating the desired output power, and watch it for a while.

Keep your hand on the BIAS ADJUST knob. Does the current rise as it warms up? You might cure that by thermally coupling the diode in Figure 3 to the device, and by adding a little emitter resistance. I like emitter resistance, particularly for higher voltage amplifiers. Then turn it up to twice the desired output power and watch its behavior. Turn the bias up and down and watch for any jumps in the collector current — those indicate oscillation. If the device is unstable during the dc operating point tests, add ac loads to the input and output, as shown in Figure 6.

After the actual drive and load networks are designed and connected to the transistor, run all of the dc tests again and look for any signs of instability. A few ohms in series with the base or collector, a 1 Ω emitter resistor, or a UHF suppressor consisting of a few turns of wire around a 22 Ω, ½ W carbon resistor are ancient cures, well-known in the 1960s. A major advantage of higher voltage power supplies is that both the absolute voltage drop and voltage drop relative to total supply voltage across these resistors is much lower for a device running on 48 V and 250 mA than for one running on 12 V and 1 A. For lower voltage devices, a ferrite bead on the base or collector lead right at the device might work. But don't cure oscillations you haven't observed! Some modern devices are wonderfully stable.

Many RF power transistors have built-in emitter or base resistance, and unnecessary resistors and ferrite beads can have unintended consequences. Once the part behaves with dc bias and successfully generates heat, go ahead and find its limits. Turn the collector supply up, turn up the base bias, and burn out the device. Note the smell, and look for signs of thermal stress or a cracked plastic case.

It's a good idea to burn one up with too much voltage, and another one with too much current (heat). If you burn up transistors on the bench, you will have the experience to correctly debug a suspected power transistor failure in the final circuit, and not spend hours extracting a perfectly good transistor from an amplifier that failed because of a disconnected power supply wire.

Note that these simple bias circuits are designed to make it easy to adjust amplifier dc operating conditions at the bench while making linearity and gain measurements. After the amplifier design is complete and satisfactory performance has been verified with measurements, it may be useful (or necessary) to add temperature compensation and other features to the bias circuit — but that is

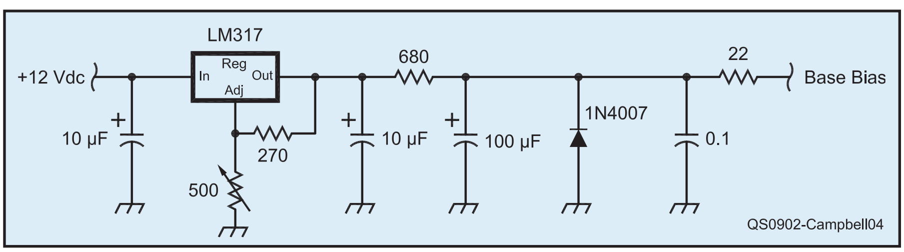



**Figure 4 — Simple base bias supply for bipolar power amplifier development.**

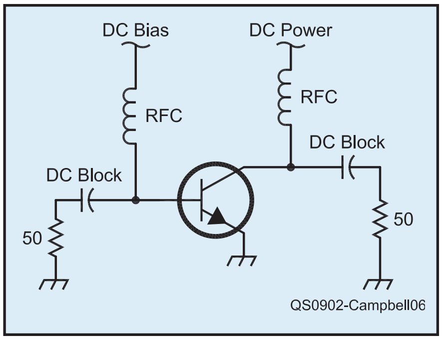



**Figure 6 — RF loads during dc tests.**

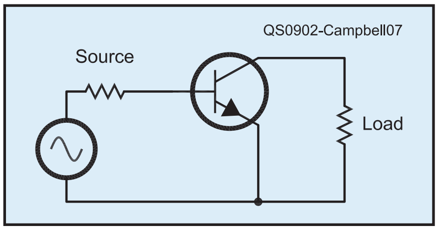



**Figure 7 — RF amplifier, small signal equivalent circuit.**

a subject for another day.

## Drive and Load the Amplifier

Transistors like to amplify, and at HF they often have considerably more gain than necessary. In that case, there is no need to match the input of an HF linear amplifier device. We want to drive it with a known, well-behaved impedance. Similarly, we don't match the output of a linear power amplifier; we present it with a known, well-behaved load impedance. The terms *drive network* and *load network* are useful to avoid some of the confusion surrounding *impedance matching* of non-linear active devices. At higher frequencies, devices have less gain, and we often adjust the drive and load networks to get more gain per stage. These techniques are illustrated in the 7 MHz and 50 MHz amplifier examples that are described in detail in Part 2.

### *The Load Network*

Let's start at the output. We already mentioned that the collector quiescent voltage is $V_{CC}$, and that it drops to near zero and up to nearly twice $V_{CC}$ with a symmetrical output waveform at the peak output power. A sine wave with a peak-to-peak voltage of twice $V_{CC}$ has a power given by $V_{CC}^2/2R$.[1] So once we have set the power supply voltage, the peak output power is determined by the load resistance R. A particularly convenient choice for R is 50 Ω. Then the peak power output is a simple function of the supply voltage: 12 V supply for 1.44 W, 24 V for 5.76 W, 100 V for 100 W and so forth. The 1.5 W CW rig with a 13.8 V supply is a classic [Ugly Weekender, Optimized].[2]

For other values or R, we use a transformer between 50 Ω and the collector. Vacuum tube amplifiers use high voltages, so the transformer (often a pi-network) typically steps up from 50 Ω to a few thousand Ω. Transistor amplifiers use lower voltages, so we often step down from 50 Ω to something much lower. Cell phone power amplifiers with 3.5 V power supplies typically present about 1 Ω impedance to the PA collector. Transistors inexpensive enough for our experiments are good for 10 or 20 W, with supplies up to 60 V or so, which means that either a direct connection to 50 Ω or simple 4:1 transformers down to 12.5 Ω are useful for our experimental amplifiers. Note that the network between the output and the transistor is determined by primarily the desired output power level and the power supply voltage, not the particular type of transistor.

### *The Drive Network*

Now, what about the input? A very simple view of the transistor is that the base drive needs to supply the collector current divided by beta into a resistance approximately equal to the emitter resistance multiplied by beta. RF beta is less than dc beta. A good choice for drive impedance is approximately equal to the collector load impedance. So, if the output is directly connected to 50 Ω, the base can be driven by 50 Ω, and if the output has a 1:4 transformer to present a 12.5 Ω load to the collector, the input can be driven by 12.5 Ω through a 4:1 transformer. Since the base of a transistor is a non-linear semiconductor junction, drive should be well-behaved when connected to an impedance that changes with drive level. This can be achieved by including loss in the drive network.

Because the transistor is fundamentally non-linear, it is important to think about the drive and load impedances at harmonics of the input waveform, and also at all the frequencies generated by intermodulation — for example, the difference frequencies between a two-tone source. The fewer distortion products the amplifier generates, the easier it is to gracefully handle them all, so linear amplifiers are easier to design in this respect than highly efficient amplifiers that use the transistor as a switch. A pure class A amplifier generates little harmonic and intermod energy, so it is common for a linear amplifier to be very clean at low drive level and exhibit unexpected behavior as drive increases.

### *Putting it All Together*

Figure 7 is the RF equivalent circuit of an ideal amplifier. It has a drive circuit, a load, the active device — and nothing else. If we could build circuits with zero lead lengths, no transmission lines and dc power supplies built into the source and load, our amplifiers might look just like Figure 7. In ancient times, radio designers learned to use transmission lines to present any desired drive and load

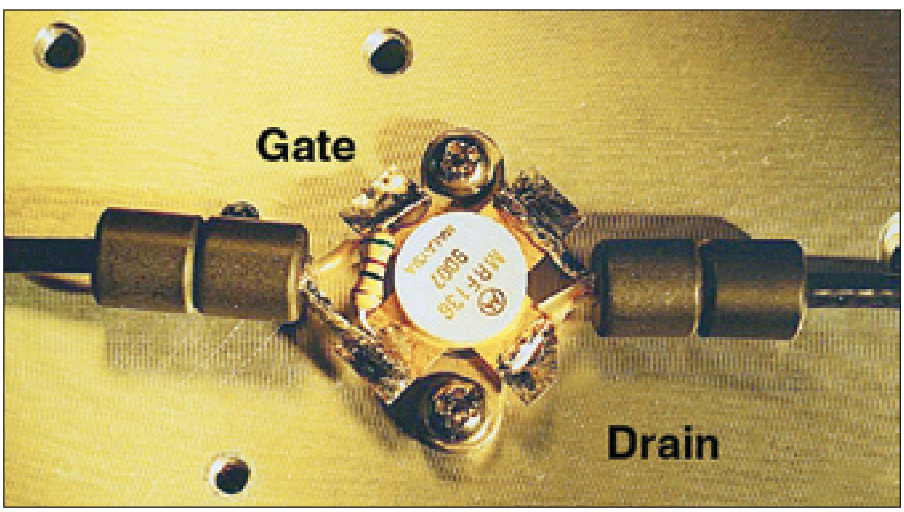



**Figure 8 — RF power device with sleeve baluns.**

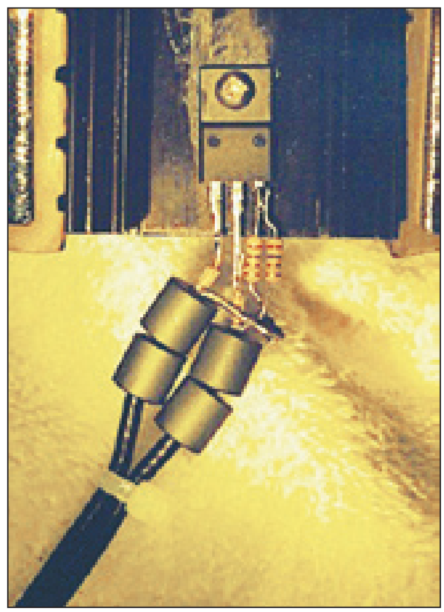


**Figure 9 — Bipolar transistor with sleeve baluns.**

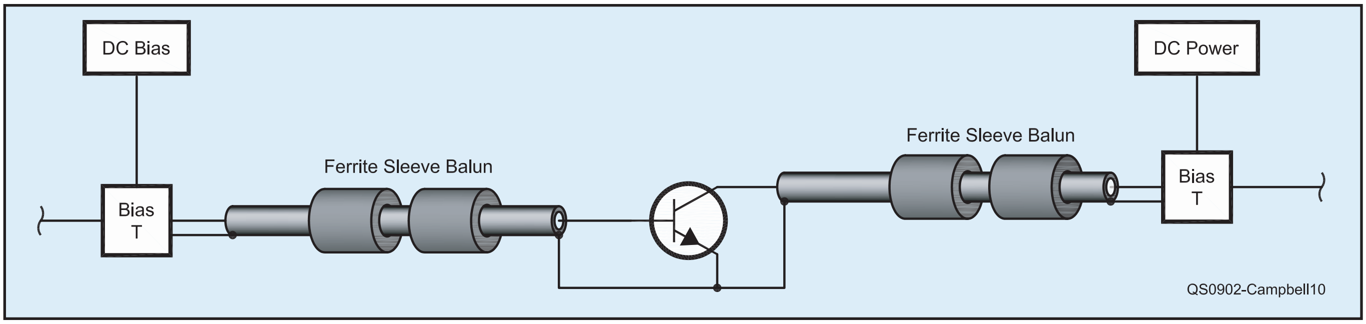



**Figure 10 — Experimental amplifier with no ground at device.**

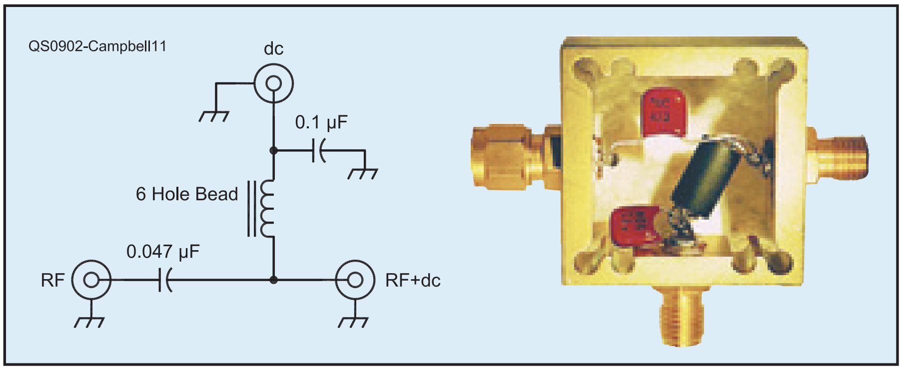



**Figure 11 — 1:1 bias T.**

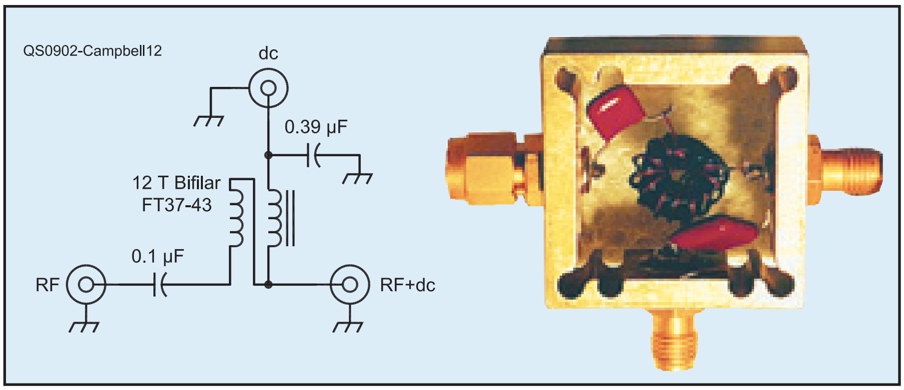



**Figure 12 — 4:1 bias T.**

impedances right at the active device terminals. One problem is defining where the drive and load impedances are connected.

Is the load connected between the collector and emitter, or between the collector and ground? Is the drive connected between the base and emitter, or between the base and a different ground? Are there multiple connections to ground, creating the possibility of ground loops? For decades the lore for transistor RF power amplifiers has been to use a large ground with all connections as short as possible, and any reactances soldered directly across the transistor leads. This is a very good plan, but it makes it hard to replace the device or experiment with different devices in the same circuit. An alternative approach is eliminate the entire concept of ground from the circuitry around the amplifier device. Figure 7 includes no ground symbol for that reason.

How can we connect to a device without ground? As radio amateurs, we already know how to do this. We connect to loads with no ground all the time — for example, dipole antennas. We can use a feed line with a balun to connect to a resistor dangling in space, an antenna, or the input of an amplifier. The balun ensures that all of the drive energy is connected directly from base to emitter, and that all of the RF energy traveling toward the transistor or reflected from it stays inside the coax, between the outside of the center conductor and the inside of the outer conductor.

Figure 8 is a photograph of an RF power MOSFET with balun connections to the input and output. The resistor soldered directly from the gate to the source is suggested in the Motorola data sheet for the device. The outside of the coax is not part of the circuit, and we can touch it without getting an RF burn or affecting circuit operation. If we connect the drive using a balun, and the load using a balun, then only drive signals flow in the drive circuit and only load signals flow in the load circuit. There are no shared ground currents, and no ground loops. It may seem counterintuitive, but eliminating a ground connection at the device can actually improve stability. Figure 9 shows an inexpensive power bipolar transistor with sleeve baluns and 0.5 Ω emitter resistance. The ferrite sleeve baluns are simply RG-174 miniature coax slipped through pairs of ferrite beads. The hole in these particular beads is a little too small, so the outer insulation was removed before sliding on the beads.

One significant advantage of driving and loading the amplifier transistor with a pair of baluns is that the need for short leads and matching components right at the transistor is eliminated. This makes it much easier to experiment with different devices. The lengths of coax through the ferrite beads are a component of the drive and load networks, and are easily handled using a Smith Chart.

Figure 10 is a block diagram of a complete experimental amplifier, showing coaxial sleeve baluns for connecting to the power amplifier transistor, a pair of bias Ts for separating the RF and dc signals on the base and collector coax and two power supplies. Figure 11 is a photograph of a simple 1:1 bias T with a six hole ferrite bead, a 0.1 μF dc blocking capacitor, and a 0.1 μF RF bypass capacitor. All three connectors are type SMA, a convenient choice for my test equipment and junk box. Figure 12 shows a bias T with a 4:1 transformer, presenting an impedance of 12.5 Ω to the active device.

## A Proper Amplifier Test Facility

A good experimental amplifier test bench includes two signal generators, a power combiner, a driver amplifier with 50 Ω output, a step attenuator, an assortment of low pass filters, a dummy load and power attenuators, an accurate RF power meter, an oscilloscope and a spectrum analyzer. That may sound like a big investment in test equipment. I have probably invested nearly the price of a new medium-grade transceiver in my RF test bench. My spectrum analyzer is homebrew,

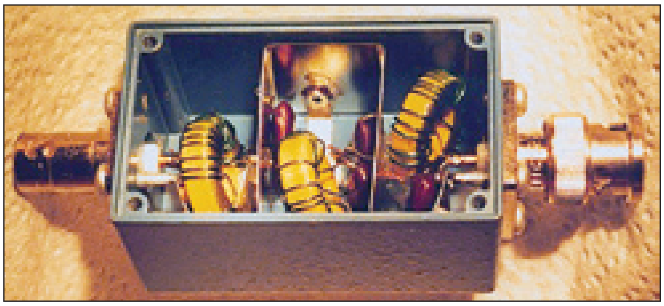


**Figure 13 — 40 meter band low pass filter.**

but all of the other test equipment on my bench was purchased on the surplus market. Any piece of test equipment can be replaced by some clever substitution, but I have always used at least a dummy load and oscilloscope when experimenting with amplifiers.

Oscilloscope outputs can be confusing and messy when harmonics are present, so I usually use a low pass filter on the amplifier output. The low pass filter should have connectors, so that it can be removed for examining harmonic waveforms, and particularly at VHF and up it is highly instructive to add a quarter wavelength of 50 Ω coax between the output network and low pass filter and observe the effects. Figure 13 is a photograph of the 40 meter low pass filter I use for experimental amplifiers up to several hundred watts' output. Since there is no penalty for having a cleaner output than the FCC requires, all of my bench low pass filters are of seventh order. Suitable designs are tabulated in *The ARRL Handbook*.[3]

When I want numerical measurements of linear amplifier performance, I use the complete bench shown in Figure 15, but when I first turn on an amplifier, adjust the bias, and explore its gain and undistorted power output I often use the much simpler setup in Figure 14. If a linear amplifier can provide undistorted amplification of an AM signal, it will have very low distortion when amplifying SSB. This is very old lore, taken directly from the 1966 *ARRL Handbook*. Both my HP8640 signal generators and my older military surplus URM-25 generators have the option of AM modulating the output, and most modern transceivers will provide an AM output as well. After I have completed the design, I often use a variable source of AM drive and an oscilloscope with 50 Ω termination for adjustments to a linear amplifier.

A quick look at the test bench reveals some of the appeal of 5 W class amplifiers for experiments. The RF load can be a simple 5 W BNC 50 Ω termination on the front panel of the oscilloscope, and the driver amplifier on the bench need only put out a watt of undistorted linear output. An FT-817 with a 6 dB pad on the output can drive the amplifier input. A DTMF microphone will generate two tones. The penalty for burning out devices is low at

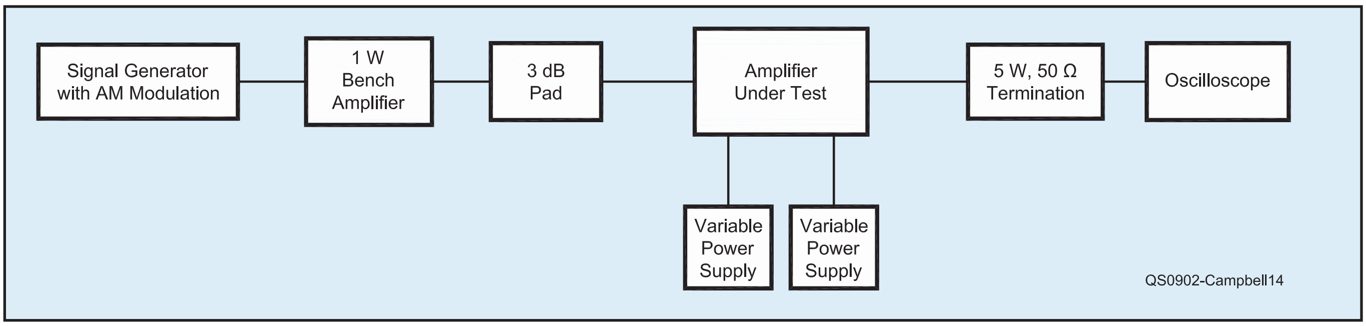



**Figure 14 — Simple linear amplifier test bench.**

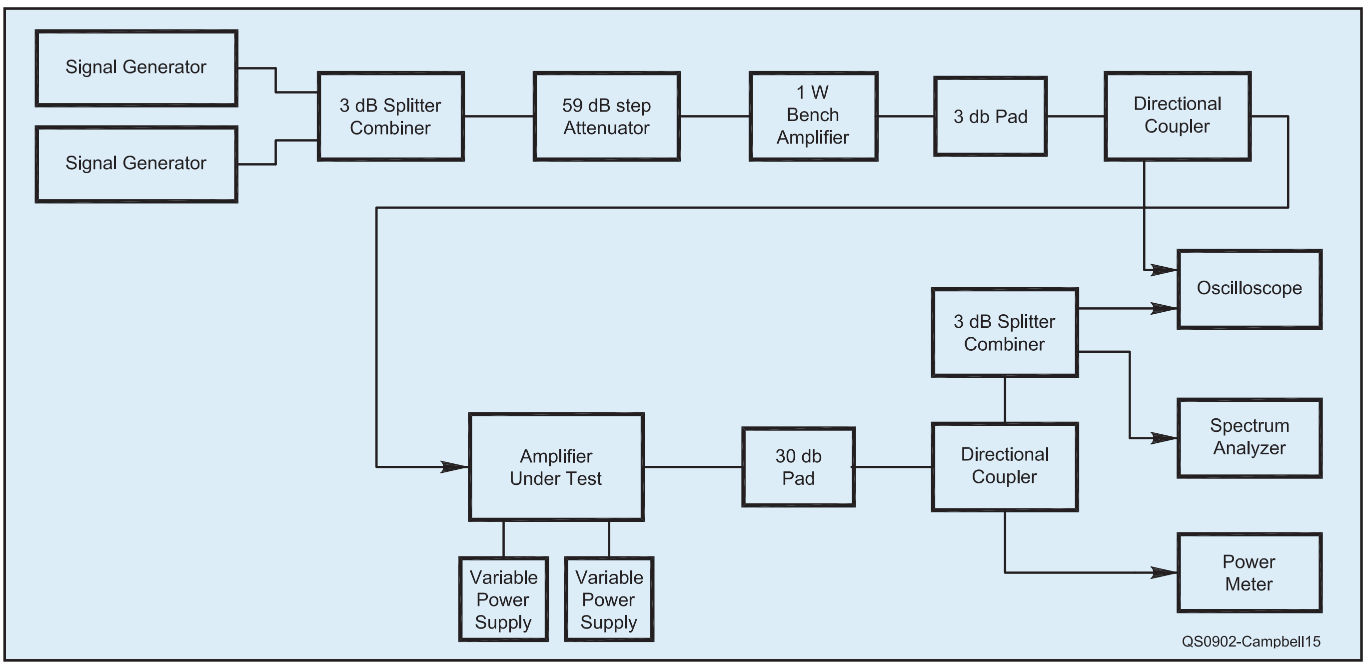



**Figure 15 — More complete linear amplifier test bench.**

the 5 W level. Besides, it has been widely observed that experiments at the low power (QRP) level are simply a lot of fun.

The AM waveform peaks are at 10 V, for a peak output power of 1 W. The carrier level is approximately 250 mW. Efficiency is low, of course, but one advantage of low power transmitters is that the power dissipated as heat in an inefficient transmitter output stage is often much less than the power used in other parts of the station. It is impossible to save 35 W in the output stage of a QRP transmitter that only draws 10 W — but it is very easy to save 35 W by turning off the overhead 75 W light bulb and turning on a 40 W desk lamp!

