Chapter 15

Transceivers, Transverters and Repeaters

TRANSCEIVERS

In recent years the transceiver has become the most popular type of purchased equipment among amateurs. The reasons for this popularity are:

1. It is economical to use LOs (especially synthesizers), IF amplifiers and filters, power supplies, DSP modules and microprocessor controls for both transmit and receive.
2. It is simpler to perform transmit-receive (T/R) switching functions smoothly and with the correct timing within the same piece of equipment.
3. It is convenient to set a receive frequency and the identical (or properly offset) transmit frequency simultaneously.

In addition, transceivers have acquired very impressive arrays of operator aids that help the operator to communicate more easily and effectively. The complex design, numerous features and the very compact packaging have made the transceiver essentially a "store bought" item that is extremely difficult for the individual amateur to duplicate at home. The complexity of the work done by teams of design specialists at the factories is incompatible with the technical backgrounds of nearly all individual amateur operators.

The result of this modern trend is that amateur home-built equipment tends to be simpler; with less power output and more specialized in design (one-band, QRP, CW only, direct conversion, no-tune, receive only, transmit only and so on). Or, the amateur designs and builds add-on devices such as antenna couplers, active adaptive filters, computer interfaces and such.

TRANSCEIVER EXAMPLE

As a way of providing a detailed, in-depth description of modern high-quality transceiver design, let's discuss one example, the Ten-Tec Omni VI Plus, an HF ham-band-only solid-state 100-W (output) transceiver, shown in **Fig 15.1**. Let's consider first the signal-path block diagram in **Fig 15.2**, one section at a time.

Receiver Front End

The receive antenna can be either the same as the transmitting antenna or an auxiliary receive antenna. A 20-dB attenuator can be switched in as needed. A 1.6-MHz high-pass filter attenuates the broadcast band. A 9.0-MHz trap attenuates very strong signals at 9.0 MHz that might create interference in the form of

Fig 15.1 — Photograph of Ten-Tec Omni VI Plus HF transceiver.

The Many Flavors of Transceivers

Today, commercial transceivers can be found in the vast majority of Amateur Radio stations in the United States — and increasingly throughout the world. This is not to suggest, however, that hams cannot design and build their own transceivers. Many here and around the globe have done just that with great success! Such homebrew designs cover the range of circuit complexity and performance.

Whether homemade or commercial, and regardless of individual design complexity, the idea and practice of packaging a receiver and transmitter (and often, even a common power supply for both functions) into one unit has eclipsed the once-standard separate *receiver* and *transmitter* combination. Those venerable pairs were characteristic of 20^{th} century ham shacks up to and even well after World War II. During the 1960s and 1970s, more transceiver designs were offered, and correspondingly more hams accepted them due to their efficiency, convenience and other beneficial features.

For the class of ham transceivers available today — in terms of sophistication and technology — what was once thought to be nearly impossible to design and build is now not only quite common, but expected in most medium and high-end commercial models! Here are some of the more common and recent commercial radios in the ham transceiver category.

Elecraft K2

The basic K2 transceiver package, shown in **Fig A**, is a QRP kit that covers CW from 80-10 Meters. With inclusion of an SSB adapter option, transmitter power output ranges from 100 mW (QRP_P level) to 12 W. Other options include a 160-m module, DSP module, audio filter, two-stage noise blanker, auto antenna tuner and the KPA100 — an RF power module that delivers 100-W output on SSB or CW. *Manufacturer*: Elecraft, PO Box 69, Aptos, CA 95001-0069; **www.elecraft.com**.

Fig A — Elecraft K2.

ICOM IC-706MKIIG

Fig B shows a versatile radio that can serve in either a mobile or base installation. This rig covers 160-10, 6 and 2 Meters, 70 cm and also sports a general coverage receiver! DSP equipped. Specified power output (SSB, CW and FM) is 100 W from 160-6 Meters and 40 W on AM. Power output capabilities are lower on the operational transmit frequencies above 50 MHz. *Manufacturer*: ICOM America, 2380 116^{th} Avenue NE, Bellevue, WA 98004; **www.icomamerica.com**.