## Evaluate What You've Got

The last activity is to experiment and think about what you observe. Try every input waveform you can generate, and look at the output waveforms. Perform two-tone tests at different tone separations. Dig up an old *ARRL Handbook* that shows how to obtain AM trapezoid patterns. The goal is to learn what makes your amplifier work well. How does it respond to high and low level input signals, high and low quiescent bias levels, and different modulation formats? Does the transistor burn out or oscillate if the load is disconnected? A good amplifier design is not based on a particular schematic or parts list — it is an amplifier designed by someone who has observed performance over a wide range of conditions and understands how all of the adjustments, components and circuit blocks interact. When you have completed this step, you don't quite have an amplifier you can use on the air, but you do have an education. Congratulations, you are an amplifier designer!

**Notes**

[1]W. Hayward, W7ZOI, R. Campbell, KK7B, and B. Larkin, W7PUA, *Experimental Methods in RF Design*. Available from your ARRL dealer or the ARRL Bookstore, ARRL order no. 8799. Telephone 860-594-0355, or toll-free in the US 888-277-5289; **www.arrl.org/shop**; **pubsales@arrl.org**.

[2]See Note 1, pp 4-27, 4-28

[3]*The ARRL Handbook for Radio Communications,* 2009 Edition. Available from your ARRL dealer or the ARRL Bookstore, ARRL order no. 0261 (Hardcover 0292). Telephone 860-594-0355, or toll-free in the US 888-277-5289; **www.arrl.org/shop**; **pubsales@arrl.org**.

*Rick Campbell, KK7B, received a BS in Physics from Seattle Pacific University in 1975 after two years active duty as a US Navy Radioman, He worked for four years in crystal physics basic research at Bell Labs in Murray Hill, New Jersey before returning to graduate school at the University of Washington. He completed an MSEE in 1981 and a PhD in electrical engineering in 1984. He served for 13 years on the faculty of Michigan Technological University and then seven years designing receiver integrated circuits at TriQuint Semiconductor. He is now with the advanced development group at Cascade Microtech and an adjunct professor at Portland State University where he teaches RF design. Rick was one of the authors of EMRFD.*

*You can contact Rick at 4105 NW Carlton Ct, Portland, OR 97229, or at* **kk7b@hotmail.com**.

# Designing and Building Transistor Linear Power Amplifiers

*Part 2 — Apply techniques from Part 1 to single band HF and 6 meter linear amplifiers.*

**Rick Campbell, KK7B**

In Part 1 of this series, I described an experimental method for designing a linear amplifier starting with a blank sheet of paper, some basic test equipment and an assortment of candidate transistors. In December 2006 *QST* I described a single band SSB exciter with 0 dBm output.[1] An output level of 0 dBm (1 mW) is very common for signal interconnections between 50 Ω blocks in radio systems. At this power level, the SSB exciter output may be connected directly to an antenna for very low power experiments, it may be amplified to any desired output level or it may be converted to a different frequency using a mixer and VFO. It could also be connected to a simple RF clipper followed by a filter to obtain higher average-to-peak ratio SSB, or it might even be converted back down to the audio range with a second oscillator for a number of interesting analog signal processing applications. Several of these applications are illustrated in Figure 1.

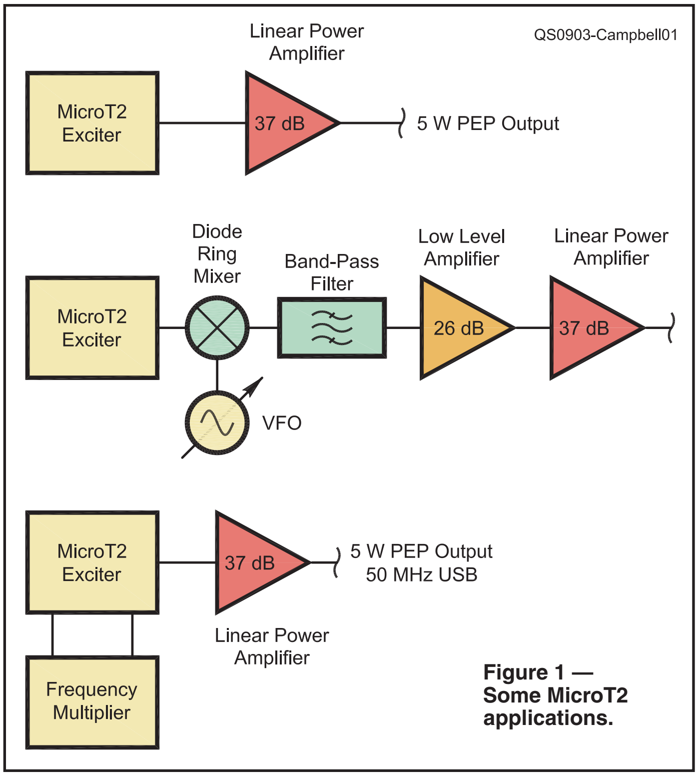



**Figure 1 — Some MicroT2 applications.**

## How Much Power do We Need?

Once the signal has been moved around and processed at the 0 dBm power level and is at the desired output frequency, most applications will require more power. If 0.25 W is enough, then the amplifier described in *Experimental Methods in RF Design*, Figure 2.93 and included in the December 2006 *QST* article is highly recommended.[2] Many on-air contacts have been made at that power level over remarkable distances when band conditions enhance the transmitted signal and noise and interference are low at the receiver. I've played that game, and every contact entered into the log is cause for a little celebration. But the bands are not always kind and high levels of noise and interference are common. You may clearly hear the station on the other end of the contact but he is probably running at least 20 times (13 dB) more power, even in a low power (QRP) contest. One more stage of amplification added to the 0.25 W amplifier can overcome that 13 dB difference. The 5 to 10 W output level is a common standard for portable radios with many commercially available examples.

## Putting Power in the Antenna

Figure 2 is the block diagram of an experimental single-band 36 dB gain 5 W linear amplifier that may be easily constructed using whatever output device is available. Two noteworthy differences between Figure 2 and other commonly published circuits are the use of a resistive attenuator and low-pass filter between the driver and final stage, and the floating ground at the final amplifier device. These two features make it easy to experiment with different final amplifier transistors without mechanical headaches or oscillations.

Figure 3 is the schematic of a 7 MHz version of the amplifier.[1] It was optimized to use common, inexpensive ($0.79) switching power supply transistors. Since the 2N5739 is not designed as an RF device, there are no suggested RF operating conditions in

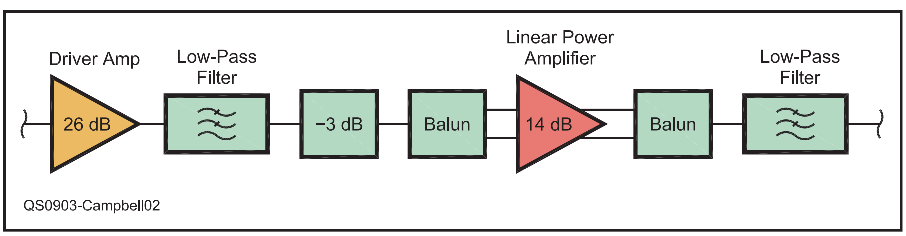



**Figure 2 — A 37 dB gain linear amplifier.**

[1]Notes appear at the end of the article..

the data sheet. The operating conditions were obtained experimentally by varying the supply voltages while watching the output waveforms. The values of the π attenuators between stages were selected experimentally for best gain and distortion distribution among the three amplifier stages. The single-section low-pass filter on the output of the driver transistor made a significant reduction in high-order intermodulation products, and seemed to improve the symmetry of the intermodulation distortion products as well.

## Tweaking it into Submission

Figure 4 is the single-tone output spectrum of the exciter driving the amplifier in Figure 3 with the two-tone output spectrum shown in Figure 5. Excellent linearity was obtained at a PEP output level of several watts.

Since the amplifier is experimental and the parts are inexpensive, I adjusted the collector supply voltage on the output stage up and down and observed the impact on AM and two-tone waveforms without worrying much about burning out the device. I also varied the base bias, and changed the drive level with a step attenuator. As expected, increased collector voltage made a big improvement in the linearity of strong signals. Increased base bias improved the linearity of small signals.

Since 100% modulated AM, SSB and two-tone outputs vary from some peak voltage all the way to zero, both collector supply voltage and base bias determine the linearity of the output. Each can also be used to destroy the device. Too much collector voltage will burn out the transistor directly (remember that the voltage at the collector will generally swing to significantly higher than twice the supply voltage, even in a linear amplifier). Too much base bias will either destroy the transistor quickly as it conducts too much collector current and overheats, or slowly as the base-emitter junction warms up and the device goes into thermal runaway. I enjoyed exploring these options in the design phase of this amplifier, but have not burned out a device since selecting the component values and supply voltages shown in Figure 3.

## Give Me Power

The collector power supply for the output stage is a common circuit, with a big capacitor instead of the expected three terminal regulator. That gives me about 18 V open-circuit, and about 16 V at maximum output. The big capacitor is split in two. The little box on the floor holds 2200 μF while another 3500 μF is in the box with the speaker, variable bias supply, TR relay and 12 V three terminal regulator. The regulator supplies regulated voltage to the receiver, transmitter and other amplifier stages.

The big capacitor provides the low impedance at audio needed in a SSB linear amplifier. By splitting it in two all of the components in the power supply and regulator circuitry are physically and electrically close to a big reservoir capacitor. Keeping power supply lines clean is particularly important around receivers. It is a simple power supply for an inexpensive transistor, and any efficiency I would have gained by using an expensive 13.8 V linear RF power transistor in one of Granberg's wonderfully engineered circuits is more than offset by

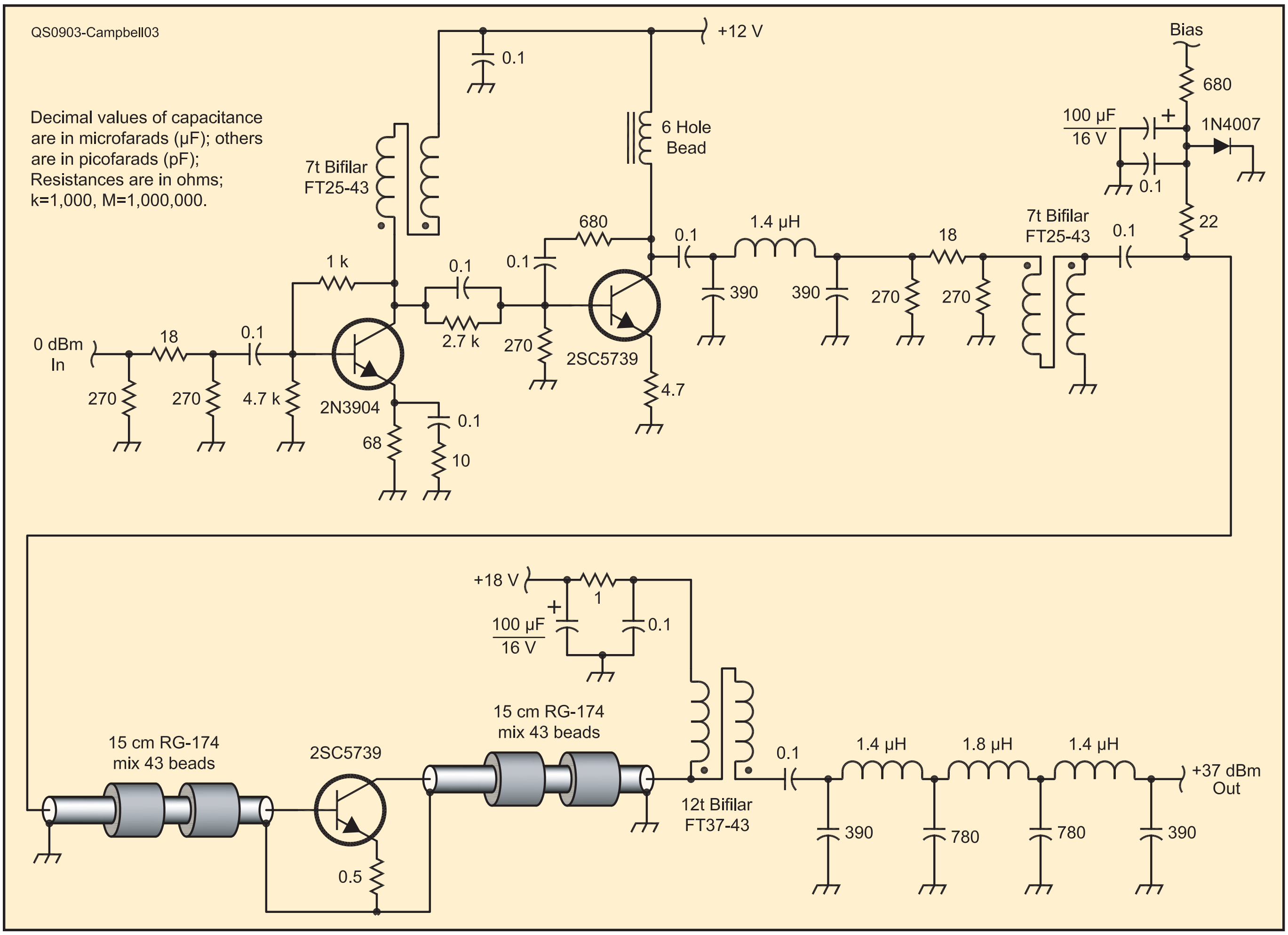



**Figure 3 — 7 MHz linear amplifier based on inexpensive active devices.**

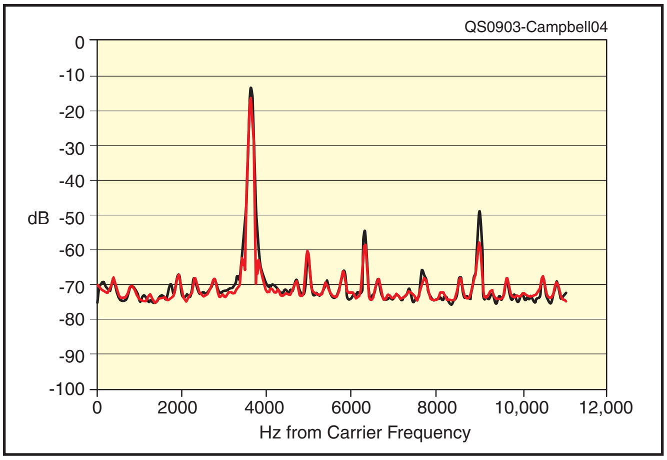



**Figure 4 — 7.165 MHz LSB single-tone output spectrum at 1 W (black) and 3 W (red) output. The desired LSB output tone is at 3.7 kHz and the carrier is at 5.0 kHz on this display at about 42 dB below the 1 W tone. Note suppressed upper sideband tones at 6.3 kHz and unsuppressed modulator harmonic distortion on upper sideband between about 9 kHz.**

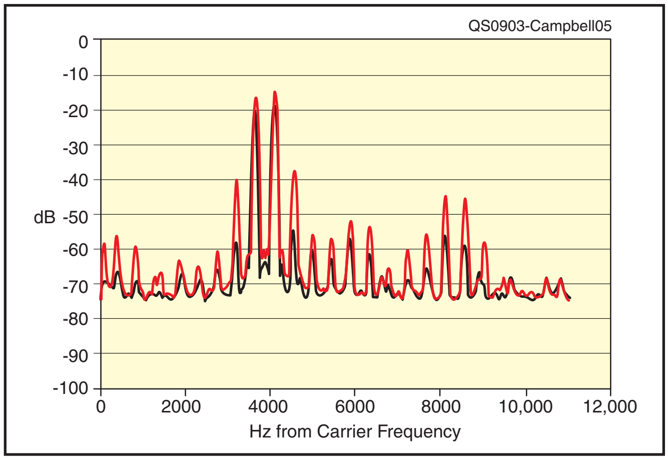



**Figure 5 — 7.165 MHz LSB two-tone output spectrum at 1 W (black) and 4 W (red) output. The carrier is at 5.0 kHz on this display at about 42 dB below the 1 W tone. Note that third order products near the desired two-tone output increase by 3 dB for each 1 dB increase in output power level. Also note the unsuppressed modulator harmonic distortion on the upper sideband between 8 and 9 kHz.**

eliminating the series regulator. For more power, I'll experiment with operating the transistor closer to its breakdown limits. I don't mind burning out a few output transistors during these experiments, because the transistor is easy to change and costs less than a cup of coffee.

## Construction Techniques

Figure 6 is a photograph of the bias control supply and TR switching. The meter reads current in the final transistor while the knob below the meter is used to set the quiescent (no signal) bias level. The power transformer was mounted where the speaker is now, but after a few experiments with magnetic shielding to eliminate residual hum in the companion MicroR2 receiver, I stopped fighting basic physics and cured the problem by putting the power transformer, rectifier and half of the capacitance in a box on the floor.[3] This ancient cure, adopted long ago, was once common with sensitive receivers, and is still standard practice for sensitive audio and scientific instruments.

After I removed the power transformer, I encountered another fringe benefit: any source of 18 V dc will now power the whole transceiver. Twelve AA cells in series will run the receiver for days as well as power intermittent SSB transmitting for 4 hours or so.

**Figure 6 — Classic 40 meter solid state QRP SSB station.**

## Putting the MicroT2 on 6 Meters

The fundamental crystal oscillator in the MicroT2 won't go above about 25 MHz with common crystals, so another approach must be used for the bands above 12 meters. The ancient lore suggests frequency multipliers, and that approach was chosen for simplicity. Two 6 meter exciters were built, one with a 16.7 MHz crystal oscillator and tripler, and the other with an 8.35 MHz oscillator, tripler and doubler. An assortment of different crystals was ordered from several different vendors, including Peterson Radio and International. The variable crystal oscillator (VXO) and ×6 multiplier schematic are shown in Figure 7. The VXO circuit is the original circuitry in the MicroT2 circuit. The only change from the values in the original 40 meter VXO described in *QST* is the value of the low pass output transformer. This was calculated using the formulas in *QST* and *The 2009 ARRL Handbook*.[4,5]

The ×3 and ×2 frequency multipliers were built on a scrap of unetched copperclad board, using ugly construction. If using ugly construction at VHF, it is important to sketch the layout first and think about which leads need to be short and which ones can be longer.

The output of the doubler is about 1 mW at 50 MHz, with all spurs suppressed at least 45 dB below the desired output. These spurs are further suppressed by the tuned

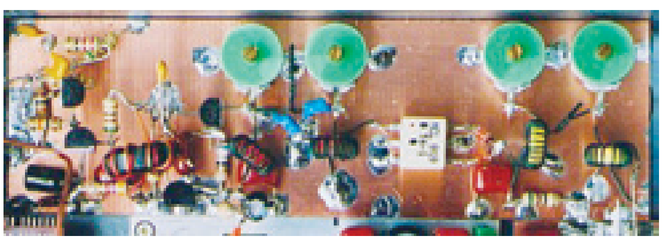
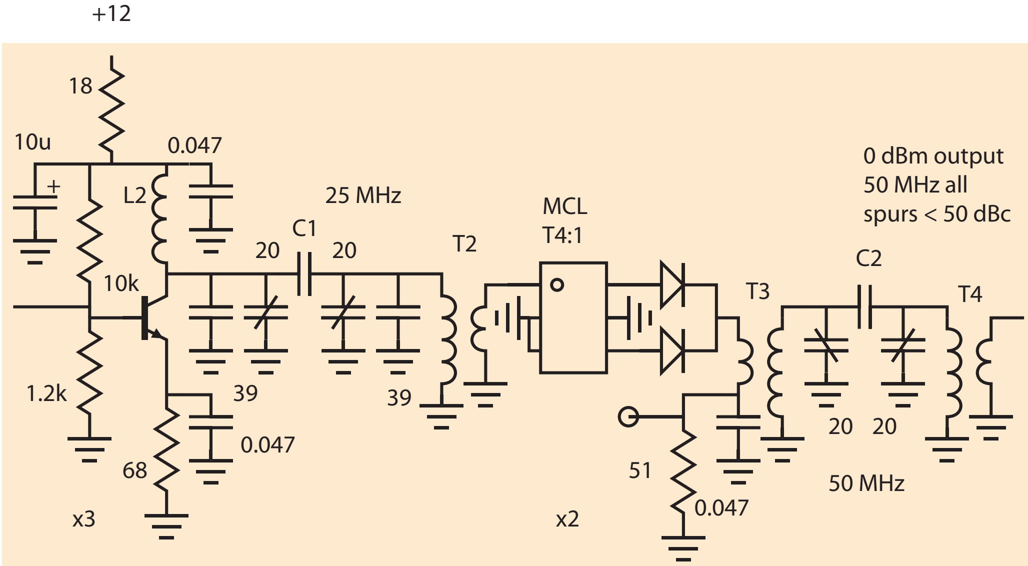


**Figure 7 — Prototype 6 meter VXO tripler and doubler. Note the short leads, gimmick capacitors and symmetry in the layout. Such circuitry is common on the low VHF bands, and works exceptionally well. The schematic is on the gollowing page.**

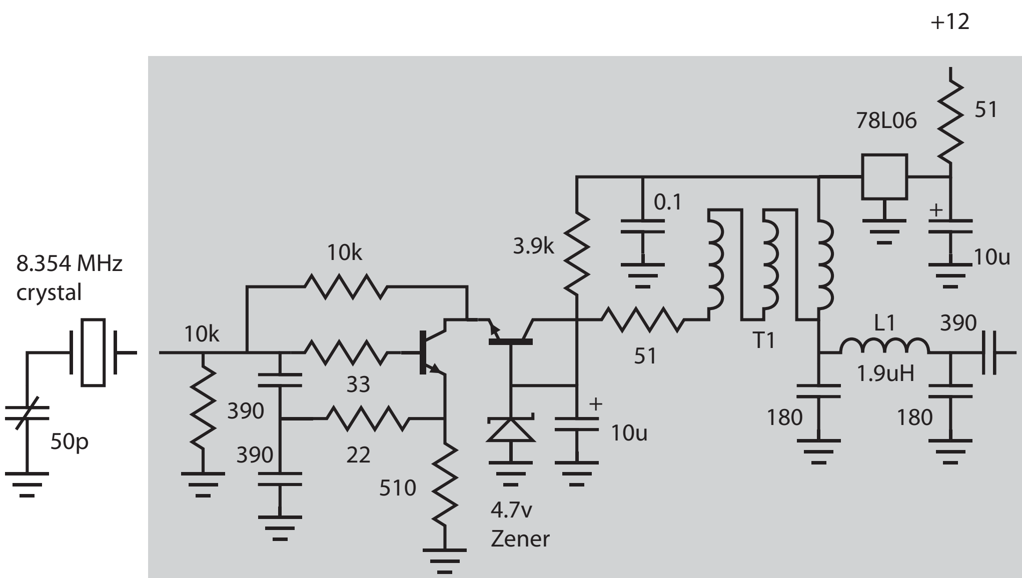



x3 and x2 built on unetched copper clad

0 dBm output drives microT2 buffer amp

T3,T4 10t T25-6 resonant at 6x crystal freq.

MCL T4:1 may be replaced by trifilar transformer like T1




All 3 transistors 2N3904 or equivalent

T1 4t trifilar on FT25-43

L1 and associated 180pF capacitors
X=100 ohms at crystal freq.

gray circuitry is part of microT2

L2 18t T25-2 resonant at 3x crystal freq.

T2 18t:2t T25-2 resonant at 3x crystal freq.