Fig B — ICOM IC-706MKIIG.

blocking or harmonic IMD, especially when tuned to the 10.1-MHz (30-m) or 7-MHz (40-m) bands.

A set of band-pass filters, one for each HF amateur band, eliminates image responses and other spurs in the first mixer. These filters are also used in the low-level transmit stages. A low-noise, high-dynamic-range, grounded-gate JFET RF amplifier with about 9 dB of gain precedes the double balanced diode mixer, which uses 17 dBm of LO in a high-side mixer.

First IF

The first IF is 9.0 MHz. Because the LO is on the high side, there is a sideband inversion (USB becomes LSB and so on) after the first mixer. A grounded-gate, low-noise JFET amplifier terminates the first mixer in a resistive load and provides 6 dB of gain. This preamp helps to establish the receiver sensitivity (0.15 µV) with minimum gain preceding the mixer. The preamp is followed by a 15-kHz-wide two-pole filter, which is used for NBFM reception. It is also a roofing filter for the IF amplifier and the noise-blanker circuit that follow it.

The noise blanker gathers impulse energy from the 15-kHz filter, amplifies and rectifies it, and opens a balanced diode noise gate. The IF signal ahead of the gate is delayed slightly by a two-pole filter so that the IF noise pulse and the blanking pulse arrive at the gate at the same time.

The standard IF filter for SSB/CW has 8 poles, is centered at 9.0015 MHz and is 2.4 kHz wide at the –6 dB points. Following this filter, two optional 9.0-MHz filters with the following bandwidths can be installed: 1.8 kHz, 500 Hz, 250 Hz or a 500 Hz RTTY filter. The optional filters are in cascade with the standard filter, for improved ultimate attenuation.

Passband Tuning Section

A mixer converts 9.0 MHz to 6.3 MHz and drives a standard 2.4 kHz wide filter. One of three optional filters, 1.8 kHz,

Kenwood TS-870S

When this DSP-at-IF radio (see **Fig C**) was first introduced, it was considered revolutionary due to the ability of the rig to achieve good selectivity without the traditional standard and optional crystal IF filters. It covers 160-10 Meters, and also has a general coverage receiver from 30 kHz to 30 MHz. RF output is continually adjustable up to 100 W (SSB, CW, FSK and FM), and up to 25 W on AM. The TS-870S requires a separate power supply. *Manufacturer*: Kenwood USA Corp, 3975 Johns Creek Ct, Suwanee, GA 30024-1265; **www.kenwood.net**.

Fig C — Kenwood TS-870S.

Ten-Tec Orion (Model 565)

This advanced transceiver, shown in **Fig D**, is the current top-of-the-line offering from Ten-Tec. A variety of automatically- or manually-selectable front-end crystal roofing filters, and dual 32-bit floating-point processors characterize the Orion's formidable high-tech receive weaponry. Excellent Software-Defined Radio (SDR) techniques are employed which include user-installable software upgrades via the Internet. RF output (SSB, CW, FM) is 100 W, and AM mode yields a 19.1-W carrier. An external power supply is required. *Manufacturer*: Ten-Tec Inc., 1185 Dolly Parton Parkway, Sevierville, TN 37862; **www.tentec.com**.

Fig D — Ten-Tec Orion (Model 565).

Yaesu FT-1000MP Mark V Field

Fig E shows the Mark V *Field* — the 100-W, internal-power-supply version of the larger 200-W Mark V. This technologically-advanced transceiver continues a model-number heritage with roots back to the analog FT-1000 and 1000D base radios. The *Field* features enhanced DSP (EDSP) and offers final amplifier operation at Class A on SSB (at reduced output) as does the regular Mark V. A variable RF front-end filter (preselector) provides for additional rejection of strong nearby signals. *Manufacturer*: Vertex Standard, 10900 Walker Street, Cypress, CA 90630; **www.vxstdusa.com**.