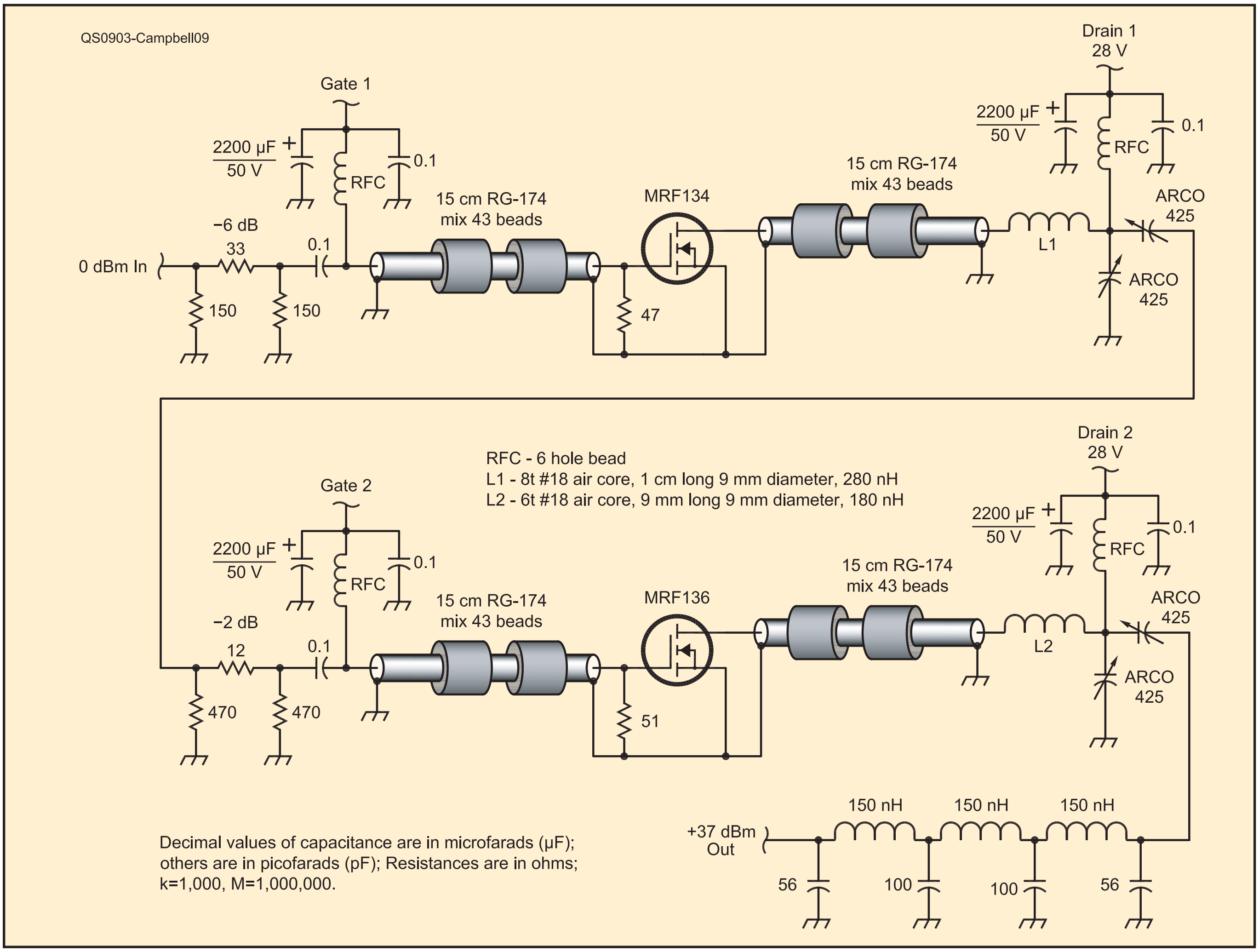



**Figure 8 — Schematic of 6 meter amplifier.**

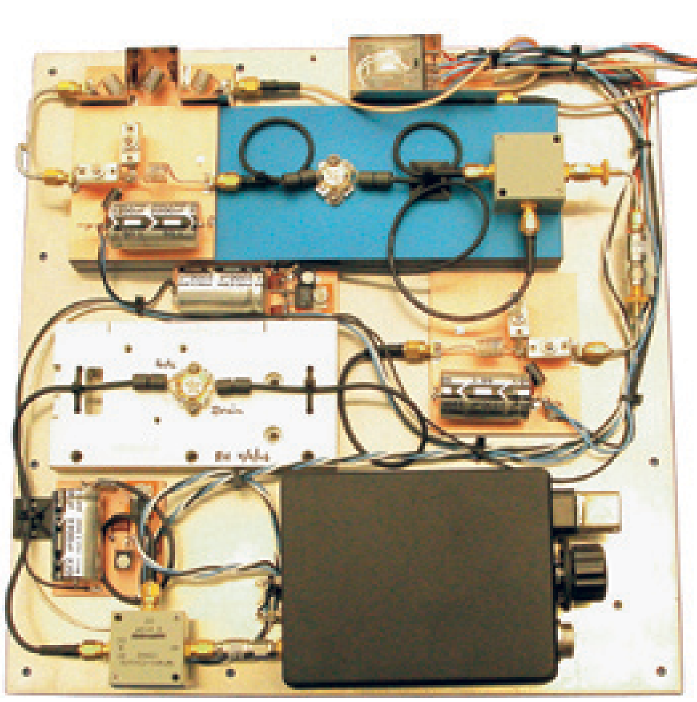


**Figure 9 — Photograph of the 6 meter 5 W SSB transmitter. The MicroT2 with ×6 exciter is in the black diecast box in the lower right. The VXO knob is in the middle, and the MIC connector on the right. The crystal socket on the front panel is a mistake — the crystal belongs inside the box where it is thermally and electrically shielded.**

RF amplifier in the MicroT2, and by the narrow-band interstage tuning networks in the linear amplifier. The tuned doubler output drives the original MicroT2 buffer amplifier circuit. The only other change to the MicroT2 is retuning the RF amplifier output to 50 MHz. That may be easily done by changing MicroT2 L3 to 16 turns on a T25-6 ferrite toroid, changing C21 to a 20 pF trimmer, and leaving C20 out of the circuit. If the MicroT2 RF amplifier stage is built using ugly construction, short leads are necessary, particularly for connections to the gate of Q6.

Experiments with running the TUF-3 mixers as third harmonic mixers with direct IQ LO drive at 16.7 MHz were initially encouraging, with very good carrier suppression at 50 MHz, but distortion was high. A very simple rig could be built with that approach.

The 8 MHz crystal from International in the large can provides a very stable frequency tuning range of about 50 kHz on 6 meters, over the useful range from 50.115 to 50.165 MHz. The 16.7 MHz crystal and tripler provides a narrower range,

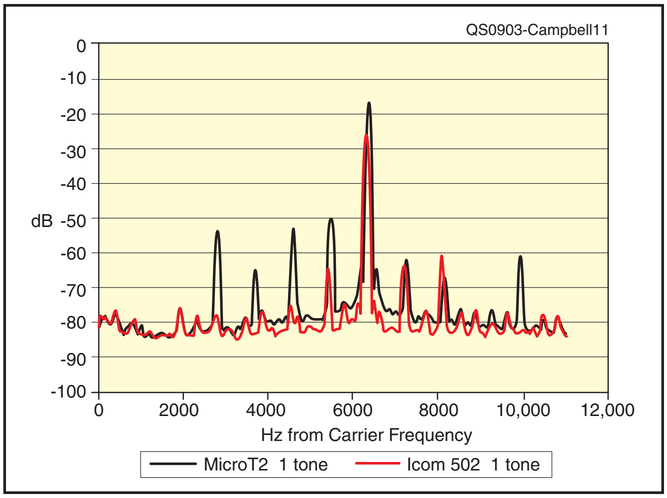



**Figure 10 — MicroT2 and PA 50.125 MHz single-tone USB output spectrum compared with ICOM IC-502 single-tone output spectrum. In each case the suppressed carrier is at 5500 Hz on this plot. The '502 output is about 0.5 W and the MicroT2 and PA is at about 5 W output. Carrier suppression and opposite sideband suppression are not as good with the MicroT2, but in-channel distortion is lower, even if the '502 is backed off 8 dB from its rated output.**

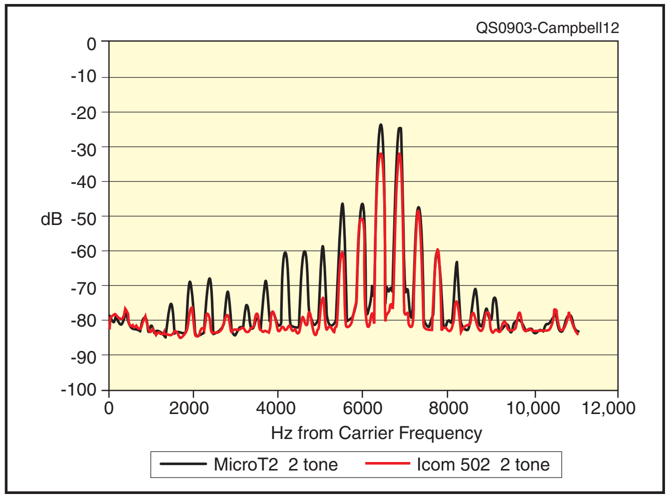



**Figure 11 — MicroT2 and PA 50.125 MHz two-tone USB output spectrum (black) compared with IC-502 two-tone output spectrum (red). In each case the suppressed carrier is at 5500 Hz on this plot. The '502 output is about 1 W PEP and the MicroT2 and PA is at about 5 W PEP output. Carrier suppression and opposite sideband suppression are not as good with the MicroT2, but in-channel distortion is lower, even when the '502 is backed off 5 dB from its rated output.**

about 35 kHz. These are observations with a sample size of one, so I hesitate to draw any firm conclusions. One observation is that the carrier suppression improves when the cans of the TUF-3 mixers are soldered to the circuit board all the way around. This is prevented by solder mask on the current production circuit boards, but it is a worthwhile modification. For much better carrier suppression, wider tuning range and transceive operation, a heterodyne approach from a lower frequency is recommended.

## The 6 Meter Amplifier

The 2SC5739 transistor has low gain at 50 MHz, so different driver and final devices were chosen for the 6 meter linear amplifier. In keeping with the experimental nature of the project, both of these devices came from the junk box, in fact they were unsoldered from a printed circuit (PC) board obtained at a flea market. The driver transistor is an MRF134, and the final is a MRF136 power FET unsoldered from an old PC board. The MRF136 is capable of much more power output than the 2SC5739, so a larger heat sink was used. The bias connection is different as well, since the FETs require forward bias of about 4 V on the gate. These small variations are easily seen in the schematic of Figure 8.

The performance of the broadband 4:1 bias T described in Part 1 degrades above 35 MHz, and with a 28 V supply, a 12.5 Ω load impedance is too low for a 5 W class amplifier. A quick search of the junk box and a few minutes with a Smith Chart resulted in the output network seen in Figure 8, which is used on both the driver and final. The MRF 134 and 136 have enough gain at 50 MHz that two stages are sufficient to amplify the output of the MicroT2 exciter to the 5 W level. Figure 9 is a photograph of the 6 meter amplifier connected to the 6 meter exciter with MicroT2 exciter and ×6 multiplier. This amplifier is simply the packaged up version of the amplifier I tested on the bench. It is still a work in progress. Note how easily the final output transistor may be changed to a different FET, or even a bipolar transistor.

Each modular section of the 6 meter transmitter is separate, including the bias Ts described in Part 1 and the output networks. The bias networks and low-pass filter are on separate boards. This makes it very easy to measure, adjust and modify any part of the circuit, or insert additional gain or attenuation anywhere. All of the pieces except the black diecast box are from the author's junk box, including the thick aluminum plates used for heat sinks. Even the MicroT2 exciter was pieced together from prototype modules from the MicroT2 project.

The plethora of 2200 µF, 50 V electrolytics will continue until that bag is empty. Because this transmitter was assembled at low cost from the available ingredients, I refer to it as the "Blue Plate Special." The 4PDT relay in the lower right corner is the TR relay, and includes an RF output and muting to the receiver and 6 meter converter. The set of contacts next to the ground plane are used for the 6 meter RF, an additional shield was added, and RF connections to the relay are made with small diameter coax.

Figure 10 is the single-tone output spectrum at the 5 W level, compared with the output of a commercial radio in the same power class. Note that the carrier level is higher than we would like, at only about 33 dB below the peak output power. The two-tone spectrum shown in Figure 11 is certainly good enough to use on the air. A comparison between the spectra of these two rigs on 6 meters illustrates a common difference between phasing and filter SSB transmitters. Phasing rigs have lower distortion in-channel, so they sound very good, but filter rigs have fewer off-channel spurious outputs.

This 6 meter SSB signal sounds exceptional on the air, and the carrier could be acquired and locked by a phase locked loop (PLL) for a signal with the fidelity of the best AM signal, at a fraction of the bandwidth and total radiated power. There is room for experiments with such modes on the VHF and UHF bands.

My personal choice is to use phasing for QRP SSB rigs and VHF-UHF SSB, where the off-channel products don't generally bother anyone. For high power operation on crowded HF bands, I follow the phasing exciter with a crystal filter and heterodyne system.

## Checking it Twice

The procedure I use for a quick check of amplifier performance before putting a signal on the air is very different from the measurements and experiments I use to design an amplifier. With these amplifiers, I connect a dummy load and wattmeter to the output of the low-pass filter, and drive the amplifier chain to saturation with a CW signal. I observe the current drain at this saturated output level, and then set the resting bias to about one tenth that level. These 5 W amplifiers idle at around 100 mA, so that is 1.8 W for the 7 MHz amplifier and 2.7 W for the 6 meter version. Then I speak into the microphone and observe that the output peaks are about 3 dB below the saturated CW output level. That results in a very nice sounding signal on the air.

If you have been doing the math, you can quickly estimate that my average output power on SSB ends up being about one tenth the saturated CW output power. PEP output capability is considerably higher than the average, but I prefer natural sounding SSB to the highly processed sound that results in an average power output very close to the PEP output capability of the amplifier. This is personal preference, and directly related to my willingness to switch to CW when signals are marginal. CW is no longer a requirement, it's a choice, and in many cases it will get through when nothing else will. SSB is nice for casual conversations, digital modes are wonderful if you don't mind sharing the fun with a computer, but CW is simple and the power advantage on transmit is only part of the equation.

The linear amplifiers described in this article are remarkable in two ways:

- The experimental design procedure provides a real education in linear amplifier design, measurement, adjustment and construction.
- They were designed around the devices on hand, and built at nearly zero cost.

In that sense, they follow the best traditions of the Amateur Radio service and innovative design engineering.

**Notes**

[1]R. Campbell, KK7B, "The MicroT2 — A Compact Single-Band SSB Transmitter," *QST*, Dec 2006, pp 28-33.

[2]W. Hayward, W7ZOI, R. Campbell, KK7B, and B. Larkin, W7PUA, *Experimental Methods in RF Design*. Available from your ARRL dealer or the ARRL Bookstore, ARRL order no. 8799. Telephone 860-594-0355, or toll-free in the US 888-277-5289; **www.arrl.org/shop**; **pubsales@arrl.org**.

[3]R. Campbell, KK7B, "The MicroR2 — An Easy to Build 'Single Signal' SSB or CW Receiver," *QST*, Oct 2006, pp 28-33.

[4]*The ARRL Handbook for Radio Communications,* 2009 Edition. Available from your ARRL dealer or the ARRL Bookstore, ARRL order no. 0261 (Hardcover 0292). Telephone 860-594-0355, or toll-free in the US 888-277-5289; **www.arrl.org/shop**; **pubsales@arrl.org**.

[5]This circuitry is nearly identical to the circuit used for the 40 meter version, and can use the same circuit traces. The output may be taken from MicroT2 C41 by leaving R59, 60 and 61 off the circuit board. The VHF ugly constructed tripler and doubler circuitry is inserted in the MicroT2 circuit in place of R60. Short small diameter coax or twisted pair should be used for the interconnections. This circuitry should be shielded from the RF output amplifier to improve carrier suppression.

*See Part 1 for Rick's biography. You can contact Rick at 4105 NW Carlton Ct, Portland, OR 97229, or at* **kk7b@hotmail.com**.

# The TAK-40 SSB CW Transceiver


*We are excited to introduce this winner of the first ARRL Homebrew Challenge competition!*

**Jim Veatch, WA2EUJ**

This transceiver was designed specifically for the ARRL Homebrew Challenge contest. The following is a list of the criteria for the contest and a brief description of how the TAK-40 meets the requirements:[1]

- *The station must include a transmitter and receiver that can operate on the CW and voice segments of 40 meters.* The TAK-40 covers 7.0 to 7.3 MHz.
- *It must meet all FCC regulations for spectral purity.* All spurious emissions from the TAK-40 are at least 43 dB below the mean power of fundamental emission.
- *It must have a power output of at least 5 W PEP.* The TAK-40 generates at least 5 W PEP for voice and CW modes. The ALC can be set as high as 7 W if desired.
- *It can be constructed using ordinary hand tools.* Construction of the TAK-40 uses all leaded components, and assembly requires only hand tools, soldering iron and an electric drill (helpful but not strictly necessary).
- *It must be capable of operation on both voice and CW.* The TAK-40 operates upper and lower sideband (USB and LSB) as well as CW. USB was included to allow the TAK-40 to easily operate in digital modes such as PSK31.
- *Parts must be readily available either from local retailers or by mail order. No "flea market specials" allowed.* The TAK-40 is constructed from materials available from Digikey, Mouser, Jameco and Amidon.
- *Any test equipment other than a multimeter or radio receiver must either be constructed as part of the project or purchased as part of the budget.* The TAK-40 only requires a multimeter for construction. Extensive built-in setup functions are included in the software including a frequency counter to align the oscillators and a programmable voltage source for controlling the oscillators.
- *Equipment need only operate on a single band, 40 meters. Multiband operation is acceptable and encouraged.* The TAK-40 operates across the 40 meter band.
- *The total cost of all parts, except for power supply, mic, key, headphones or speaker, and usual supplies such as wire, nuts and bolts, tape, antenna, solder or glue must be less than $50.* The cost of the parts required to built the TAK-40 is $49.50.

The TAK-40 also includes some features that make it very smooth to operate:

- Automatic gain control — regulates the audio output for strong and weak signals.
- S-meter — simplifies signal reports.
- Digital frequency readout — reads the operating frequency to 100 Hz.
- Dual tuning rates — FAST for scanning the band and SLOW for fine tuning.
- Speech processor — get the most from the 5 W output.
- Automatic level control — prevents overdriving the transmitter.
- Transmit power meter — displays approximate power output.
- Bootloader — accepts firmware updates via a computer (cable and level converter optional).

## Circuit Description

The TAK-40 transceiver is designed to be constructed on four modules:

- Digital section and front panel.
- Variable frequency oscillator (VFO).
- Intermediate frequency (IF) board, and
- Power amplifier (PA).

The overall design is a classic superheterodyne with a 4 MHz IF and a 3 to 3.3 MHz VFO. The same IF chain is used for transmitting and receiving by switching the oscillator signals between the two mixers. Figure 1 shows the block diagram of the TAK-40 transceiver. Each board is described below. Detailed schematics, board layout and parts list are on the *QST* article details Web site.[2]

### *Digital Board*

The digital board contains the microprocessor, front panel controls, liquid crystal display (LCD), the digital to analog converter for the VFO, the beat frequency oscillator (BFO) and the oscillator switching matrix. Figure 2 is the schematic of the digital board with components numbered in the 100 range. The front panel switches are multiplexed on the LCD control lines for economy so the display will not update when a button is pressed.

[1]Notes appear on page 37.

The BFO is a voltage controlled oscillator (VFO) using a ceramic resonator (Y101) as a tuned circuit. The pulse width modulator (PWM) output from the microprocessor is filtered (R124, C114, R131, C108) and used as the control voltage for the BFO. The microprocessor (U105) varies the BFO frequency for upper or lower sideband modulation. The microprocessor is also used to stabilize the BFO, if the BFO varies more than 10 Hz from the set frequency, the microprocessor adjusts the PWM to correct the BFO frequency.

The digital board also contains the switching matrix for the VFO and BFO (U106, U107). The NE-612 mixers on the IF board work nicely when driven with square waves and aren't sensitive to duty cycle. One section of each tri-state buffer (74HC125) is used to convert the output of the VFO and BFO to a square wave. The remaining sections control which oscillator goes to which mixer and which oscillator is applied to the frequency counter. The counter counts the VFO then the BFO and adds the result to calculate the operating frequency. The 20 MHz oscillator (OSC101) that runs the microprocessor is accurate to 100 PPM, so the frequency displayed may be as much as 1 kHz off. Don't operate within 1 kHz of the band/segment edge just to be sure.

The digital to analog converter (DAC) (U103) used to drive the VFO is a Microchip MCP4922 dual 12 bit DAC. The outputs of each converter are coupled with an 8:1 resistive divider (R116, R117) effectively creating a 15 bit DAC. Since the band is split into two 150 kHz sections, this results in approximately 10 Hz steps. Actually since the tuning is not linear, steps at the bottom of each band are slightly larger than steps at the top.

### IF Board

In receive mode, RF is filtered in an impedance matching RF filter (C254, L208, C240, C235, L207, C234, C226), applied to the first mixer and mixed (U201) with the VFO signal to result in a 4 MHz IF. This signal is filtered in a 6-element crystal ladder

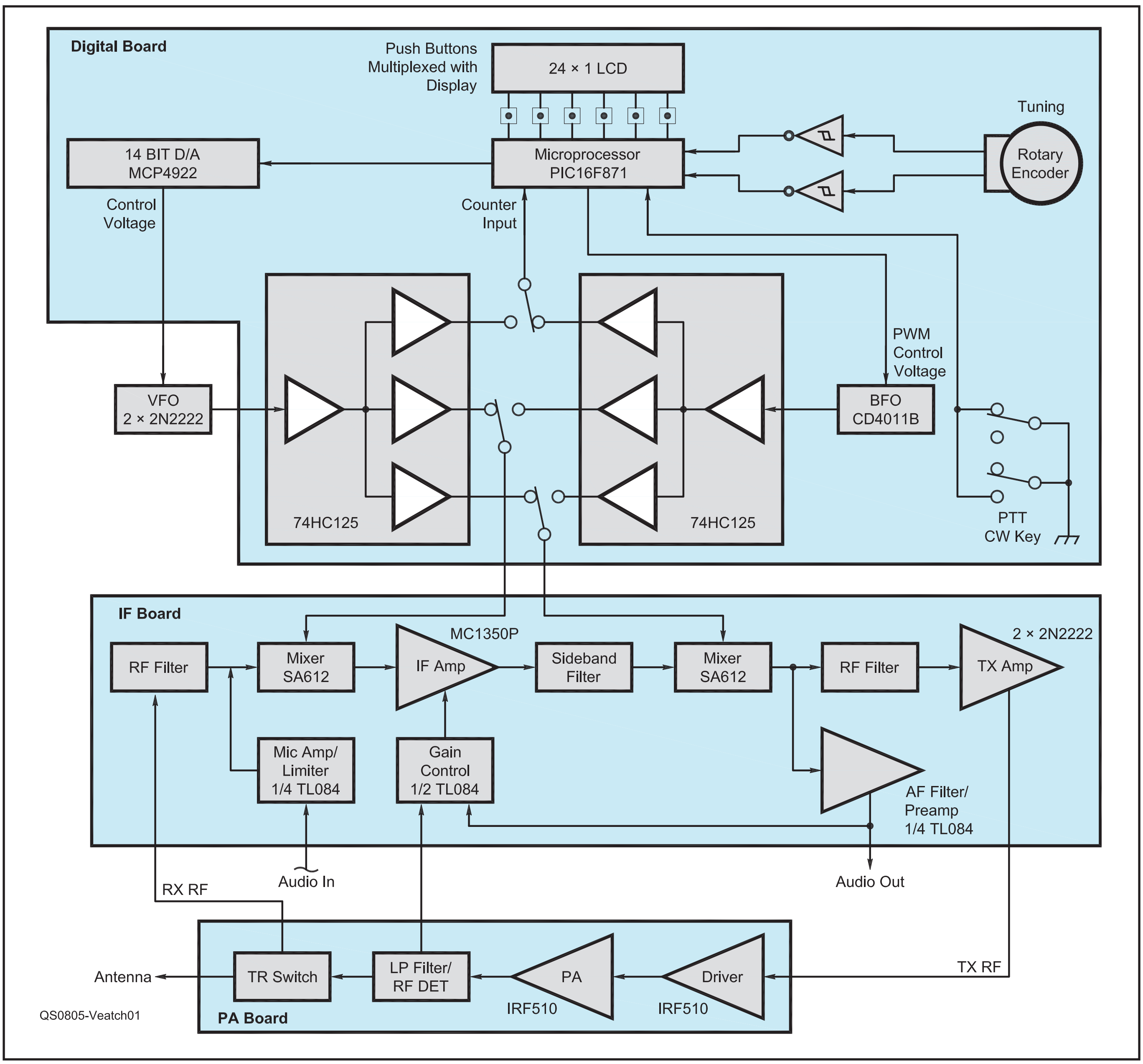



**Figure 1 — Block diagram of TAK-40, Homebrew Challenge winner. This radio includes many more features and capabilities than we expected to find in a $50 radio! All schematic diagrams and a parts list can be found at www.arrl.org/files/qst-binaries/.**

filter (Y201-Y206) with a bandwidth of a bit more than 2 kHz. The signal is then amplified by an MC1350P IF amplifier (U202). The amplified signal is applied to the second mixer (U203) and mixed with the BFO signal to produce the receive audio.

The audio is filtered and amplified to drive a set of computer speakers. Audio is also used to generate an AGC signal for the IF amp and the S-meter. The audio-derived AGC pops and clicks a bit but it's an improvement over manual gain control. There is a provision for adding a manual gain control (it didn't fit into the budget). All audio and AGC functions are handled by a quad op-amp (U204).

In transmit mode, microphone audio is amplified and limited (soft-clipped) then applied to the first mixer and mixed with the BFO to create a 4 MHz IF signal. The IF is filtered, amplified (just as with the received signals) and sent to the second mixer to be mixed with the VFO to create an RF signal. The RF signal is filtered by a filter identical to the receive input filter. This is followed by two stages of amplification to bring the transmit signal to 2 $V_{PP}$. There is a manual transmit gain control setting and the RF detector on the PA board reduces the IF gain for automatic level control (ALC) on transmit.

Transmit and receive signals are diplexed into and out of the mixers so no switching is necessary. Switches are used to mute the receive audio during transmit and a diode RF switch is used at the input to the receive filter to protect the input during transmit. Parts on the IF board are numbered in the 200 range.

### *VFO Board*

The VFO circuit is a straightforward Colpitts oscillator (Q301) with an emitter follower buffer (Q302). Tuning is achieved by varying the reverse bias on a MV209 (D302) varactor diode. A second MV209 (D301) is used to switch between the lower and upper 150 kHz sections of the band. There are no expensive trimmer caps to set the range. Tuning is achieved by winding too many turns on the inductor (L301), then removing turns until the correct tuning range is achieved. The VFO drifts a bit for the first ½ hour but eventually settles down. Parts on the VFO board are numbered in the 300 range.

### *PA Board*

The driver (Q401) and PA (Q402) are located on the PA board. Both stages use an IRF-510 MOSFET, which is overkill for the driver but I couldn't find a better device for $0.69. The gate voltage is pulled down during receive to reduce current draw and heat. The PA is biased class A and can produce 7 to 8 W output. The RF detector (R405, R406, D403 and C413) simply measures the RF voltage at the output so it's only accurate into a 50 Ω load. No protection is provided for excessive SWR conditions. Thus it is possible to damage the PA transistor with prolonged operation into a poorly matched antenna system. A tuned TR switch (C412, D404, D405 and L405) isolates the receiver input during transmissions. Parts on the PA board are numbered in the 400 range.

### *Chassis*

Fortunately, the TAK-40 requires relatively little chassis wiring. A small harness for the LCD and push button switches, cable for the rotary encoder audio in and out, and key line wiring are all that are required for the front panel. The IF board connects to the VFO, IF and PA boards for control and metering. Two RF lines run between the IF and PA boards.

## Construction

The best way to build this radio would be to buy the printed circuit boards (PCB) but this approach won't fit within the $50 budget. I've included files in the Web *QST* binaries package (see Note 1) that can be sent to **expresspcb.com**. They will send you two complete sets of boards for just over $100. I suspect that if you got a part-time job mowing lawns and saved up enough money to order the PCBs you would complete the radio sooner than if you built it using any other technique and with a higher probability of success. Be that as it may, to build the TAK-40 for less than $50 we'll have to resort to more creative techniques. Perfboard is expensive! Deadbug style is messy and difficult to rework/troubleshoot so I've used a different approach in the prototype.

Print out the mechanical files for each board. Each drawing includes a parts placement, hole position, top copper and bottom copper drawing. Cut out the hole drawing and stick it to the copper side of the copper clad PCB using glue stick or print it on a self sticking label. Make sure that the printer is printing a 1:1 size ratio using the dimensions of the board shown on the drawings. Mark each hole with a center punch (hammer and nail works file) then remove the drawing and drill all of the holes. Refer to the top copper drawing and mark every hole that does not connect to the ground plane with a fine point permanent marker. Next touch each hole with a larger diameter drill bit to remove the copper but don't go all the way through. Using the parts placement drawing, the bottom copper drawing and the schematic, build the board. Take care not to short the non-grounded component leads to the copper and directly solder component leads that need to be grounded. The technique results in a good ground, short signal runs and solid mounting.

I built the prototype on a wooden frame and printed the front panel on photo paper in an inkjet printer. See Figure 2. The tuning knob was made by using a hole-saw to make a circular wooden slug, drilling and tapping the sides for set screws and cutting off 6-32 screws to use as set screws. The encoder is made from rebuilding a potentiometer with the guts of a wheel mouse (see binaries package). I mounted the VFO board in an Altoids tin for three reasons: mechanical stability, electrical shielding and it is only a cool homebrew radio if part of it is in a food container.

Separate the inductors L101, L201, L202, L204, L207, L208 and L405 from the PCB by ¼ inch because close proximity of the copper ground plane seems to detune the tuned circuits. Scrape the copper from under the toroidal inductors L301, L401, L402, L403 and L404. RadioShack sells a pack of magnet wire that includes #22 and #26 enameled wire. To make bifilar windings, twist two conductors using a clamp on one end and a drill or Dremel tool to twist the wire. It's very important to get 8 to 10 twists per inch in the wire before it goes on the core. The driver (Q401) doesn't need a heat sink but the final transistor (Q402) needs about 30 $in^2$ of aluminum or copper attached to the heat sink tab. I used copper flashing but aluminum cake pans, soda cans or anything you can find to spread the heat will work.

## Adjustments

After completion of the digital board and front panel, the microprocessor can be powered up and the BFO aligned. Carefully recheck all connections looking for shorts and wiring errors and apply power. The display should show a frequency around 4 MHz. Powering the TAK-40 while holding the SWAP/SETUP button places the TAK-40 in setup mode. Repeatedly pressing SWAP/SETUP toggles between the five setup modes. Here is a summary of the setup modes in the order they appear:

### *LSB BFO Setup*

The left portion of the display shows the frequency of the BFO at 100 Hz and the right portion shows the BFO setting at 10 Hz resolution. The main tuning knob adjusts the BFO setting (right display). Pressing SELECT stores the setting and updates the BFO. The microprocessor stabilizes the BFO frequency by counting the frequency with 10 Hz resolution and adjusting the BFO as necessary.

### *USB/CW BFO Setup*

This is the same as the LSB setup, above, but adjusts the setting for USB and CW modes.

### *VFO A Range Test*

The left portion of the display shows the VFO frequency and the main tuning knob adjusts the VFO frequency. This is useful when adjusting the VFO circuit and verifying the tuning range.

### *VFO B Range Test*

Same as VFO A test but displays the upper frequency range.

### *BFO Range Test*

The right portion of the display shows the BFO frequency and the main tuning knob adjusts the BFO frequency. This is useful for setting VR102 to make sure the BFO tuning range is 3.995 to 4.005 MHz.

Once the digital board is working properly, assemble, inspect and connect the VFO board to the digital board. Adjust the number of turns on L301 for 3.000 to 3.150 MHz in VFO A test #3 and 3.150 to 3.300 MHz in VFO B test #4.


**Figure 2 — Close-up of the TAK-40 front panel.**

## Final Assembly

Build the IF board and wire it to the MIC and SPEAKER jacks and the digital board. Connect a set of amplified computer speakers and a 40 meter antenna to the RF INPUT port of the IF board and you should be able to receive signals.

Build the PA board and connect it to the IF board and digital boards, follow the alignment procedure and you're almost ready to operate.

## Final Tune Up

There are five potentiometers to adjust to align the TAK-40 (VR101 is not used):

- VR102 — sets the BFO range. Use setup mode 5 above to display the BFO frequency and rotate the MAIN TUNING knob clockwise until the frequency stops increasing. Set VR102 for a BFO frequency of 4.006 MHz. Rotate the MAIN TUNING knob counterclockwise until the BFO stops decreasing and verify that the BFO tunes below 3.995 MHz.
- VR201 — Sets the AGC threshold. With no signal applied to the TAK-40 adjust VR201 for 2.5 V dc at pin 4 of the microprocessor (U105).
- VR401 — Sets the PA bias. Adjust for 600 mA current draw LSB mode key down, VR203 set to minimum.
- VR203 — Sets the transmit drive level. Set for 7 W (3.7 V dc at pin 7 of U105) into 50 Ω on CW mode with VR202 set to minimum (wiper toward R227).

## Homebrew Challenge Results are In!

*Joel R. Hallas, W1ZR*
*QST Technical Editor*

The Homebrew Challenge was a contest announced in *QST* for August 2006 and updated in October 2006. Entrants were required to submit a home constructed voice and CW, 5 W minimum output radio by August 1, 2007. The radio had to be reproducible from no more than $50 of new parts.

In October 2006, by popular demand, we offered a second category to the competition, allowing the use of a PC as part of the control, display or processing function as well as using it to program a microprocessor.

We are pleased that we had four entries that passed the documentation and price confirmation check. They also went through an ARRL Laboratory evaluation to make sure that they met all the ARRL and FCC technical requirements before being subjected to a thorough operational evaluation by ARRL staffers.

We have two winners to announce, one in each category. The PC supported winner was Jim Veatch, WA2EUJ, who gathered the most points in the evaluation by our judges and is the author of this article describing his radio. In a way his radio could be considered a contender for the other award as well, since he has agreed to provide his firmware onto builders' processors at no cost if they don't have the requisite programming capabilities. The winner with a radio totally without use of a PC is Steve Weber, KD1JV, who came in close behind in overall scoring by the judges. His radio will be described in a subsequent article.

In addition to the winners above, entries were received from Dave Cribe, NMØS, and Doug Pongrance, N3ZI. We enjoyed exploring and operating each radio. Each had its strong points and unique features, making selection difficult. Each judge spent many hours operating, comparing and scoring the radios based on their technical proficiency as well as operating features and reports from distant stations.

We thank the judges for contributing their time to this effort. They were W1AW Station Manager Joe Carcia, NJ1Q; ARRL Lab Manager Ed Hare, W1RFI; Contest Branch Manager Sean Kutzko, KX9X; *QEX* Editor Larry Wolfgang, WR1B, and me. All the judges, with the exception of me, had considerable experience operating low power (QRP) radios in contests and other venues. Ed Hare has served as a judge for various QRP equipment contests (ARCI) and noted these entries stood well in comparison to many he has judged previously.

We also thank ARRL Lab Engineer Michael Tracy, KC1SX, for fitting in HBC testing between product review evaluations and his other responsibilities, as well as for helping set up the operational evaluation suite in the newly renovated W1HQ/W1INF Headquarters Operators Club station.

■ VR202 — Sets the ALC. Adjust to reduce CW output to 6 W (3.4 V dc at pin 7 of U105) into 50 Ω.

## Operation

Operating this radio is a breeze; the receiver is not super sensitive but it seems relatively impervious to strong signals. The rule of thumb I use is if the noise level increases when the antenna is plugged in, the receiver is sensitive enough given the current operating environment. With a GAP Triton on the roof of my Baltimore row house the TAK-40 receiver works just fine. Don't scoff at 5 W either. Do a little math. A 5 W transceiver is 13 dB below a 100 W unit, so if you hear a signal from a 100 W transmitter that's 20 or 30 dB above the noise, the other operator should hear you just fine.

My on the air experience is that most operators can't believe that it's only 5 W. I worked 15 states on LSB in about a two week period. Lots of phone operators use more than 100 W, but you can work them as well and they are usually excited about working a QRP station especially homebrew. CW is even easier. Fewer stations run high power and less signal to noise ratio is required. Just listen for a station calling CQ or a QSO ending and give a call. I haven't tried PSK31 yet but I expect good results there as well. Don't expect to sit on a frequency, call CQ and rake in the DX. Practice, patience, good operating skills and lots of listening, however,will be rewarded with plenty of ham radio action.

## Controls

Here is a brief summary of the front panel controls and what they do. The switches are multiplexed with the LCD lines so if you hold down a switch the display won't update. Normal operation resumes when the switch is released. It's also possible that pressing a switch may corrupt an important bit. If the display shows strange looking data, just cycle the power and the LCD will recover.

MAIN TUNING knob — Used to adjust the frequency. It can be programmed for left or right-hand operation by swapping the A and B encoder lines

SELECT — Used in setup mode, also for future expansion (CW keyer, RIT, PBT) and other functions if the software developer ever gets going. Holding the SELECT button down during start-up puts the TAK-40 in bootloader mode ready to accept new firmware.

MODE — Selects LSB, USB or CW. Current setting retained following power off.

RATE — Selects fast or slow tuning speeds. It defaults to slow on power up.

VFO A/B — Selects 7.0 to 7.15 MHz range or 7.15 to 7.3 MHz range.

V to M — Stores the current frequency in memory.

SWAP — Swaps the current and memory frequencies. Holding SWAP during power up places the TAK-40 in setup mode.

## Acknowledgments

All circuitry used in the TAK-40 was designed specifically for use in the TAK-40. I looked at many designs on the Internet and in printed sources but no circuits were taken directly from any specific source. The most valuable tools were manufacturers' data sheets, *The ARRL Handbook* and the Internet.

### Notes

[1]This project was named for three people who put up with years of basement radio development: Theresa, Ashley and Kensi.

[2]**www.arrl.org/files/qst-binaries/**.

*Jim Veatch, WA2EUJ, holds an Amateur Extra class license and has been a ham since 1976. Jim has degrees in electronic technology and electrical engineering. He spent 12 years engineering long range HF and VHF sites for air-to-ground voice communications around the world. He is currently employed by L3 Communications developing RF direction finding systems. Jim is active on HF and 2 meters and is a volunteer in the Baltimore City RACES organization. He can be reached at 1704 Bolton St, Baltimore, MD 21217 or at* **wa2euj@arrl.net**.




**Figure A — Judge Larry Wolfgang, WR1B, operating one of the four Homebrew Challenge Contest radios at W1HQ. Left to right are the radios of KD1JV, WA2EUJ, N3ZI and NMØS.**

# Strays

## US HOUSE RESOLUTION HONORS FIRST RESPONDERS, HAMS

◊ House Resolution 851, passed in December by the 110th Congress, which praised the work of first responders during the severe storms that struck Oregon and Washington in early December, included the following:

Resolved, That the House of Representatives —

(1) honors the citizens of the Pacific Northwest for their courage in facing the storm and efforts in helping their neighbors in a time of great need;

(2) honors the National Weather Service, State and local police officers, fire fighters, local rescue personnel, other first responders, and amateur radio operators for their efforts in the face of the severe storm;

(3) extends its thoughts and prayers to those whose lives have been devastated, and who have lost their housing, transportation, communications, water, heat, or electricity; and

(4) extends its profound and deepest sympathies to the families and friends of those who perished.

H Res 851 was introduced by Rep David Wu (D-OR) and received bipartisan support.

**By Ed Hare, W1RFI**

# The Tuna Tin 2 Today

Ham radio lost its kick? Go QRP with this weekend project! Worked All States with a 40-meter half-watter?
**You betcha!**


The original Tuna Tin 2

In the 1970s, the late Doug DeMaw, W1CER/W1FB, ARRL Technical Editor, was one of several Headquarters staff who published homebrew projects, many with a QRP twist. One of those was a simple, two-transistor 40-meter transmitter that used a tuna can as the chassis. Dubbed the "Tuna Tin 2," it was a popular project, introducing many hams to homebrewing and QRP. A series of events, some quite amazing, have come together to keep the magic alive—the original Tuna Tin 2, built in the ARRL Lab, is still on the air and articles, Web pages and kits are available for this famous rig. Some have dubbed the Tuna Tin 2 revival as "Tuna Tin 2 mania"—an apt term to describe the fun that people are still having with this simple little weekend project.

This article has been edited from the original, written by DeMaw and published in the May 1976 QST. You can download a copy in Adobe PDF format from the ARRL Members-Only Web site at: **http://www.arrl.org/members-only/extra/features/1999/0615/1/tt2.pdf**. Some of the original parts are no longer available, so modern components have been substituted, using values that were featured in a column in QRP with W6TOY on the ARRL Web Extra. I think that Doug would have been pleased to see just how popular that little rig still is, almost a quarter century after he first designed it and built it in the ARRL Lab.— *Ed Hare, W1RFI, ARRL Laboratory Supervisor*

Workshop weekenders, take heart. Not all building projects are complex, time consuming and costly. The TunaTin 2 is meant as a short-term, gotogether-easy assembly for the ham with a yen to tinker. Inspiration for this item came during a food shopping assignment. While staring at all of the metal food containers, recollections of those days when amateurs prided themselves for utilizing cake and bread tins as chassis came to the fore. Lots of good equipment was built on make-do foundations, and it didn't look ugly. But during recent years a trend has developed toward commercial gear with its status appeal, and the workshop activities of many have become the lesser part of amateur radio. While the 1-kW rigs keep the watt-hour meters recording at high speed, the soldering irons grow colder and more corroded.

A tuna fish can for a chassis? Why not? After a few hours of construction, 350 milliwatts of RF were being directed toward the antenna, and QSOs were taking place.

Maybe you've developed a jaded appetite for operating (but not for tuna). The workshop offers a trail to adventure and achievement, and perhaps that's the elixir you've been needing. Well, Merlin the Magician and Charlie the Tuna would probably commend you if they could, for they'd know you were back to the part of amateur radio that once this whole game was about—creativity and learning!

## Parts Rundown

Of course, a tunafish can is not essential as a foundation unit for this QRP rig. Any $6^1/_2$-ounce food container will be okay. For that matter, a sardine can may be used by those who prefer a rectangular format. Anyone for a Sardine-2? Or, how about a "Pineapple Pair?" Most $6^1/_2$-ounce cans measure $3^1/_4$ inches in OD, so that's the mark to shoot for. Be sure to eat, or at least remove the contents before starting your project!

Although the original project used all RadioShack parts, some of the parts are no longer stocked. The 2N2222A transistor is

### Kits and Boards

While the original Tuna Tin 2 can be built from scratch, surprisingly, printed-circuit boards and kits are still available.

The September 16, 1999 *QRP with W6TOY* column in the *ARRLWeb Extra* featured a modern version of the Tuna Tin 2[1]. FAR Circuits can supply the printed circuit for W6TOY's version (not built on a tuna tin) as well as the original design PC board.[2]

Those who want to buy everything all in one place can buy a complete kit, including PC board from the NJ-QRP Club[3]. Send a check for $12 postpaid to George Heron, N2APB, New Jersey QRP Club, 2419 Feather Mae Ct, Forest Hill, MD 21050. Doug Hendricks, KI6DS also designed a version of the Tuna Tin 2, for the Northern California QRP Club (NorCal)[4].

JOE BOTTIGLIERI, AA1GW

**W6TOY's version of the Tuna Tin 2 design—without the tuna can.**

[1]See: **http://www.arrl.org/members-only/extra/features/1999/09/16/1/**.

[2] FAR Circuits, 18N640 Field Ct, Dundee, IL 60118-9269, tel 847-836-9148; **http://www.cl.ais.net/farcir/**

[3]NJ-QRP Club, contact: George Heron, N2APB, 2419 Feather Mae Ct, Forest Hill, MD 21050; **n2apb@amsat.org**; **http://www.njqrp.org/**. NJ-QRP has a section of their Web site devoted to the Tuna Tin 2 revival. See **http://www.njqrp.org/tuna/tuna.html**.

[4]Northern California-QRP Club (NorCal), 3241 Eastwood Rd, Sacramento, CA 95821; tel 916-487-3580; **jparker@fix.net**; **http://www.fix.net/NorCal.html**. Like the NJ-QRP Club, NorCal also has a Tuna Tin 2 revival page at: **http://www.fix.net/~jparker/norcal/tunatin2/tunatin.htm**.

widely available. The original coils have been replaced with inductors wound on toroidal cores. Printed circuit boards are available from several sources and the NJ QRP Club is offering a complete kit of parts. (See the sidebar "Kits and Boards".)

The tiny send-receive toggle switch is a mite expensive. The builder may want to substitute a low-cost miniature slide switch in its place. A small bag of phono jacks was purchased also, as those connectors are entirely adequate for low-power RF work.

Finding a crystal socket may be a minor problem, although many of the companies that sell crystals can also supply sockets (you can locate a number of crystal manufacturers and distributors on the ARRL TISFIND database at **http://www.arrl.org/tis/tisfind.html**). Fundamental crystals are used in the transmitter, cut for a 30-pF load capacitance. Surplus FT-243 crystals will work fine, too, provided the appropriate socket is used. If only one operating frequency will be used, the crystal can be soldered to the circuit board permanently. Estimated maximum cost for this project, exclusive of the crystal, power supply and tunafish, is under $20. The cost estimate is based on brand new components throughout, inclusive of the

### The Tuna Tin 2 on the Road

Those who've read our on-line publication, the *ARRLWeb Extra*, probably saw the article that appeared in the June 15th edition titled "The Tuna Tin 2 Revival." This article told an incredible tale of how the original Tuna Tin 2 was lost from the ARRL Lab and was found years later in a box of junk under a fleamarket table in Boxboro, Massachusetts. The Tuna Tin 2 was refurbished by Bruce Muscolino, W6TOY, and put back on the air by me on June 4, 1999. Since that time, over 400 hams have had the pleasure of working the original Tuna Tin 2, some using their own Tuna Tin 2 rigs built in the 70s (or built anew from the available kits).

#### California Dreamin'

After making about a hundred contacts from home, I was asked to attend an IEEE meeting in Long Beach, California. My sister, Bev, lives in the area, so I planned a week-long visit. I tossed the Tuna Tin 2 and a G5RV into my suitcase, hoping to give a few West Coast hams a chance to make a contact with the original.

After all the hugs and kisses, I explained to my sister what I was up to. She grinned, remembering the wild days of my youth, climbing trees to string wires all over our property, back when I was WN1CYF. As I looked over the site, though, I was not too hopeful; about the best I thought I could do would be to try a random wire around the balcony, maybe risking a run over to a small tree or two. I looked roofward and sighed, "Gee, it would be nice to get an antenna up on the roof." She made a quick call to Debbie, the building manager and close friend, who winced painfully and said, "Don't fall off!" and, in a classic Schultz accent, "I know nothing!"

We took the G5RV up to the emergency roof access, walked boldly out, and I proceeded to string the antenna up while Bev stood guard. I got the antenna up, dropped the feedline past the upstairs apartment balcony and hoped for the best.

Sure enough, the "antenna police" were on alert—the tenant right below us heard the noise and wondered what was going on. Just as we got back to the apartment, the phone rang; it was Debbie. She told us of the complaint, told us the excuse she gave and wished us luck.

With Bev watching with great interest, I hooked up the Heath HW-8 I used as a receiver, hooked up the Tuna Tin 2, the code key and antenna tuner, and gave the band a fast listen. Signals were booming in. On June 19, I worked my first contact with the Tuna Tin 2 from the West Coast, W6PRL/QRP. Every evening, after a day of offshore fishing, Bev and I expected to find that the antenna police had confiscated the wire, but somehow, it stayed up the whole week. By the end of the week, 45 new stations were in the Tuna Tin 2 log!

#### Among the Monsoons and ScQRPions

I was then asked if I would be willing to attend the ARRL Arizona State Convention at Ft Tuthill. That is an annual pilgrimage for many a QRPer; how lucky could I get? I agreed, but warned the ARRL Division Director that I might spend a bit more time away from the ARRL booth than usual. In the meantime, I casually asked Joe Carcia, NJ1Q, the W1AW station manager, if he could arrange for W1AW/7/QRP to be used at the convention. After some consultation with Dave Sumner, a new QRP "first" was in the works. In the meantime, the Arizona ScQRPions[1], an Arizona QRP club, asked me if I would give a presentation at the QRP forum they sponsor at Ft Tuthill every year. I agreed, but with one condition—they had to be willing to host W1AW/7/QRP at their booth. I would have loved to be a fly on the wall as that e-mail was read!

A *great* time was had by all, but W1AW/7/QRP did not go off without a hitch. An operator error (mine) damaged the receiver (the binaural receiver, designed by Rick Campbell). The local QRPers came through, though, and several receivers were made available to the operation to finish the day. Even worse, later in the day, it looked like all was lost! During a quick test of the Tuna Tin 2, one of the resistors emitted a puff of smoke, and the power went to 0 W. I had just blown up the original Tuna Tin 2!