Fig E — Yaesu FT-1000MP Mark V Field.

500 Hz (CW) or 250 Hz can be selected instead. A second mixer translates back to the 9.0-MHz frequency. A voltage tuned crystal oscillator at 15.300 MHz (tunable ±1.5 kHz) is the LO for both mixers. This choice of LO and the 6.3-MHz IF results in very low levels of harmonic IMD products that might cross over the signal frequency and cause spurious outputs. The passband can be tuned ±1.5 kHz.

The composite passband is the intersection of the fixed 9.0-MHz passband and the tunable 6.3-MHz passband. If the first filter is wide and the second much narrower the passband width remains constant over most of the adjustment range. If both have the same bandwidth the resultant bandwidth narrows considerably as the second filter is adjusted. This can be especially helpful in CW mode. **Fig 15.3** shows how passband tuning works.

IF Amplifiers after Passband Tuning

A low-noise grounded-gate JFET amplifier, with PIN-diode AGC, establishes a low noise figure and a low level of IF noise after the last IF filter. Two IC IF amplifiers (MC1350P) provide most of the receive IF gain. These three stages provide all of the AGC for the receiver. The AGC loop does not include the narrow-band IF filters. Two AGC recovery times (Fast and Slow) are available. AGC can be switched off for manual RF gain control as well. The AGC drives the S-meter, which is calibrated at 50 µV for S9 and 0.8 µV for S3.

Product Detector

The IC product detector (CA3053E) uses LO frequencies of 9.000 MHz for LSB and CW (in receive only), 9.003 MHz for USB. When switching between USB and LSB, for a constant value of signal carrier frequency (such as 14.20000 MHz), the LO of the first mixer is moved 3.00 kHz in order to keep the signal within the passband of the IF SSB filters. More about this later.