I did a quick troubleshooting job and identified that the output transistor had short-circuited. Special thanks go to Niel Skousen, WA7SSA, who dug into his portable junkbox. (Niel is a real ham's ham! How many hams do you know who bring their junkbox to a hamfest?) He quickly located a 2N2222A. I handed him the Tuna Tin 2 and asked him if he would mind installing it. After that W1AW/7/QRP was back on the air.

After the convention, using a borrowed receiver, I took the Tuna Tin 2 on a whirlwind tour of Arizona, although I only got to operate two

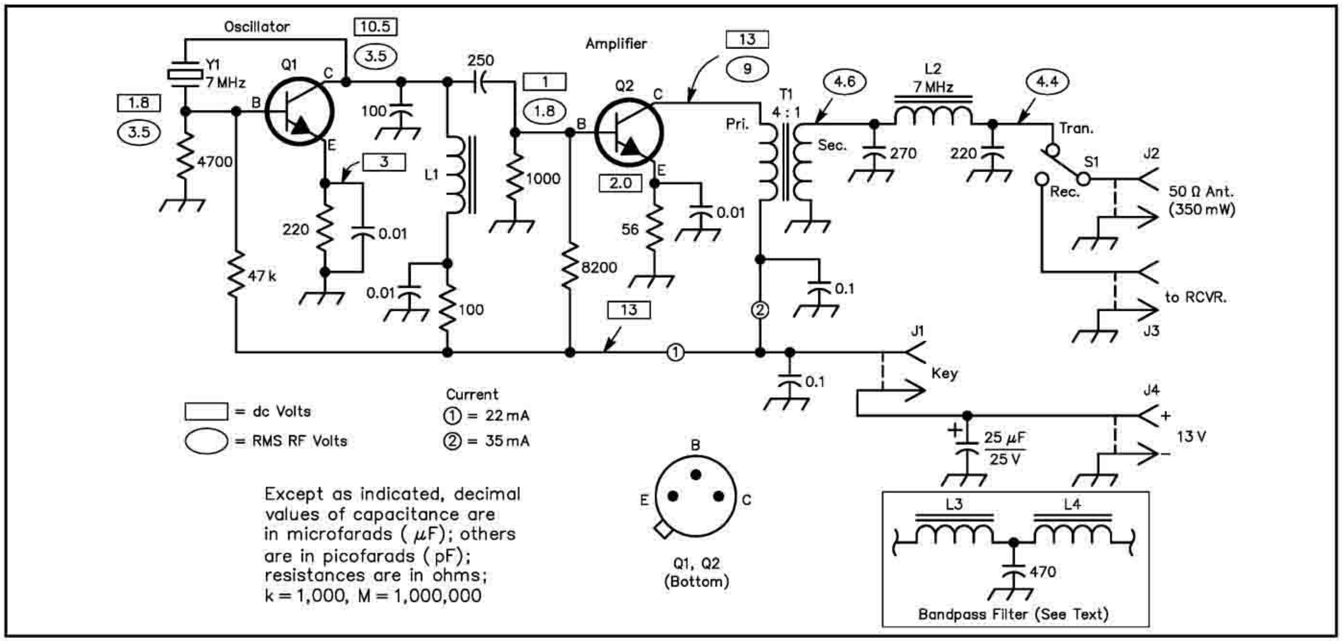



**Figure 1—Schematic of the Tuna Tin 2 QRP rig. Note that the polarized capacitor shown in the schematic is an electrolytic.**

**J1—Single-hole-mount phono jack. Must be insulated from ground. Mounts on printed circuit board.**
**J2, J3, J4—Single-hole-mount phono jack. Mount on tuna tin chassis.**
**L1—22 μH molded inductor**
**L2—19 turns of #26 wire on a T-37-2 toroidal core**
**L3, L4—21 turns of #24 wire on a T-37-6 toroidal core**
**Q1, Q2—2N2222A or equivalent NPN transistor.**
**S1—Antenna changeover switch. Miniature SPDT toggle (see text).**
**T1—4:1 broadband transformer. 16 turns of #26 wire on the primary, 8 turns of #26 wire on the secondary, on an FT-37-43 toroidal core.**
**Y1—Fundamental crystal, 7 MHz.**

nights from a campsite in Williams. I had brought along my DK9SQ[2] 33-foot portable fiberglass mast, so my antenna went up and down quickly. (Let me tell you, this is one great product. I literally put up my 40 meter inverted **V** in 5 minutes, 33 feet in the air. Taking it down was even faster.) It was monsoon season in Arizona and it rained each night. Despite the downpours, I doggedly squeezed in operating time in between thunderstorms, and added a few new ones to the log.

### Hanging Out in the Park

Just two weeks later, I was off to Golden, Colorado for the Colorado State Convention (during which I got to show off the Tuna Tin 2 to the Colorado QRP Club[3]) and the trusty Tuna Tin 2 and portable mast came along with me. I scoped out the hotel area—no good. The noise level from the high-tension lines was just too high. The convention was held in a small park, so after the confab ended I walked a mile back to the hotel, loaded up the Tuna Tin 2, batteries, key, antenna and mast, and trekked back to the park. Fifteen minutes later, the antenna was standing proud and tall, and I made my first CQ. A security guard stopped by, and fearing the worst, I explained what I was doing. "Okay," she said, and drove away. A few minutes later I had a nice surprise—Rod Cerkoney, N0RC, showed up to operate with me!

The Tuna Tin 2 came back home, and I got it ready for the QRP Extravaganza Weekend (my name for it) on Halloween, with the QRP-ARCI/ARRL "Black Cat" party and the NorCal Zombie Shuffle operating event. You can read that tale in Rich Arland's "QRP Power" column in this issue.

### Are We Having Fun Yet?

Did I have fun? Do you need to ask? I guess I was just in the right place at the right time, and have been privileged to be the center of all this Tuna Tin 2 activity. What is important to me, though, is that the magic that DeMaw created in the ARRL Lab still lives. It has, in fact, it has taken on a life of its own.

The Tuna Tin 2 will be on the air on 40 meters a lot over the rest of the winter, spring and summer. You'll hear it from W1RFI, from W1AW, and possibly some other station locations. I do have one more "special event" in the works, but I am sworn to secrecy. The Tuna Tin 2 will play a part in it. I won't tell you what call it will use, but I will say that you will know it when you hear it. And when you do, you will know that the magic is still alive.

I hope that lots of hams build some of the various Tuna Tin 2 replicas, and that they get a chance to work the original. I will do my best to keep it on the air. I am sure that Doug DeMaw would approve.—*W1RFI*

[1]See the Arizona ScQRPions site on the Web at: **http://www.extremezone.com/~ki7mn/sqrppage.htm.**
[2]The DK9SQ mast is available for $99 plus $5 shipping and handling from Kanga US, 3521 Spring Lake Dr, Findlay, OH 45840; tel 419-423-4604; **kanga@bright.net**; **http://www.bright.net/~kanga/kanga/.**
[3]Colorado QRP Club, PO Box 371883, Denver CO 80237-1883; **rschneid@ix.netcom.com**; **http://www.cqc.org/.**

**Ed Hare, W1RFI, operating the TT2 from his sister's apartment in Los Angeles.**

### TT2 Performance

Keying quality with this rig was good with several kinds of crystals tried. There was no sign of chirp. Without shaping, the keying is fairly hard (good for weak-signal work), but there were no objectionable clicks heard in the station receiver. There is a temptation among some QRP experimenters to settle for a one-transistor oscillator type of rig. For academic purposes, that kind of circuit is great. But, for on-the-air use, it's better to have at least two transistors. This isolates the oscillator from the antenna, thereby reducing harmonic radiation. Furthermore, the efficiency of oscillators is considerably lower than that of an amplifier. Many of the "yoopy" QRP CW signals on our bands are products of one-transistor crystal oscillators. Signal quality should be good, regardless of the power level used.

The voltages shown in Figure 1 will be helpful in troubleshooting this rig. All dc measurements were made with a VTVM. The RF voltages were measured with an RF probe and a VTVM, The values may vary somewhat, depending on the exact characteristics of the transistors chosen. The points marked 1 and 2 (in circles) can be opened to permit insertion of a dc milliammeter. This will be useful in determining the dc input power level for each stage. Power output can be checked by means of an RF probe from J2 to ground. Measurements should be made with a 51- or 56-Ω resistor as a dummy load. For 350 mW of output, there should be 4.4 $V_{rms}$ across the 56-Ω resistor.

Operating voltage for the transmitter can be obtained from nine Penlite cells connected in series (13.5 volts). For greater power reserve one can use size C or D cells wired in series. A small ac-operated 12- or 13-V regulated dc supply is suitable also, especially for home-station work.—*W1FB*

[Although this rig met all the Part 97 surious emission requirements when built in 1976, additional filtering is needed to meet today's rules. A bandpass filter for 40 meters is shown as an inset in Figure 1. It can be installed between S1 and the antenna jack.—*W1RFI*]

left-over parts from the assortments. Depending on how shrewd he is at the bargaining game, a flea-market denizen can probably put this unit together for a few bucks.

### Circuit Details

A look at Figure 1 will indicate that there's nobody at home, so to speak, in the two-stage circuit. A Pierce type of crystal oscillator is used at Q1. Its output tickles the base of Q2 (lightly) with a few mW of drive power, causing Q2 to develop approximately 450 mW of dc input power as it is driven into the Class C mode. Power output was measured as 350 mW ($^1/_3$ W), indicating an amplifier efficiency of 70%.

The collector circuit of Q1 is not tuned to resonance at 40 meters. L1 acts as an RF choke, and the 100-pF capacitor from the collector to ground is for feedback purposes only. Resonance is actually just below the 80-meter band. The choke value is not critical and could be as high in inductance as 1 mH, although the lower values will aid stability.

The collector impedance of Q2 is approximately 250 Ω at the power level specified. Therefore, T1 is used to step the value down to around 60 Ω (4:1 transformation) so that the pi network will contain practical values of L and C. The pi network is designed for low Q (loaded Q of 1) to assure ample bandwidth on 40 meters. This will eliminate the need for tuning controls. Since a pi network is a low-pass filter, harmonic energy is low at the transmitter output. The pi network is designed to transform 60 to 50 Ω.

L1 is a 22-μH molded inductor. L2 is made with 19 turns of #26 wire on a T-37-2 core. Final adjustment of this coil (L2) is done with the transmitter operating into a 50-Ω load. The coil turns are moved closer together or farther apart until maximum output is noted. The wire is then cemented in place by means of hobby glue or Q dope

T1 is made with 16 turns of #26 wire on the primary, 8 turns of #26 wire on the secondary, on an FT-37-43 ferrite core. This is good material for making broadband transformers, as very few wire turns are required for a specified amount of inductance, and the Q of the winding will be low (desirable).

Increased power can be had by making the emitter resistor of Q2 smaller in value. However, the collector current will rise if the resistor is decreased in value, and the transistor just might "go out for lunch," permanently, if too much collector current is allowed to flow. The current can be increased to 50 mA without need to worry, and this will elevate the power output to roughly 400 mW.

### Construction Notes

The PC board can be cut to circular form by means of a nibbling tool or coping saw. It should be made so it just clears the inner diameter of the lip that crowns the container. The can is prepared by cutting the closed end so that $^1/_8$ inch of metal remains all the way around the rim. This will provide a shelf for the circuit board to rest on. After checkout is completed, the board can be soldered to the shelf at four points to hold it in place. The opposite end of the can is open.

### Summary Comments

Skeptics may chortle with scorn and amusement at the pioneer outlook of QRP enthusiasts. Their lack of familiarity with low-power operating may be the basis for their disdain. Those who have worked at micropower levels know that Worked All States is possible on 40 meters with less than a watt of RF energy. From the writer's location in Connecticut, all call areas of the USA have been worked at the $^1/_4$-W power plateau. It was done with only a 40-meter coax-fed dipole, sloping to ground at approximately 45° from a steel tower. Signal reports ranged from RST 449 to RST 589, depending on conditions. Of course, there were many RST 599 reports too, but they were the exception rather than the rule. The first QSO with this rig came when Al, K4DAS, of Miami answered the writer's "CQ" at 2320 UTC on 7014 kHz. An RST 569 was received, and a 20-minute ragchew ensued. The copy at K4DAS was "solid."

If you've never tried QRP before, the first step is easy. Just contact the QRP Amateur Radio Club International (QRP-ARCI), 848 Valbrook Court, Lilburn, GA 30047-4280; **http://www.qrparci.org/.**

### Fishy Excitement at the Meriden ARC

Renewed interest in the Tuna Tin 2 transceiver prompted the Meriden (Connecticut) Amateur Radio Club to build these classics as a club project. Bob Stephens, KB1CIW and Jamie Toole, N1RU secured components for 20 kits. Tim Mik, WY1U, supplied 20 cat food cans, cleaned and stripped of labels. (We had to assume that each can had, in fact, contained tuna flavor cat food. We didn't want to stray too far from the original design!) Tim also brought along his original Tuna Tin 2, which he had built as a newly licensed teenager over 20 years ago.

Several of the more experienced members were quite helpful in assisting those less knowledgeable in the arcane arts of schematic reading and toroid winding. Counting the number of turns, especially on the transformer, is not quite the simple task that it seems at first. Other tips on soldering and building in general were freely passed on from the veterans.

Honors for the first contact went to MARC president Bill Wawrzeniak, W1KKF. After finishing his rig, he brought it home, connected an antenna and almost immediately made contact with a California ham. With his new Tuna Tin 2, WY1U worked Ed Hare, W1RFI, operating the W1AW special event at ARRL HQ on Halloween. Most of the other kits were completed and put on the air over the next several weeks.

Building the Tuna Tin 2 is a terrific activity for any club. It can be completed in one or two evenings. The circuit is simple enough to provide an excellent springboard for education in electronic and RF theory without getting bogged down in too many esoteric topics. Building the kit is a great way to learn or sharpen construction skills. And, of course, there's no substitute for the pride and satisfaction of telling the station at the other end of the QSO, "RIG HR IS HMBRW TT2".—*John Bee, N1GNV,* QST *Advertising Manager*

CATS BY GIL, W1CJD

VHF and UHF CW Beacons

By Michael Sapp, WA3TTS


144.300MHz Beacon

A Yaesu FT-290R to a 20W 2M FM Radio Shack amplifier which is operated at approximately 7W output. A Cooling fan is required for the duty service of beacon operation.  The 2M amplifier was modified to transmit-only operation by providing a low voltage +DC level to the detector diode of the carrier-operated antenna relay circuit.   The FT-290R is keyed with an XT4-B Beacon Keyer in the small black box on the left.

432.322MHz Beacon

A Microwave Modules MMT432/28 transverter which is operated at 4W output. A Signetics 531P 28.322 crystal oscillator IC and low pass filter are located in the small Bud box on top of the MMT432/28 transverter. The 28.322MHz oscillator is powered from a +5V regulator mounted on top of the Bud box.

The 28.322MHz RF energy is keyed with a Daico SPDT RF PIN switch to generate the CW message from the XT-4-B Beacon Keyer. The output of the RF PIN switch is directed to the IF transmit input port of the MMT432/28 to generate the 4 Watt 432.322MHz signal.

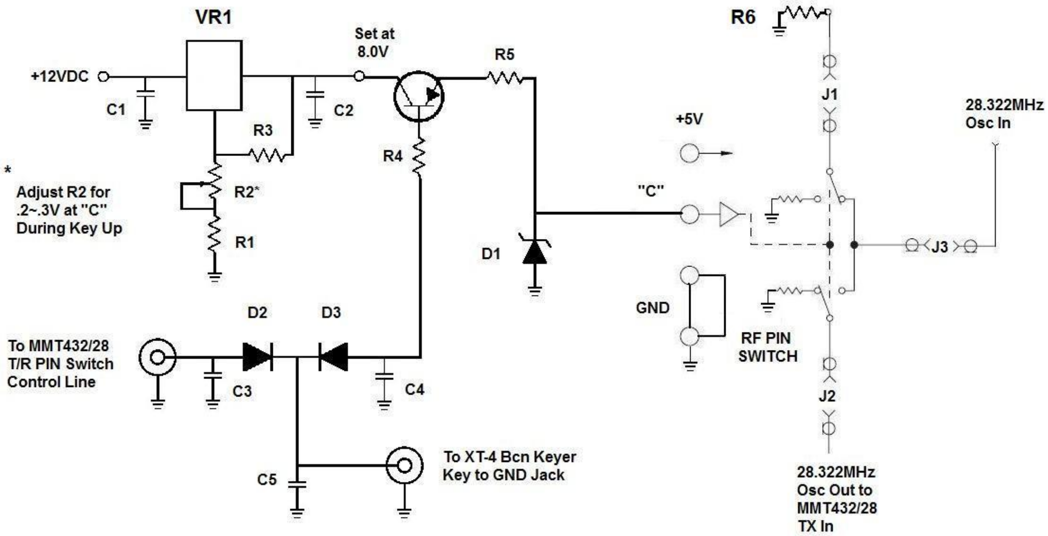
The T/R PIN switch in the MMT432/28 is keyed in tandem with the 28.322MHz oscillator via the XT4-B Beacon Keyer.

Blocking diodes on the small perf-board visible on top of the MMT432/28 transverter isolate the +5V Daico PIN switch control voltage from the +12V control voltage on the MMT432/28 PIN switch line. The XT4-B beacon keyer grounds both control lines simultaneously for CW beacon operation.

The regulator circuit on the right side top of the MMT432/28 provides an optimized voltage setting for the TTL level operation of the Daico PIN switch---5 volts "high" and ".2 to .3 volts "low."  The 10W MMT432/28 transverter runs cool at 4W output using it's internal PIN switching feature.

Proper thermal management is an essential aspect of successful, long-term, beacon transmitter operation.  In general, it is advisable to operate conventional amateur equipment at 33 to 40 percent of the rated intermittent service power level.  Additional cooling fans or other measures may be required to prevent thermal-related equipment failures.

MMT432/28 Keying Control Detail & Parts List




Parts List

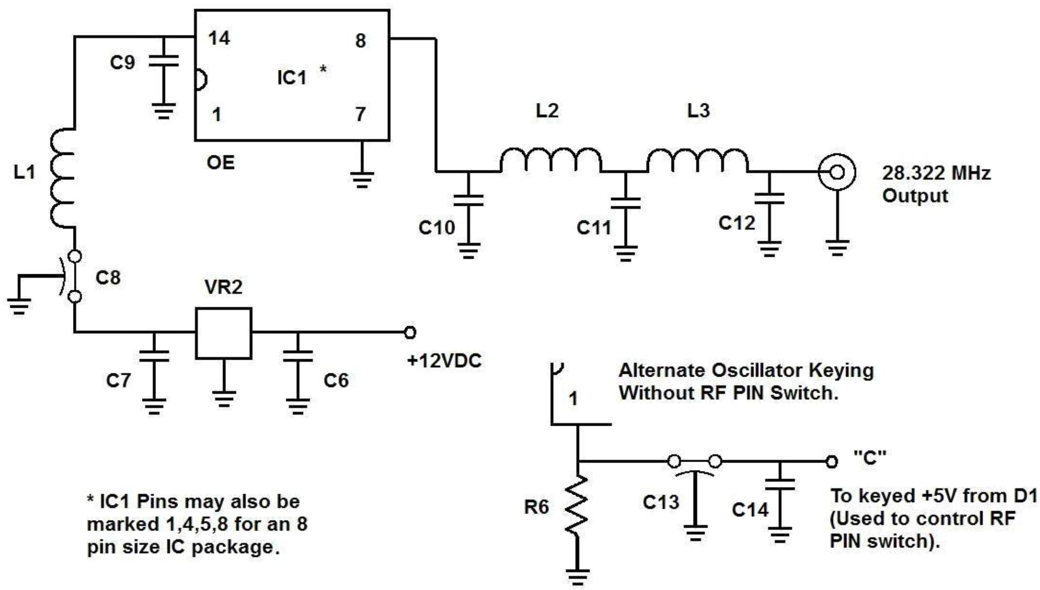
| | | | |
|---|---|---|---|
| C1,C3,C4,C5 | 0.1uf 50V polyester film. | R1 | 680 ohm 1/2W. |
| C2 | 1uf 35V tantalum. | R2 | 1K ohm 15T 3/4W Cermet potentiometer |
| D1 | 5.1V 1/2W Zener diode. | | |
| D2, D3 | 1N4001. | R3 | 220 Ohm 1/2W. |
| Q1 | 2N3906. | R4 | 4.7K Ohm 1/2W. |
| R5 | 390 ohms 1/2W. | R6 | 50 Ohm SMA termination. |
| VR1 | LM317. | | |

RF PIN Daico 0622 or Mini-Circuits ZSDR-230, SPDT and TTL control type RF PIN Switch.

Data Sheet & Reference

pdf1.alldatasheet.com/datasheet-pdf/view/140517/DAICO/CDS0622.html
www.fairchildsemi.com/datasheets/LM/LM317.pdf

## 28.322 MHz IF Oscillator Detail & Parts List




Parts List

| | | | |
|---|---|---|---|
| C6, C9 | 0.1uf 50V polyester film. | C8, C13 | 0.001uf ceramic feedthrough |
| C7 | 1uf 10V tantalum. | | |
| C10, C12 | 220pf 50V silver mica. | C11 | 330pf 50V silver mica. |
| C14 | 100uf 35V electrolytic. | | |
| R6 | 1K ohm 1/4W. | L1 | 100uH 1/2W molded inductor. |

L2, L3 .290uh 6T #24 enamel wire, close wound on .25" drill bit shaft, with 1/2"leads. Scrape enamel from 1/2" of the wire leads nearest to coil on the drill bit shaft. Bend leads at right angle to coil and cut leads. Remove coil from drill bit shaft. Lightly pull or compress the coil's 1/2 inch long leads until the 6 coil turns are slightly separated and .230" long. Check and adjust coil value on antenna analyzer at 28.3 MHz in Inductance measuring mode. Trim coil leads as required after soldering into circuit. Check and readjust coil length.

| | |
|---|---|
| VR2 | LM7805 5 volt regulator. |
| IC1 | Epson SG-531PT 28.322MHz oscillator IC. |

Data Sheet & Reference

pdf.datasheetcatalog.com/datasheet/epson/SG-531P.pdf
www.fairchildsemi.com/datasheets/LM/LM7805.pdf

Beacon Antennas

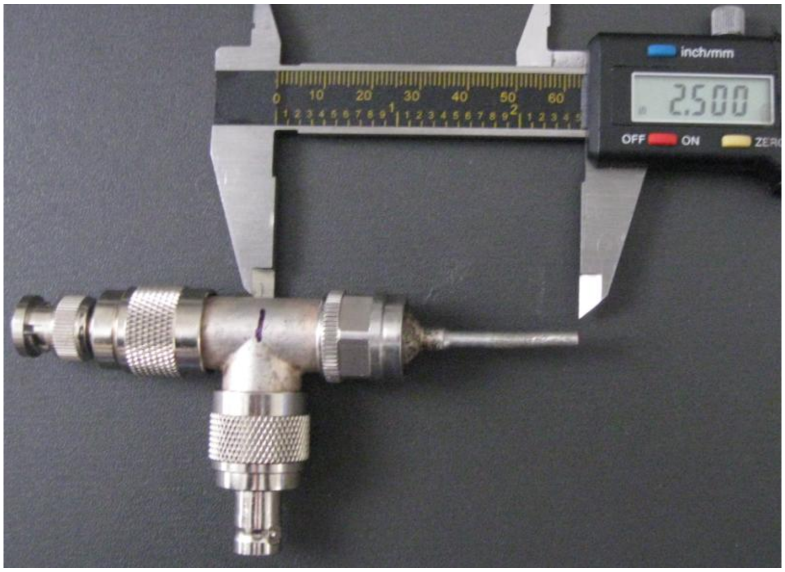
A pair of 144 MHz PAR Loop antennas and a 4-stack of Ben Lowe's "432 MHz Lowe's Loops"[1] are used on 432 MHz. These antennas are mounted on two heavy-duty 10 foot long Radio Shack masts, guyed at the 15 foot mast level and are roof-mounted. A 50 MHz PAR Loop is also present. A Diamond MX2000 Triplexer allows a single run of CNT-400 feed line from the antennas to the beacon transmitters.

A second Diamond MX2000 Triplexer allows the output from multiple beacons to be combined on the other end of the CNT-400 feed line. The series configuration of two triplexers on the coaxial line also provides substantial additional harmonic filtering at 100 MHz and 288 MHz (up to 60dB). However, at 432MHz, the triplexers act as high-pass filters and can freely pass 864 MHz energy. For this reason, a simple 1/4 wave open coaxial stub is used at 864 MHz

[1] July 2006 QST, p28.

on the output of the MMT432/28 transverter to provide an additional 40 dB of 2nd harmonic filtering.  It was observed that the output power of the MMT432/28 MHz transverter rose slightly at 432 MHz with the addition of the 864MHz stub filter.

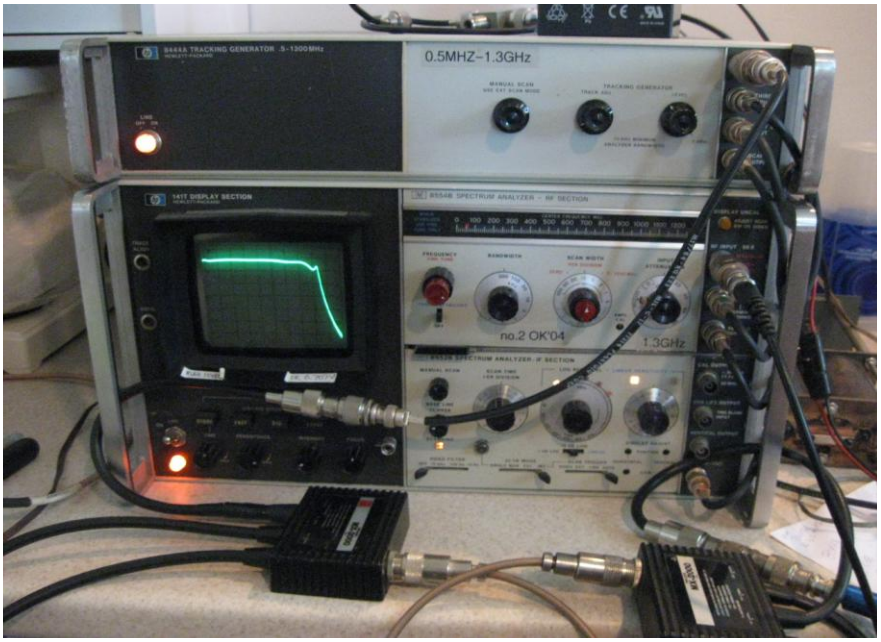
864 MHz 1/4 Wave Stub Filter Detail



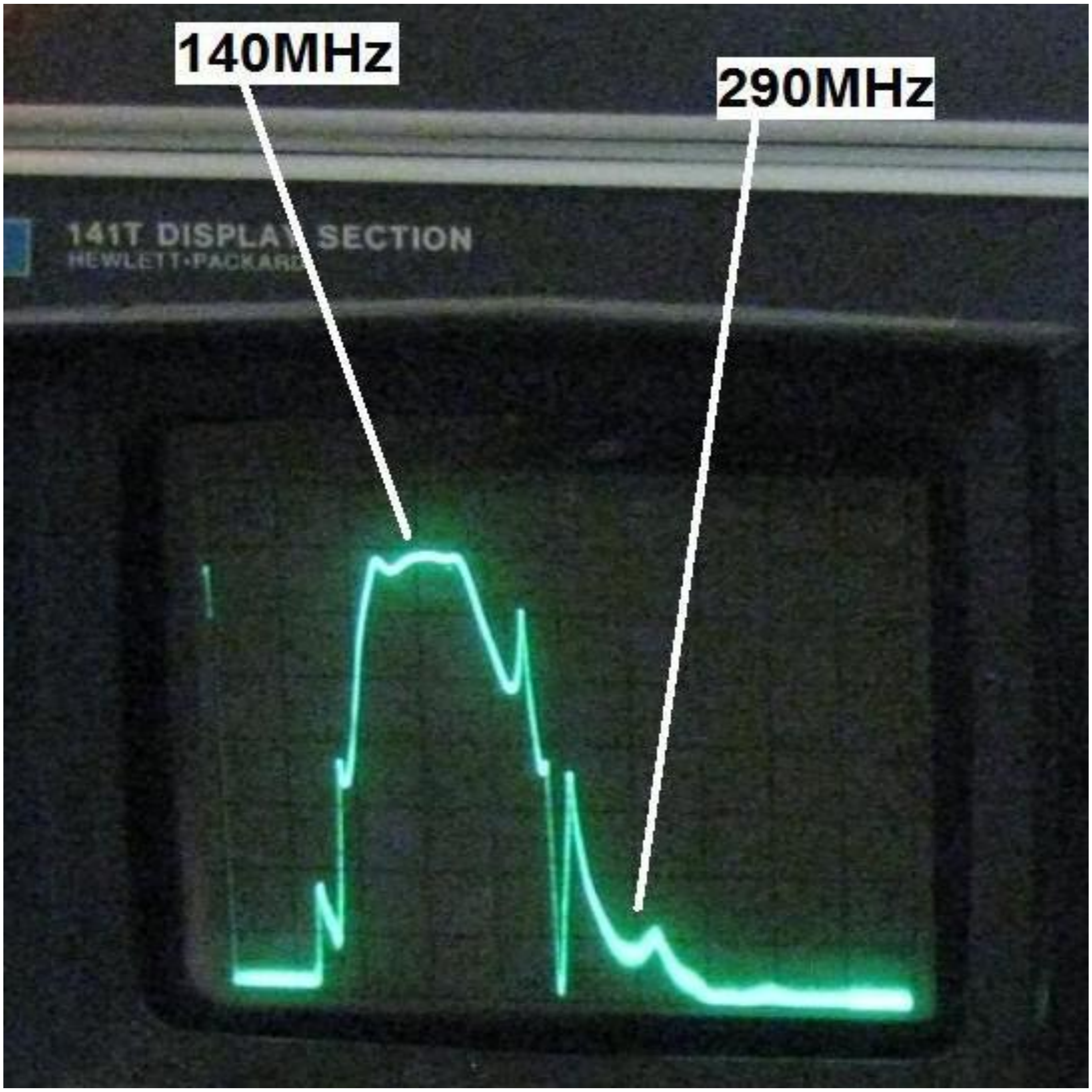

This 864 MHz harmonic filter consists of a Type N 50 ohm female T adapter and a short length of RG-141 rigid cable with a male N connector. BNC adapters complete the RF connection to the transverter and the RF watt meter used for output monitoring to the antenna.

The combined length from the exact center of the T adapter to the open end of the RG-141 cable is 2.500 inches for this coaxial stub tuned to 864MHz. This 2.5 inch length is just slightly longer than the calculated electrical length. (Note: a quarter wave at 432MHz = 6.83 inches. Divide 6.83 inches by 2 and apply the 70 percent velocity factor for RG141 cable = 2.39 inches at 864 MHz).


864 MHz  1/4 Wave Coaxial Notch Filter Performance.
10dB per Division Vertical, 50 MHz per Division Horizontal.




Back-to-Back Diplexer Configuration Showing 60dB Notch at 100MHz.
View Centered on 50MHz, 10MHz per Division Horizontal and 10dB per Division Vertical.




Back-to-Back Diamond MX-2000 Triplexer Performance on the 144MHz Ports.
View Centered on 240MHz and 50MHz per Horizontal Division and 10dB per Vertical Division.

# VHF Open Sources

## Design of Low Power High-Stability Low Phase Noise Single Frequency VHF Sources with High Spectral Purity

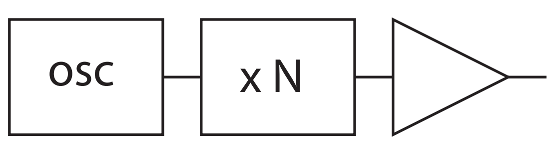
Rick Campbell November 2008

This paper describes in exhaustive detail the design, measurement and testing of a family of high stability low phase noise VHF signal sources with high spectral purity. The three examples are for 50 MHz, 144 MHz, and 222 MHz, but enough information is presented that a designer can modify the component values to achieve similar performance on any frequency through the VHF range from 30 to 300 MHz.

There may be nothing new in these designs, but the optimized circuits, their detailed behavior and the component by component design considerations are not in the current textbooks. These details have been recovered from lore freely shared among retired radio designers and rediscovered by the author through hours of experimentation and analysis.

The sources described here are not the only approach: phase locked loops and direct digital synthesizers are more modern, and therefore have appeared more frequently in recent literature. The sources presented here were designed and built because they are useful, and offer advantages for applications that don't require extensive frequency agility. They have exceptional frequency stability and close-in phase noise, modest power requirements, and the ability to be built in any quantity (including one) using commonly available components. The name "VHF Open Source" refers to the free disemination of all design, construction and measurement details, to facilitate understanding, duplication, redesign, and part substitution. The only request is acknowledgement of this document when ideas, schemetics, photos or circuit board artwork are directly lifted from these pages.

**Block Diagram** The block diagram of the VHF open source is nearly 100 years old. The diagram includes an oscillator followed by a frequency multiplier. An amplifier often follows the frequency multiplier, as shown in the figure below.



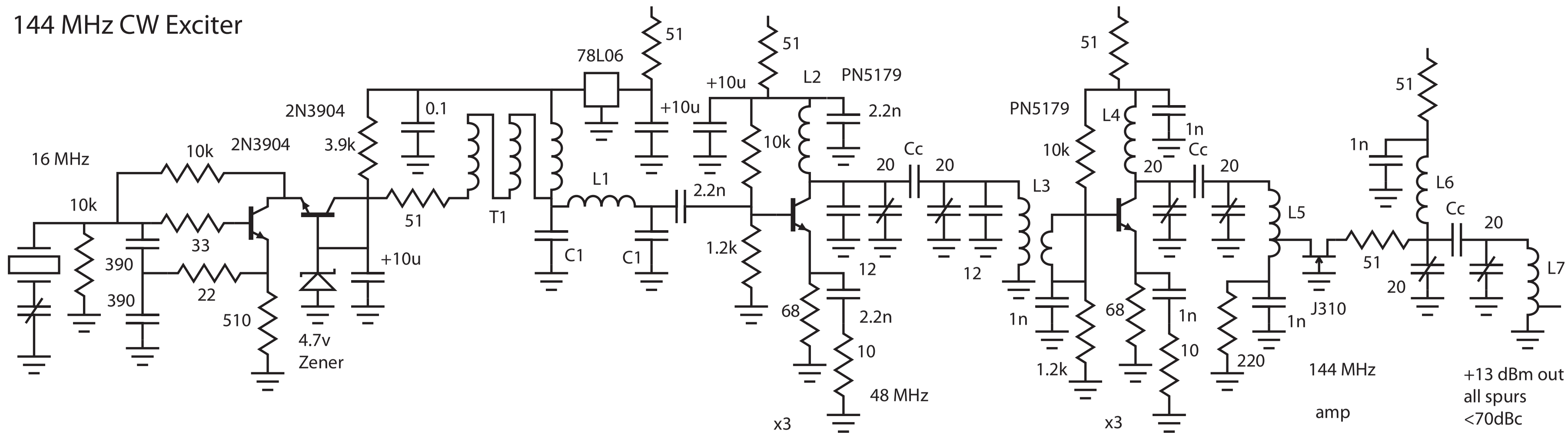

Many texts state that the frequency multiplier is needed because the oscillator frequency is limited. As best this is an oversimplification. A more important function of the frequency multiplier is to isolate the oscillator from the outside world. Frequency doublers are particularly useful, as 2nd harmonic leakage into an oscillator will not modify the phase within the loop, with an attendant frequency shift. Frequency sources with only a DC input and an RF output on a frequency other than the basic oscillator are well behaved.

Complete 20 milliwatt 144 MHz CW Source

Rick Campbell KK7B November 2008

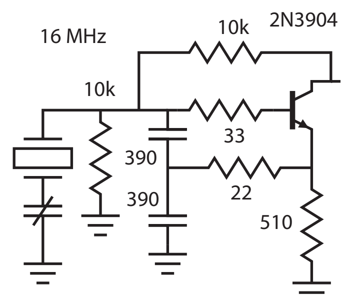
Spectral purity of output depends on electromagnetic shielding and isolation between stages not shown in the schematic

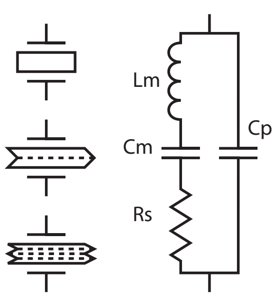
## 144 MHz CW Exciter



**Oscillator** The basic oscillator circuit is a familiar Colpitts circuit, with a tapped capacitor serving as an autotransformer between the emitter and base of a common collector amplifier circuit. The common-collector amplifer has a gain of less than 1, so the circuit will not oscillate without the voltage gain provided by the high-Q quartz resonator and tapped capacitor. When directly connected to the buffer amplifier circuit on the next page, the reflection coefficient at the juntion of the two 10 k resistors where the crystal connection is just slightly greater than 1 across most of the high frequency range from 3 to 30 MHz. To isolate the oscillator from variations in transistor performance over process and temperature, the transistor is embedded in a network of series and parallel resistors. The 2N3904 is a quiet general purpose NPN transistor with low noise at audio and an Ft above 300 MHz. 390pF capacitors work from 6 MHz through 18 MHz with active crystals. 220pF may be a better choice above 10 MHz, and 150pF above 16 MHz.

With gain just sufficient to maintain oscillation, multiple levels of voltage stabilization on the operating conditions of the active device, isolation between the oscillator and external circuitry, and resistors swamping out the semiconductor parasitics, the operating frequency is determined by the quartz crystal network. The primary source of drift is the temperature variations of the crystal, and a secondary source of drift is the thermal stability of the variable capacitor in series with the quartz crystal.



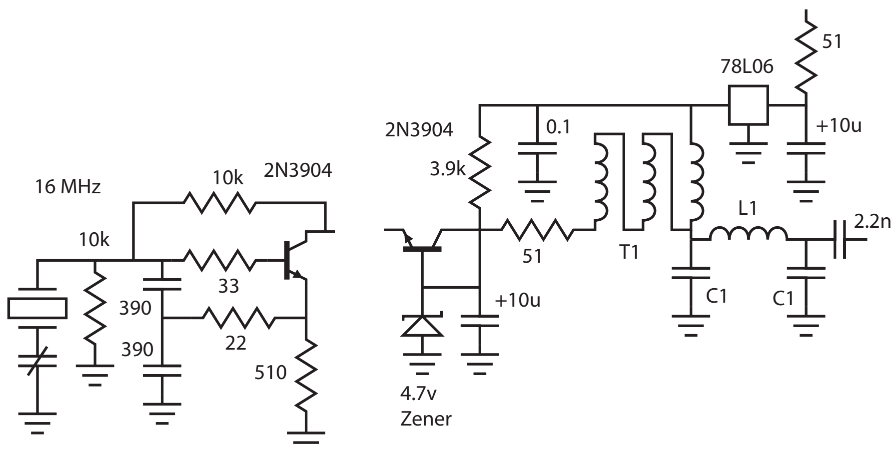

The schematic symbol of a quartz crystal is shown on the upper left. The drawings below the schematic symbol illustrate the shear vibrational modes of the piezoelectric slab of quartz. The upper drawins shows a fundamental mode, and the lower drawing illustrates a third order mode of the same piece of quartz. Note that the thickness determines the resonant frequency. The schematic model to the right has a motional inductance Lm, motional capacitance Cm, and series resistance Rs that model the mechanical-piezoelectric behavior of the quartz blank, and a parallel capacitance Cp that represents the actual capacitance between the metal plating on the surfaces of the crystal.

A custom crystal with selected temperature curve and an air or glass dielectric piston trimmer capacitor will provide remarkable frequency stability, typically 1 part in $10^8$ in the author's examples. For crystals designed to be operated at room temperature, a foam packing bead slipped over the crystal will significantly reduce short-term drift by increasing the thermal time constant of the crystal package. For low battery drain operation in harsh thermal environments such as winter mountaineering, the crystal oscillator has been packaged in a separate small enclosure worn inside clothing. The operator may then carry an extra candy bar to help maintain a constant crystal temperature instead of a lead acid battery to run a crystal oven. The crystal frequency may be tweaked over a narrow range--10 kHz or less--at the fundamental by adjusting the series capacitance between about 2pF and 50pF.

The basic Colpitts oscillator circuit is designed to operate with the buffer circuit shown below.

This circuit may be analyzed using Linear Technology Switcher Cad III or other Spice simulator to select values for the capacitors. Remove the crystal and drive the network at the junction of the 10k resistors using a reflection coefficient simulator. An example file is at the link on the Portland State University RF Design Web Page.

**Oscillator - Buffer** The Colpitts oscillator-common base buffer circuit below has been widely published and duplicated in various forms since the late 1970s. The earliest example in the author's references is a 1979 Ham Radio article by Joe Reisert describing a high performance battery powered frequency standard for amateur microwave weak-signal communication.




Several subtle and important circuit and physics details contribute to the performance of this circuit. Examining the DC operation first, note that the 6 volt regulator sets up a current through the 4.7 zolt zener diode determined by the 3.9k resistor. That sets the base voltage on the common base buffer stage at approximately 4.7 volts, and an emitter voltage of about 4.0 volts. The voltage divider from the emitter of Q2 consisting of a pair of 10k resistors sets the base voltage on the oscillator transistor at about 2.0 volts, and an emitter voltage of about 1.3 volts. the 1.3 volt drop across the 510 ohm emitter resistor sets a current through the transistor pair of about 2.6 mA. When the circuit oscillates, the current increases slightly. The total current drain for the complete circuit during operation is about 4 mA.

The 4.7 volt zener operates in the sweet spot between zener and avalanche modes. Avalanche breakdown has a positive temperature coefficient, and dominates above about 6 volts. Zener breakdown dominates at lower voltages, and has a negative temperature coefficient. Voltage regulating diodes operating near 5 volts exhibit both breakdown mechanisms, and have nearly zero temperature coefficient. The junction capacitance of a zener diode is relatively high, on the order of 100 pF, which acts as an internal bypass capacitor for high frequencies, but the breakdown mechanism is noisy, and the 10 uF electrolytic capacitor across the zener diode bypasses low frequency noise at the transistor base.

The oscillator-buffer output power is determined by the drive into the emitter of the common base stage, the collector voltage, and the impedance presented to the collector. With the values shown, the impedance at the collector is about 500 ohms, and the output power is about +4 dBm. Replacing the 78L06 with a 78L09 results in an output power of about +8 dBm.

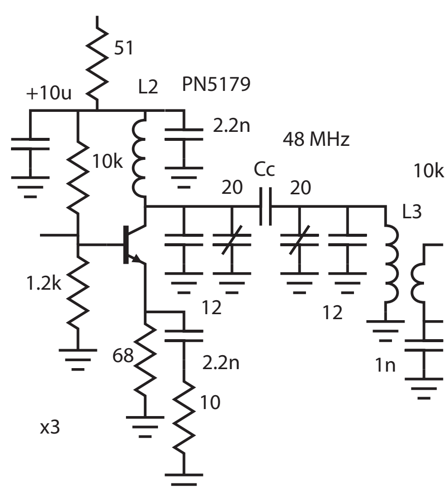
+7 dBm is 5 milliwatts, or 0.71 volts peak across a 50 ohm load.  The trifilar wound ferrite transformer T1 has a 3:1 step-down from the collector to the 50 ohm load and additional resistance in series with the collector, so the voltage swing at the collector is a little more than 3 times the peak voltage at the load.  The voltage swing at the collector for +8 dBm output is thus about 6 volts pea-to-peak, and the voltage swing at +4 dBm is about 4 volts peak-to-peak.  The pi-network CLC on the output is a low-pass filter to provide an output that is closer to a sine wave.  These values may be adjusted to optimize drive to the following multipleir stage to improve harmonic output and DC eficiency.

When the buffer amplifier is operated within it's linear range--with output level determined primarily by signal level at the emitter rather than by power supply voltage--the common base amplifier has high reverse isolation S12.  This is useful when driving a non-linear circuit such as a frequency multiplier, as it isolates the quartz crystal oscillator from the non-linear load.

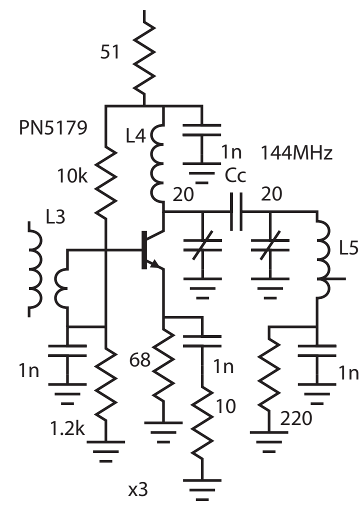
**Frequency Multipliers**  Folloing the oscillator-buffer is the first of several frequency multiplier stages.  Each frequency multiplier is designed to be driven by approximately +4 dBm and to provide a clean sine wave output at about +4 dBm at the second or third harmonic to the next stage.  The primary frequency multiplication mechanism is current limiting in an over-driven class A amplifier stage.  The frequency multiplier stages are biased for a quiescent current of about 1mA.  Current increases to about 4 mA with drive.  The voltage at the emitter resistor is a convenient test point for tuning previous stages, since it increases linearly with operating current.  This is a classic technique well known to mobile radio technicians.

The bypass capacitor is degenerated by a series resistor to provide a non-zero AC emitter resistance.  This raises the impedance at the base, which reduces the drive power requirement from the previous stage.  Since it also reduces distortion and gain, there is a complex trade-off between efficient frequency multiplier operation, drive power needed from the previous stage, operating current, and operating voltage. It is highly instructive to observe frequency multiplier operation at the bench and in a transient simulator to explore the relationship between all of various parameters.

A narrow double-tuned circuit provides enough spectral purity for X2 and X3 frequency multiplers that that drive to the following stage looks like a sine wave.  The double-tuned circuit also performs an impedance transformation between roughly 1k presented to the collector and 50 ohm drive to the next stage.  The number of turns on the output link on L3 is adjusted for optimum drive to the next stage. The undesired fundamental and harmonic outputs from a X3 multiplier will be suppressed more than 40 dB relative to the desired output.  This is expressed compactly as "-40 dBc undesired outputs."  While this is sufficient spectral purity for proper operation of the next stage, it is not good enough for many applications.    The tuned output amplifier after the last X3 stage provides added suppression of undesired harmonic outputs.

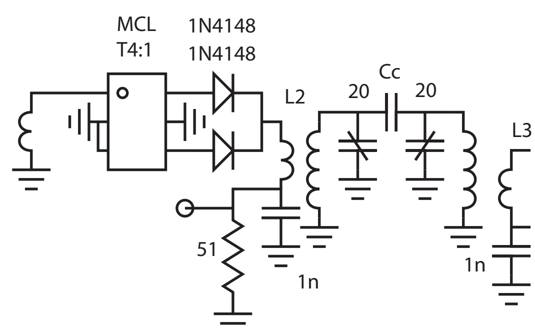


A second frequency multiplier stage is shown at the right. The primary difference between the two stages is the practical implementation of the selective elements in the double tuned circuit on the output. Below 100 MHz, toroidal inductors wound on powdered iron cores are used, tuned either by squeezing and spreading turns, or with poly trimmer capacitors as shown. The self-shielding properties of toroid cores help keep the magnetic fields in the vicinity of the appropriate areas of the circuit board, but do litle to prevent electric field coupling. At frequencies above 60 MHz air-core solenoids become compact and useful. Tuning may be achieved by squeezing and spreading turns, or with poly trimmer capacitors as shown. Coupling capacitor Cc are typically 1 pF or less, and may be either chip capcitors or gimmick capacitors made from short lengths of insulated twisted pair.