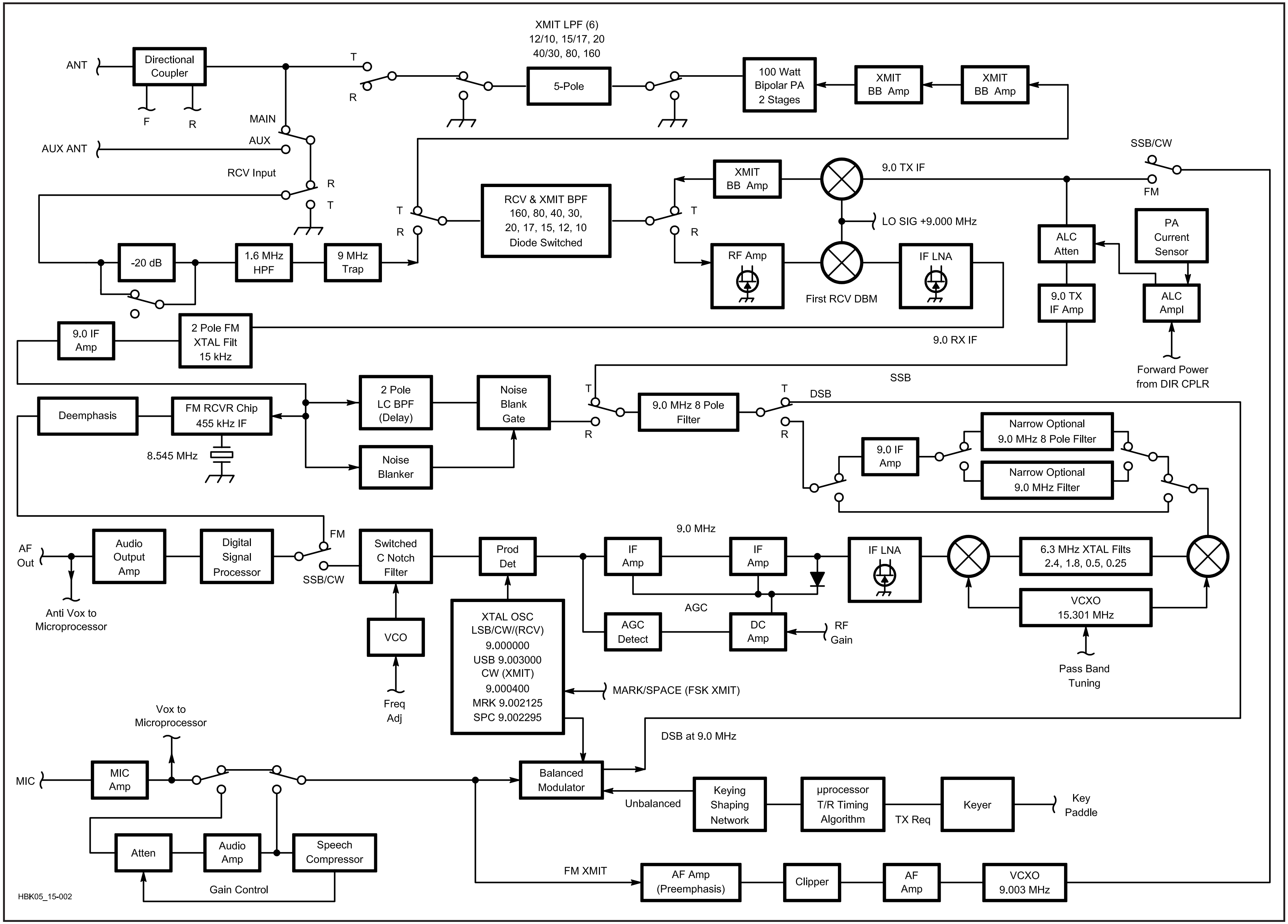


Fig 15.2 — Signal path block diagram, receive and transmit, for the Omni VI Plus transceiver.

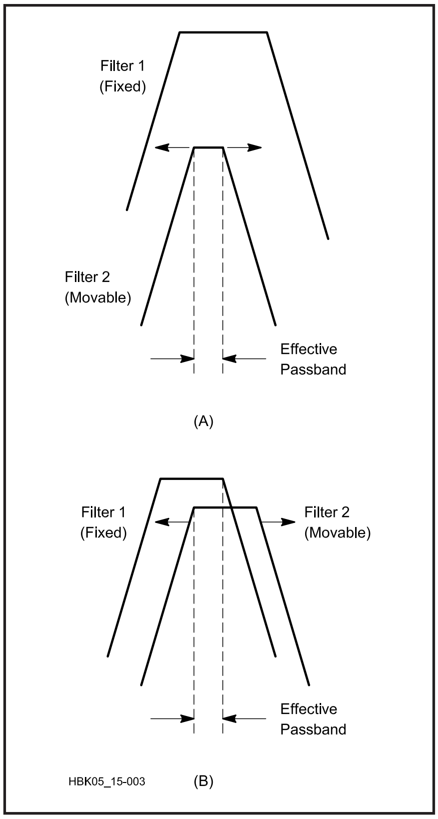


Fig 15.3 — Explanation of passband tuning. A: wide first filter and narrow second filter. B: two narrow filters.

Audio Notch Filter

In the CW and digital modes, a switched-capacitor notch filter (MF5CN) places a narrow notch in the audio band. The location of the notch is determined by the clock rate applied to the chip. This is determined by a VCO (CD4046BE) whose frequency is controlled by the front panel NOTCH control.

NBFM Reception

After the 15 kHz wide IF filter at 9.0 MHz and before the noise blanker, the IF goes to the NBFM receiver chip (MC3371P). A mixer (8.545-MHz LO) converts it to 455 kHz. The signal goes through an off-chip ceramic band-pass filter, and then goes back on-chip to the limiter stages and a quadrature detector. A received signal strength indicator (RSSI) output provides a dc voltage that is proportional to the dB level of the signal. This voltage goes to the front panel meter when in the NBFM mode. A squelch function (NBFM only) is controlled from a potentiometer on the front panel.