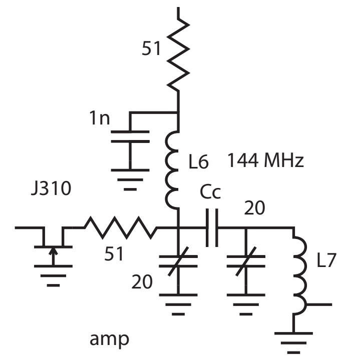

The frequency multiplier shown above is driven from a link wound on the toroid, to illustrate just one way to couple signals between stages. Often the choice of interstage coupling is made for convenience of the layout. The electric and magnetic fields around inductors, tuning capacitors, and all the interconnecting traces are significant, and changes to the layout often have more impact than changes in component values or circuit topology. It is important to optimize stage-by-stage at the bench while observing the effects of component placement and circuit topology. There are no 3D electromagnetic-electronic simulators capable of handling all the circuit board and component parasitics, dielectric and magnetic properties of different component materials, and the myriad devices in common use at VHF. There is no substitute for a designer with depth of understanding and experience participating in all aspects of the design, from sketches of the block diagram to analysis and simulation of candidate circuit schematics through prototyping and optimizing at the bench. Until you build and measure it, you don't know what you don't know.

Balanced diode frequency doublers are attractive alternatives to active frequency multipliers when stage gains and power levels may be adjusted to compensate for the expected 6 to 8 dB conversion loss. They require clean sine wave drive, and the output waveform is rich in even harmonics. They are well-behaved, with a nearly linear relationship between drive and output levels over a significant range from about +3 to +16 dBm drive for the version shown at the right.




At higher frequencies, and for higher multiples such as 4 5 6 and 7, passive diode multipliers in conjunction with narrow filters and 50 ohm gain block ICs are attractive. Linear gain block ICs draw more current than optimized cascaded frequency multiplier stages, which may be significant for battery operated applications.

Balanced diode frequency doublers are particularly useful as the last stage of a frequency multipler chain when a modest output level is needed. As previously mentioned in conjunction with oscillators, low level x2 and /2 signals may be added to a fundamental without altering the phase of the fundamental. This has significant benefits for balanced mixers, direct conversion receivers and free running oscillators. An additional benefit to using a diode doubler as the final stage in a local oscillator is that there are no power supply currents flowing at the output frequency. This improves shielding and bypassing performance.




**Isolating Output Amplifier** Unlike balanced diode multipliers, transistor frequency multipliers are non-linear circuits optimized for operation with particular drive and load levels and impedances. Microwave frequency multipliers are often operated with an isolator on the output to prevent load impedance variations from affecting multiplier operation. Using an isolating amplifier on the output of a VHF frequency multiplier chain achieves the same function, and offers a convenient place for additional selectivity to reduce close-in harmonics of the fundamental oscillator. The common gate J301 amplifier shown at the right serves both functions well. S11 is well-behavied and determined by gm of the device. S12 is approximately -40 dB for excellent isolation between drive and load, and S21 is modest at VHF.

**Electromagnetic Shielding** Practical VHF circuits need electromagnetic shields to confine signals to particular regions in space. The amount of shielding is a compromise between cost, performance, and weight. Reducing undesired signals to undetectable levels requires that individual stages be constructed in individual modules with fully shielded interconnecting cables, as is common in space electronics and spectrum analyzers. It is instructive to design circuit modules and circuit boards with the option for additional shielding, and then observe the performance on a spectrum analyzer as shielding is added. The 144 MHz oscillator-multiplier amplifier chain shown in the earlier schematic has spurious outputs suppressed roughly 60 dBc with no shields, and more than 70 dBc with small tinned steel shields between stages. Separating the last X3 multiplier and common gate amplifier into individual diecast boxes with interconnecting semi-rigid SMA cables reduces all undesired outputs below -90 dBc, with no changes to the circuit diagram. Obtaining the desired output level and suppression of unwanted outputs to about 40 dBc may be achieved with little shielding, but suppression of unwanted responses below 50 dBc requires electromagnetic design and measurements.

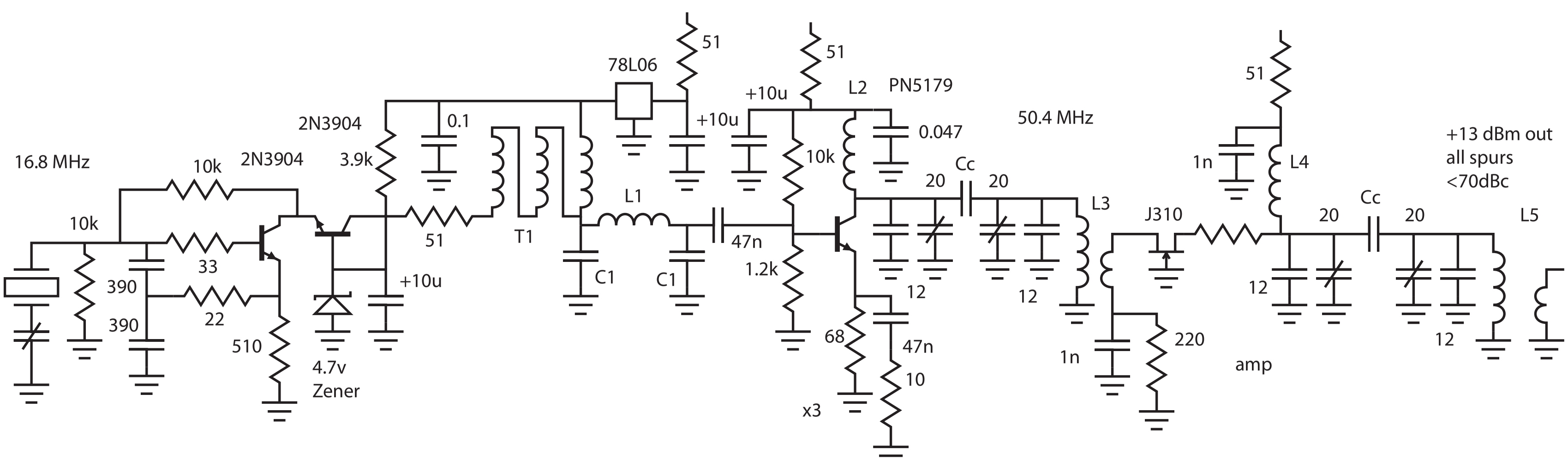
**Simulation Versus Measurement** There is little in a circuit simulator to indicate the inportance of electromagnetic coupling between VHF components. Disappointing performance on an open circuit board may lead the designer down the path of adding additional tuned interstage components. Such additions add complexity and tune up time without solving the problem if unwanted outputs are radiated across the board or coupled on power supply lines. A simulator is a valuable tool to obtain a 1 dB improvement in the gain of an amplifier, but seldom useful if an additional 10 dB suppression of a -90 dBm spurious output signal is needed. A careful designer will simulate nearly everything, measure everything possible, and ponder every detail of the design, from the models used in the simulator to E-field coupling in high impedance portions of the circuit and H-field coupling in low impedance circuit areas.

Complete 20 milliwatt 50 MHz CW Source

Rick Campbell KK7B November 2008

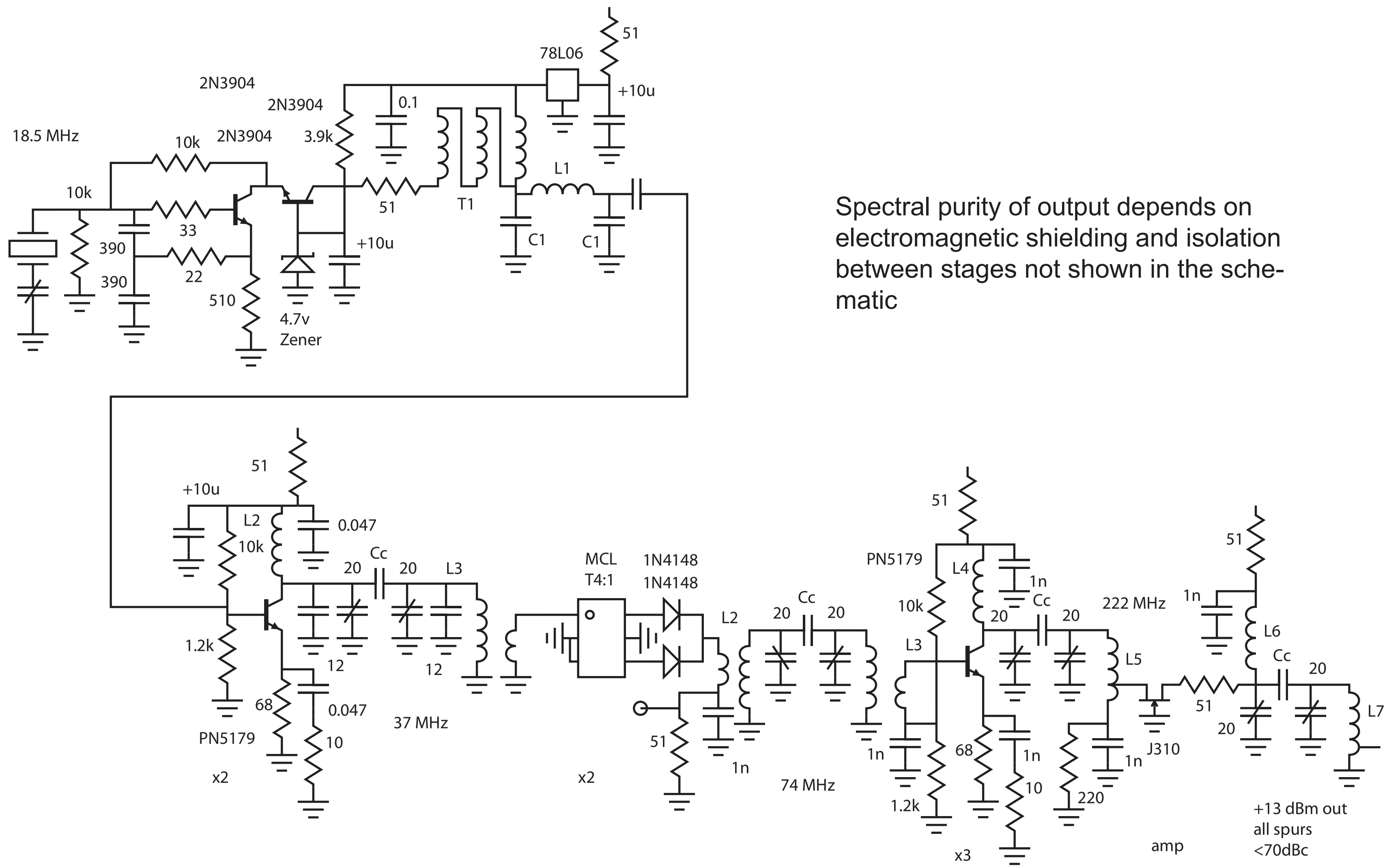
Spectral purity of output depends on electromagnetic shielding and isolation between stages not shown in the schematic

50 MHz CW Exciter



Complete 20 milliwatt 222 MHz CW Source

Rick Campbell KK7B November 2008

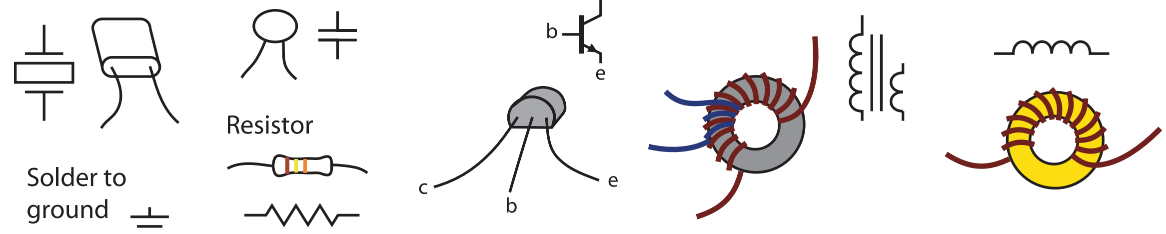


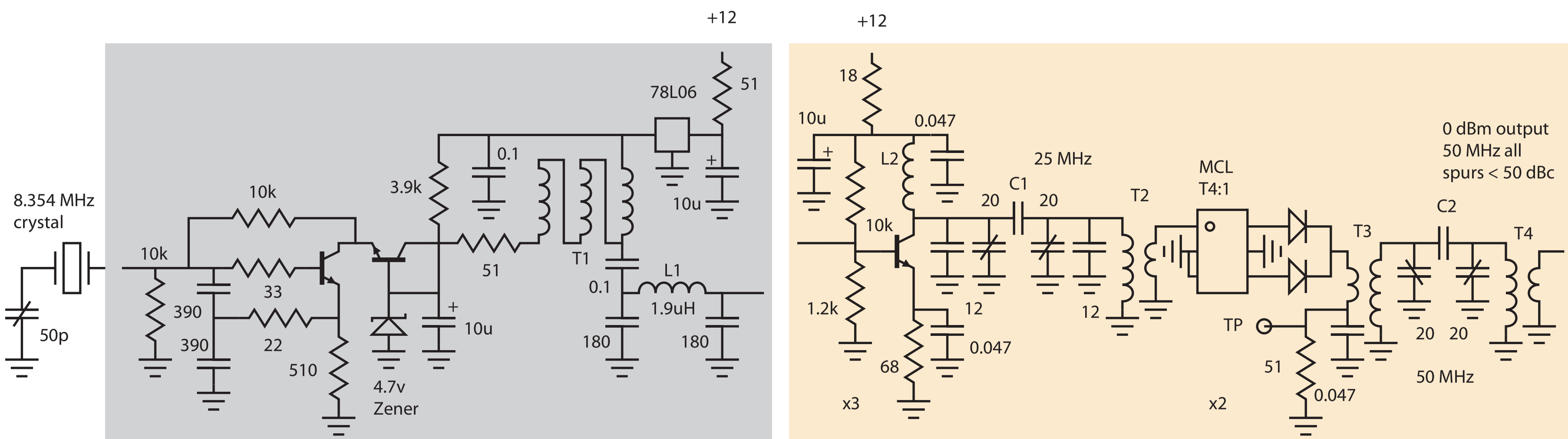

Spectral purity of output depends on electromagnetic shielding and isolation between stages not shown in the schematic

1 milliwatt 50 MHz CW Source

Rick Campbell KK7September 2007

# 50.125 MHz VXO for microT2 exciter




All 3 transistors 2N3904 or equivalent

T1 4t trifilar on FT25-43

L1 and associated 180pF capacitors X=100 ohms at crystal freq.

gray circuitry is part of microT2

L2 18t T25-2 resonant at 3x crystal freq.

T2 18t:3t T25-2 resonant at 3x crystal freq.

x3 and x2 built on unetched copper clad

T3,T4 16t:2t T25-6 resonant at 6x crystal freq.

MCL T4:1 may be replaced by trifilar transformer like T1

TP reads ~0.4 volts when properly tuned

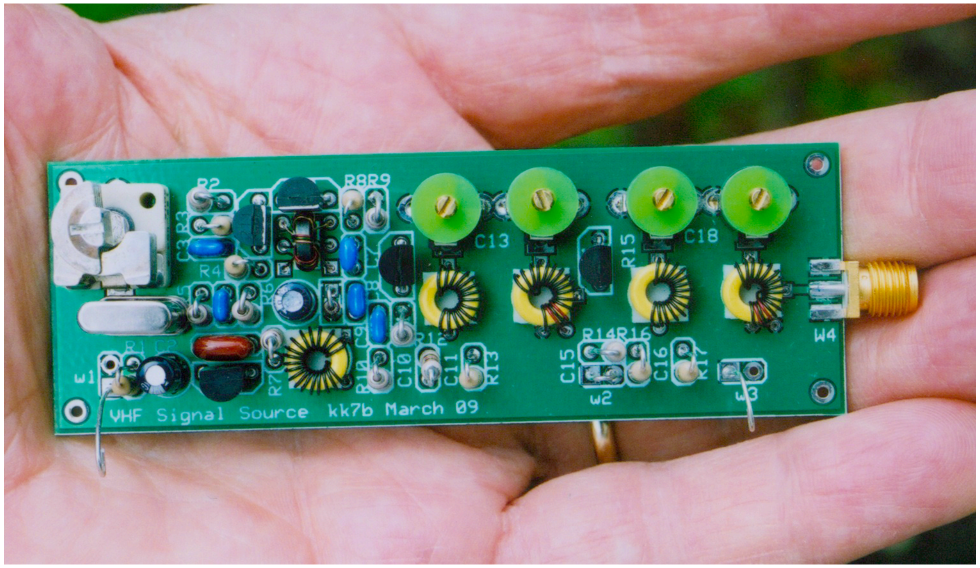
0 dBm output drives microT2 buffer amp

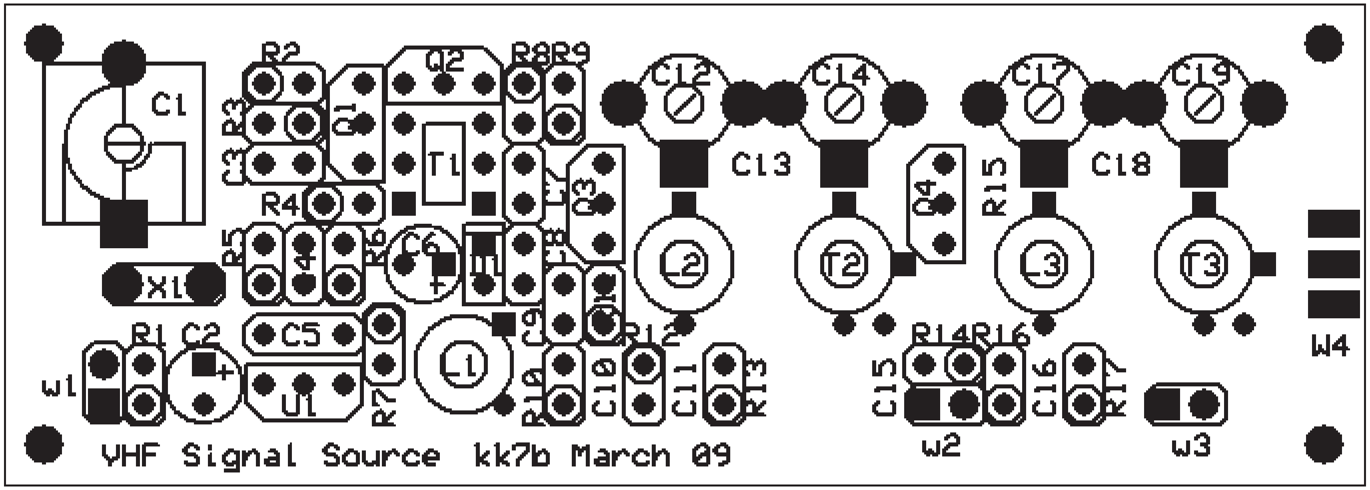
C1 3/4" long twisted #28 gimmick

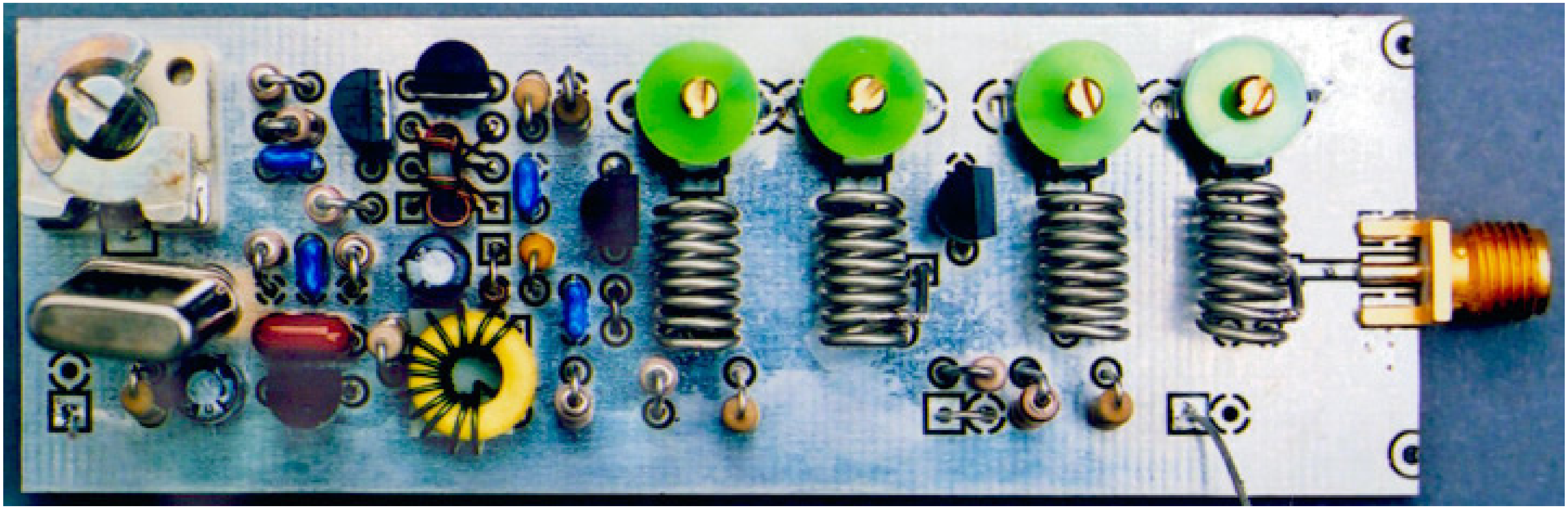
C2 3/8" long twisted #28 gimmick

41 and 58 MHz spurs -45 dBc

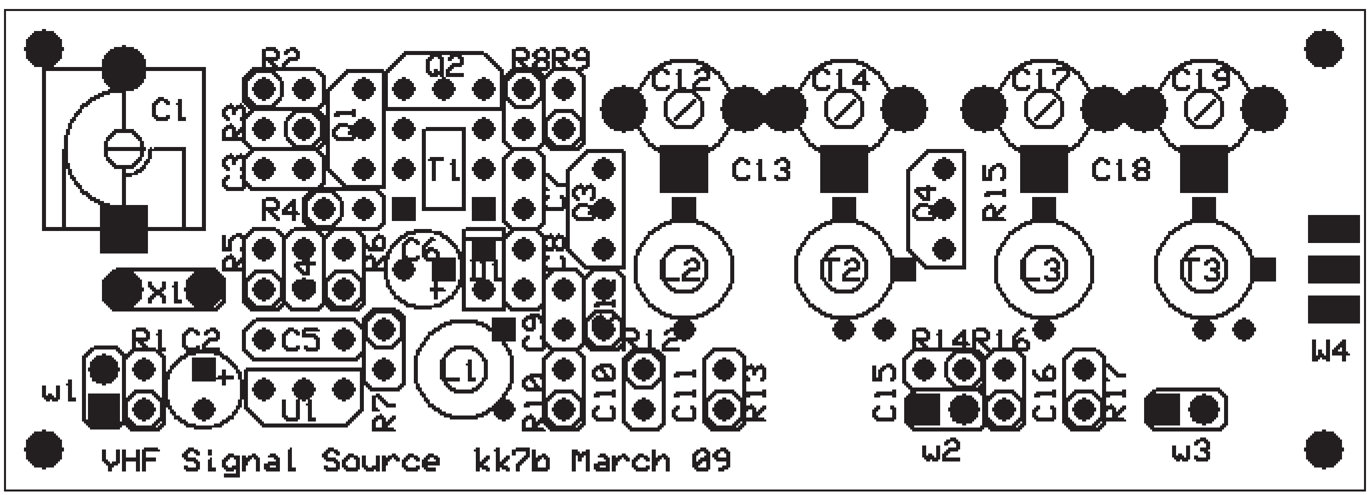
**50 MHz**
**Signal Source**





144 MHz
Signal Source



# A WEST COAST LIGHTWAVE PROJECT

**Steve McDonald, VE7SL / Markus Hansen,VE7CA**

With the growing popularity of Web blogs devoted to Amateur Radio, the Internet has become a wonderful source of technical topics. One such blog caught my interest this past summer, when I began to follow the daily postings of Roger, G3XBM, in the United Kingdom (see note 1).

I found Roger's notes describing his LED lightwave experiments to be particularly inspiring. Further searching led me to the UK Nanowave Group and a series of *Radcom* lightwave articles that I found difficult to resist (see note 2). It seemed that many of our UK counterparts were becoming very active in building and operating simple LED lightwave stations and appeared to be having far too much fun in the process!

Roger's notes and the *Radcom* articles were passed to Markus, VE7CA and to John, VE7BDQ, both ardent homebrewers, who also believed the concept of communicating with lightwaves would be an interesting challenge.

The project was soon broken into four basic requirements so that work could begin:

- a lightwave receiver
- a lightwave transmitter
- an optical system and enclosure for both RX and TX
- a CW tone modulator

## RECEIVING

It wasn't long before construction began on a basic receiving system designed around the G3XBM receiver and additional information found at Clint Turner's (KA7OEI) website (see note 3).

The receiver we chose to build was a G3XBM modification of one designed many years ago by K3PGP for his laser experiments. It consisted of a small inexpensive PIN photodiode (BPW34) driving a JFET amplifier, followed by several stages of audio amplification (see Figure 1). The completed receivers are very compact as can be seen by the one shown here constructed by John, VE7BDQ (see Figure 2 on the next page).

There are numerous inexpensive photodiodes that will work very well in this circuit. Although the G3XBM receiver used an SFH213 photodiode, we used BPW34's. This particular diode works best in the IR region, but still performs suitably in the slightly higher deep-red light part of the visible spectrum where we planned to transmit (see Figure 3).

To increase the light-gathering capability of the system, inexpensive plastic Fresnel lenses were purchased in order to focus incoming light onto the photodiode's tiny cell as well as for use

**IMPORTANT SIDEBAR**

Canadian Amateurs operating a Lightwave Optical system should be aware of Transport Canada's / Canadian Aviation Regulations with regard to any Directed Bright Light (DBL) source and operate in accordance to these regulations.

DBL's are potentially hazardous and penalties do exist for their inappropriate use.

The Canadian Aviation Regulations (CAR) prohibit "projecting a bright light source" into airspace.

**601.14**

In this Division, "directed bright light source" means any directed light source (coherent or non-coherent), including lasers, that may create a hazard to aviation safety or cause damage to an aircraft or injury to persons on board the aircraft.

**601.20**

Subject to section 601.21, no person shall project or cause to be projected a bright light source into navigable airspace in such a manner as to create a hazard to aviation safety or cause damage to an aircraft or injury to persons on board the aircraft.

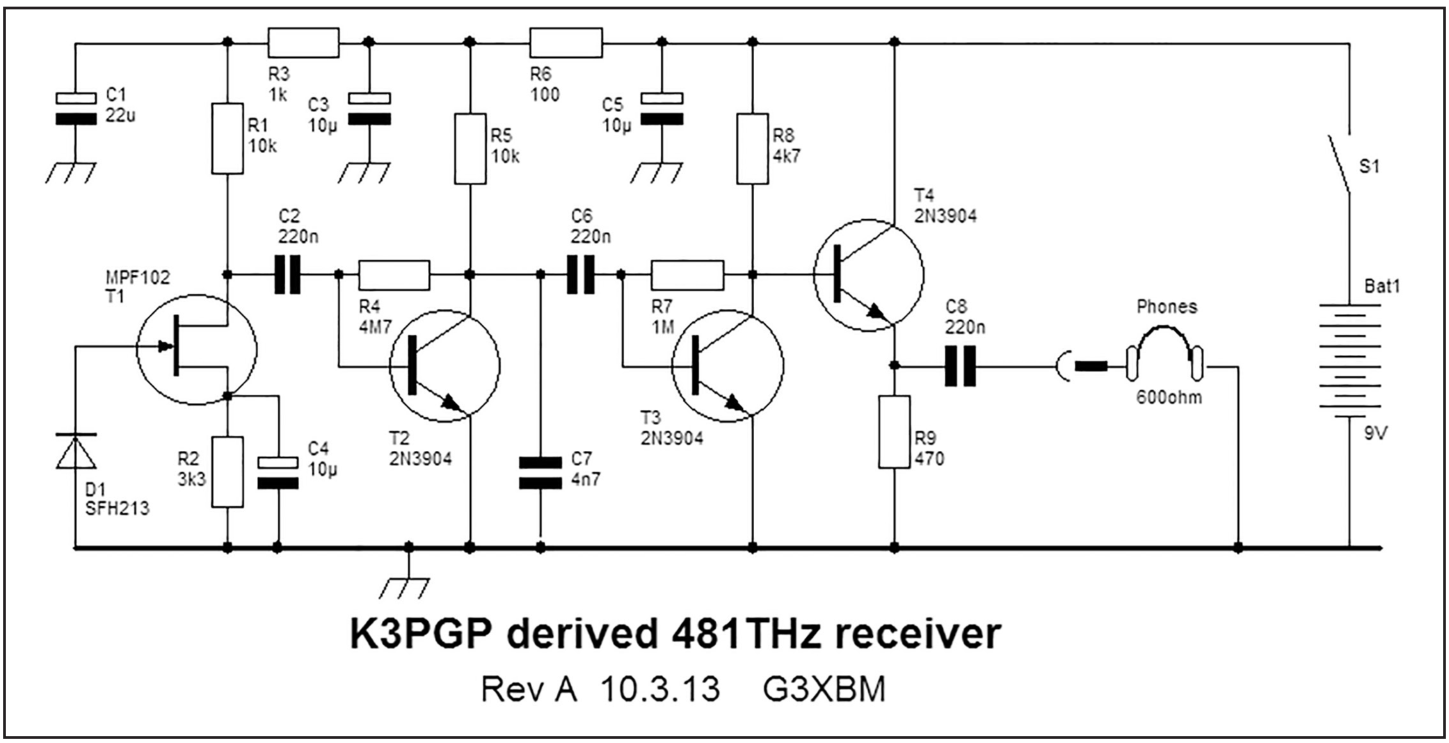



**Figure 1: Schematic diagram of the basic lightwave receiver used at both stations; courtesy of G3XBM.**

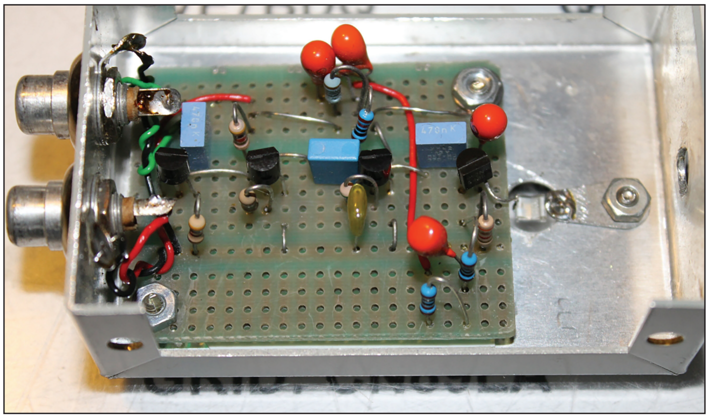


**Figure 2: One of the finished receivers built by John, VE7BDQ.**

in the transmitter (see note 4). John devised a brilliantly simple mounting support for the receiver using the split shaft locking collet removed from an old potentiometer. The mount allowed for easy three-axis movement (forward/backward, up/down, left/right) and precise positioning of the photodiode at the Fresnel's focal point. A similar mount was constructed for the transmitter's LED as well (see Figure 4).

The finished receivers turned out to be exceptionally sensitive. Initial nighttime listening tests revealed an unexpected abundance of interesting signals! One of the first signals heard was a repetitive low frequency "thump-thump", which turned out to be the audio signature of flashing strobe lights from various aircraft, both near and far.

The receiver could easily detect the jet aircraft strobes from incoming planes heading for Vancouver International while they were still over 70 miles away above the coastal mountains on their descent and still above 10,000 feet.

From my receiving location on the eastern shore of Mayne Island, in the middle of Georgia Strait, I could hear many different signals as I panned the receiver along the mainland's southern coast. Many sounded like radar sweeps and others like strobes, and all with different timing cycles and modulation rates. Some sounded rough and growly while others were pure and "T9".

Attesting to the receiver's sensitivity, most of the signals showed no visible sign of their presence to my eyes, even when scanning with binoculars to find the source. Once the receiving systems were working well, construction of the transmitters began.

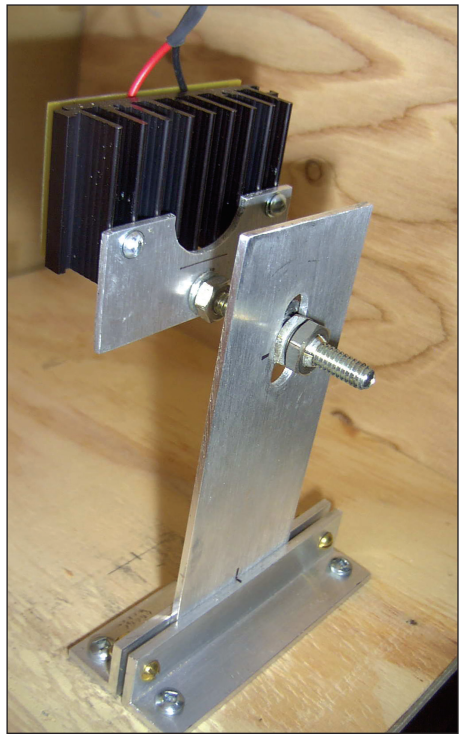


**Figure 4: The adjustable mounting system used for alignment of the LED and the receiver.**

## TRANSMITTING

The heart of the transmitter is a single Luxeon Red Rebel LED (see Figure 5 on the next page) mounted on a small heatsink.

The tiny LED operates at 2.4V @ 700ma while producing light in the deep-red

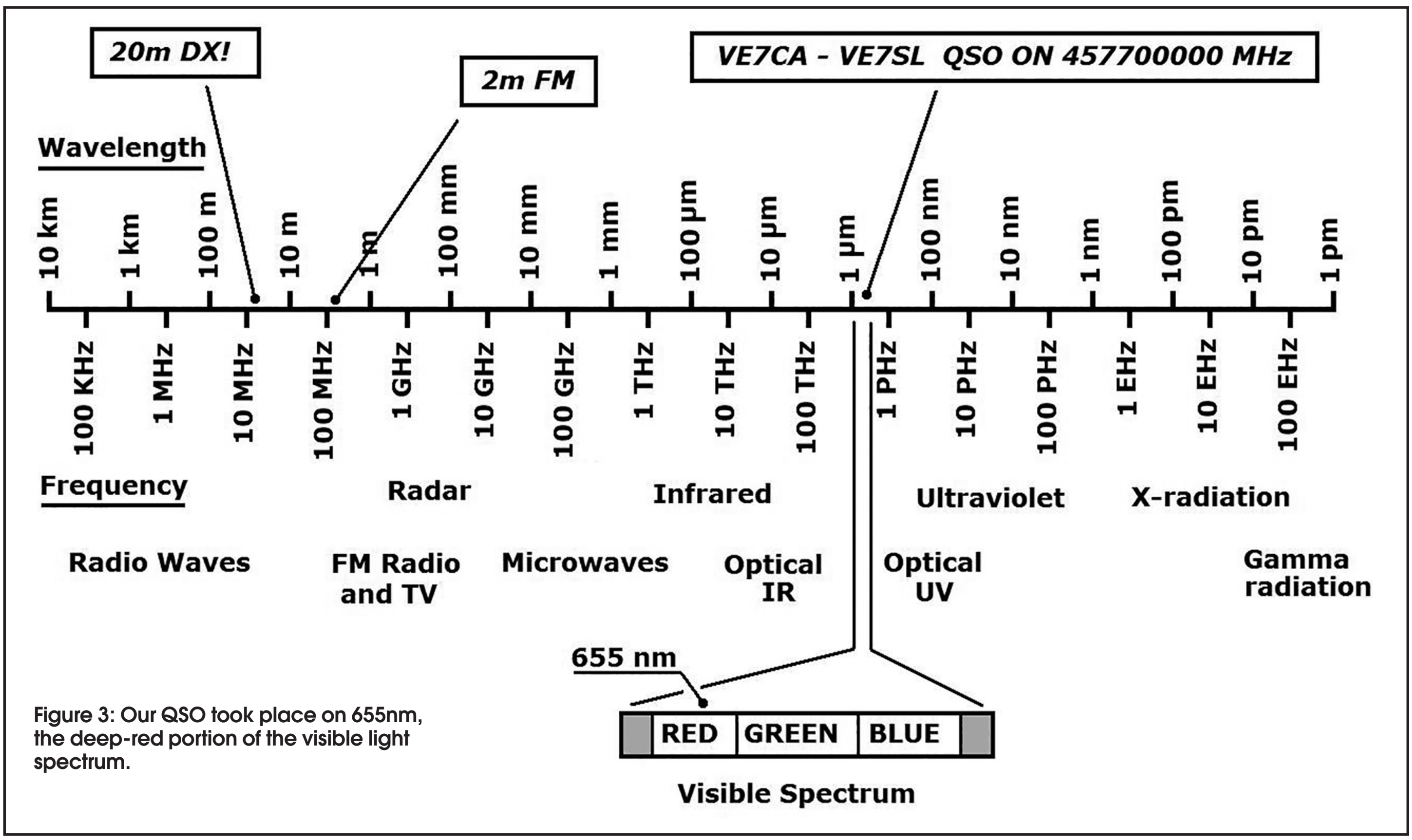
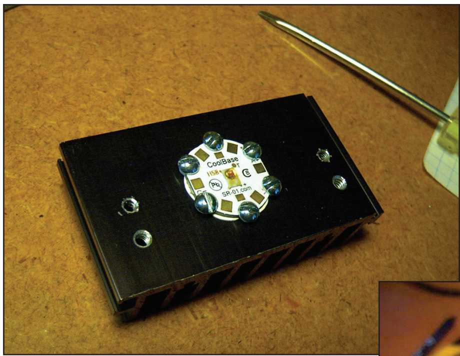



Figure 3: Our QSO took place on 655nm, the deep-red portion of the visible light spectrum.



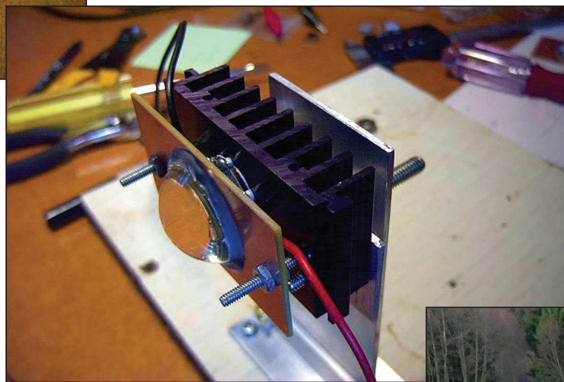


**Figure 5 (top): The Red Rebel LED mounted on its Star Base and heatsink.**

**Figure 6 (right): The collimating lens and LED module on adjustable mount.**

**Figure 7 (far right): The VE7CA lightwave station ready to go.**

portion of the visible spectrum at 655nm or approximately 460THz (see the box at the top right). The LED is mounted directly behind an inexpensive 30mm glass collimating lens in order to have its light fully illuminate the Fresnel lens without any power-wasting "spillover" (see note 5). The collimating lens, along with the LED and heatsink, are all mounted on a sliding carrier similar to the one used in the receiver so that it can be precisely aligned behind the larger Fresnel lens (see Figure 6).

In order to keep the system as simple as possible and to give us a better chance of success, we chose to CW modulate the lightwave signal with a 600 Hz keyed tone. Several simple transmitting schemes can be found on Roger's (G3XBM) blog where further details are available (see note 1).

A single 556 IC (dual 555's) was employed as the tone source as well as for a dual-tone "beacon-mode" signal. The output from the 556 was used to drive a power MOSFET (IRF540) which controlled current to the LED (see Figure 8).

Both the transmitter and the receiver boxes, along with their respective lenses, were mounted side by-side to ensure that both were pointing at the same target as shown here by the VE7CA station ready to go (see Figure 7).

The final task was to ensure that the LED was accurately positioned with relation to the Fresnel. This required aiming the transmitter at a flat surface at least 150 feet away and finetuning the focus carriage. Once the correct position was found, it was possible to see the actual LED die and its two tiny connecting wires on the distant target image.

## ON THE AIR

Since two complete stations had now been built, we anxiously waited for a break in the west coast rain for an initial "on-air" test.

When the weather eventually broke, a test QSO was scheduled on a clear but cold evening. Markus, along with Jim, VE7BKX, set up his equipment near West Vancouver's Cypress Provincial Park enroute to the ski hills, giving him a clear line-of-sight path to my front yard location on Mayne Island, 54 kilometres away on the far side of Georgia Strait (see Figure 9 on the next page).

### THz

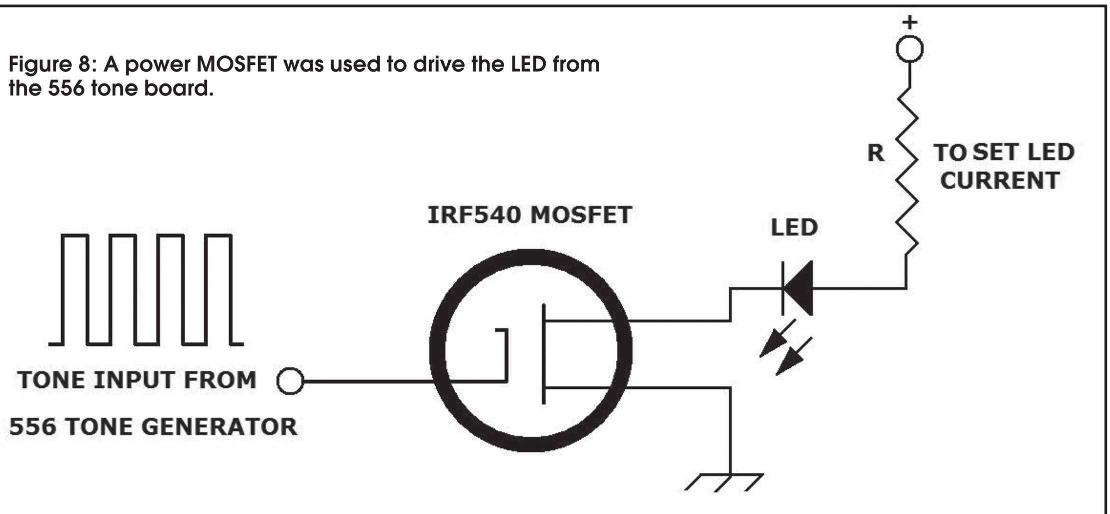
"THz" is the abbreviation used for "terahertz", the unit of electromagnetic wave frequency equal to one trillion hertz (10^12 Hz). It is mostly used to express the frequencies used for infrared (IR), visible and ultraviolet (UV) radiation. 1THz has a wavelength of .3mm.

Shortly before dusk, I pointed towards Markus's location and activated my transmitter in the beacon-mode. Markus heard me almost immediately and, after refining his alignment, replied by activating his beacon signal. Not knowing what to expect in the way of signal levels, we were all astounded at the strength of our signals – a true 599 or better!

Switching to straight CW and exchanging signal reports and grid square information made the contact "official", allowing us to then have a nice 20 minute CW ragchew before it became too cold on our fingers to continue (see note 6).

Interestingly, we were able to work full break-in style (QSK) as the transmitters did not interfere with the continuously running receivers, a nice surprise.

**Figure 8: A power MOSFET was used to drive the LED from the 556 tone board.**



Our next goal is to move further afield and try to complete a QSO at a much further distance.

We are also considering adding voice modulators to the system and possibly shifting to the IR range for better efficiency.

In addition, John is interested in trying some "non-line-of-sight" (NLOS) experiments to see if it is possible to bounce signals across Georgia Strait from the cloud layer bottoms. One of the project's major goals is to try to encourage similar activity amongst Canadian Radio Amateurs and to encourage the joy of homebrewing your own station equipment.

If you intend to operate an LED lightwave system you must:

1) pay proper attention to where the system is deployed. Such a system must not be operated near airports or pointed towards aircraft and there are severe penalties for doing so (please read the sidebar for more information)

2) treat an LED light system with care. Although not physically damaging like laser light, modern LEDs are very bright and should never be looked at directly.

3) Be aware of other nearby activity. Although not physically damaging, a bright LED light can cause momentary distraction to automobile drivers or onlookers.

We hope that you will check out some of the references and links provided and get in on the fun as well. See you on 460THz!

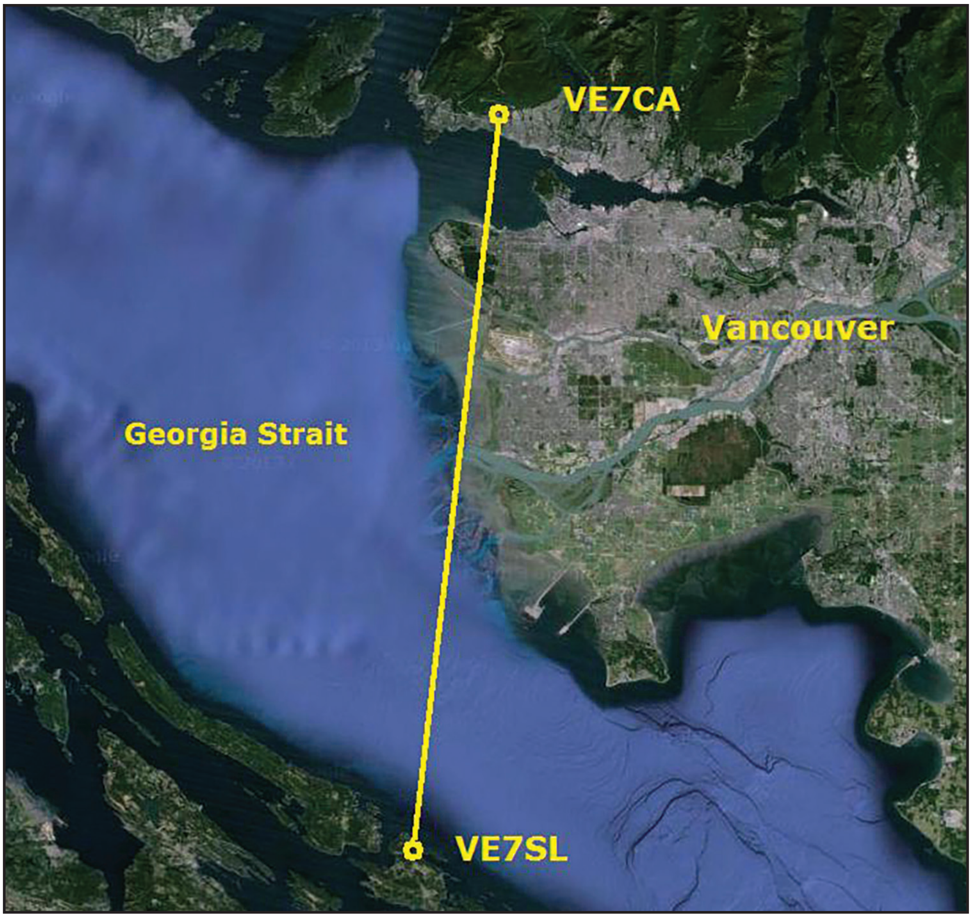



**Figure 9: The 54 kilometreoptical path between Mayne Island and West Vancouver; courtesy of Google Maps.**

## NOTES

1) Several pages of Roger's optical adventures can be found online at: http://g3xbm-qrp.blogspot.ca/search/label/optical

2) The four-part *Radcom* article, "Adventures In Optical Communication" can be downloaded from http://groups.yahoo.com/neo/groups/UKNanowaves/info. It is well worth joining the group just to read this excellent series.

3) Probably the Web's best overall source of Amateur optical communications information can be found at: http://modulatedlight.org/optical_comms/optical_index.html

4) The Fresnel lens model A260 was purchased at: http://www.3dlens.com/shop/largefresnellens.php

5) The inexpensive 30mm PMN collimating lens was purchased at: http://www.surplusshed.com/

6) To see a short cellphone video of signals received near Cypress Park by VE7CA, visit YouTube and search for "VE7SL LW".

*Steve McDonald, VE7SL, was first licensed as a teenager in 1963 (VE7ANP). He is now retired on Mayne Island, BC, after teaching high school Tech-Ed for 35 years. "My radio time is spent homebrewing and DXing, with a focus on 6m, LF and our new 630m band. I maintain my 'VE7SL Radio Notebook' website at: http://members.shaw.ca/ve7sl/ as well as a new Blog at http://ve7sl.blogspot.ca/ Please stop by."*

*Markus Hansen, VE7CA, has been an Amateur since 1959. He is now retired and enjoying a little more time for experimenting. Markus has had several articles published by the ARRL and one by RAC describing different antenna projects and his homebrew HBR-2000, a 160 to 6 metre full-fledged transceiver. He continues to be active on 160 to 6 metres mostly operating CW and some AM on 15 metres with a restored Viking Range and Collins 51j-4. Markus maintains a website at ve7ca.net describing many of his ham-related experiments and restoration projects.*

TCA