Audio Digital Signal Processing (DSP)

The DSP is based on the Analog Devices ADSP 2105 processor. The DSP program is stored in an EPROM and loaded into the 2105's RAM on power-up. DSP can be used in both SSB and CW. In USB or LSB (not CW or data) the DSP automatically locates and notches out one or several interfering carriers. In SSB or CW the manual audio notch filter described previously is also available, either as a notch filter or to reduce high frequency response (hiss filter). In the CW mode the DSP can be instructed to low-pass filter the audio with several corner-frequency values. A DSP noise reduction function tracks desired signals and attenuates broadband noise by as much as 15 dB, depending on conditions.

Audio Output

The 1.5-W audio output uses a TDA2611 chip. Either FM audio or SSB/CW audio or, in transmit, a CW sidetone, can be fed to the speaker or headphones. The sidetone level (a software adjustment) is separate from the volume control. The audio output, after A/D conversion, is also fed to the Anti-VOX algorithm in the microprocessor.

Transmit Block Diagram

Now, let's look at the path from microphone or key to the antenna, one stage at a time.

Microphone Amplifier

The suggested microphone is 200 Ω to 50 kΩ at 5 mV (–62 dB). A polarizing voltage for electret mics is provided. The Mic Amp drives the balanced modulator, either directly or through the speech compressor. It also supplies VOX information to the microprocessor, via an A/D converter. The microprocessor software sets Vox hang time and sensitivity, as well as the Anti-VOX, via the keypad. Timing and delays for T/R switching are also in the software.

Speech Processor

The audio speech processor is a compressor, as discussed previously. A dc voltage that is proportional to the amount of compression is sent to the front panel meter so that compression can be set to the proper level. Clipper diodes limit any fast transients that might overdrive the signal path momentarily.

Balanced Modulator

The balanced modulator generates a double-sideband, suppressed carrier IF at 9.0 MHz. The LO is that used for the receive product detector. There is a carrier nulling adjustment. In CW and FSK modes, the modulator is unbalanced to let the LO pass through. A built-in iambic keyer (Curtis style A or B) is adjustable from 10 to 50 WPM. An external key or keyer can also be plugged in.

IF Filter

The standard 9.0015 MHz, 2.4-kHz-wide 8-pole filter (also used in receive) removes either the lower or upper sideband. The output is amplified at 9.0 MHz.

ALC

The forward-power measurement from the PA output directional coupler is used for ALC, which is applied at the output of the first 9.0-MHz IF amplifier by a PIN diode attenuator. A front panel LED lights when ALC is operating. An additional circuit monitors dc current in the PA and cuts back on RF drive if the PA current exceeds 22 A.

Output Mixer

This mixer translates to the output signal frequency. The same LO frequency is used for each transmit mode (USB/LSB) and the same 3.00000-kHz frequency shift is used to assure that the frequency readout is always correct.

Band-pass Filters

The mixer output contains the image, at 9.0 plus LO and low values of harmonics and harmonic IMD products. A band-pass filter for each ham band, the same ones used in receive, eliminates all out of band products from the transmitter output.

PAs

Four stages of amplification, culminating in push-pull bipolar MRF454s in Class AB, supply 100 W output, CW or PEP from 160 to 10 m. Temperature sensing of the transistors in the last two stages helps to prevent thermal damage. Full output can be maintained, key down, for 20 minutes. Forced air heat-sink cooling allows unlimited on-time.

LO Frequency Management

The LO goals are to achieve low levels of phase noise, high levels of frequency stability and at the same time keep equipment cost within the reach of as many amateurs as possible. As part one of the LO analysis we look at the method used to adjust the LOs in order to keep the speech spectrum of a USB or LSB signal within the 9.0-MHz IF filter passband. This method is somewhat typical for many equipment designs. Refer to **Fig 15.4**.

First Mixer and Product Detector

An SSB signal whose carrier frequency is at 14.20000 MHz, which may be LSB or USB, is translated so that the modula-

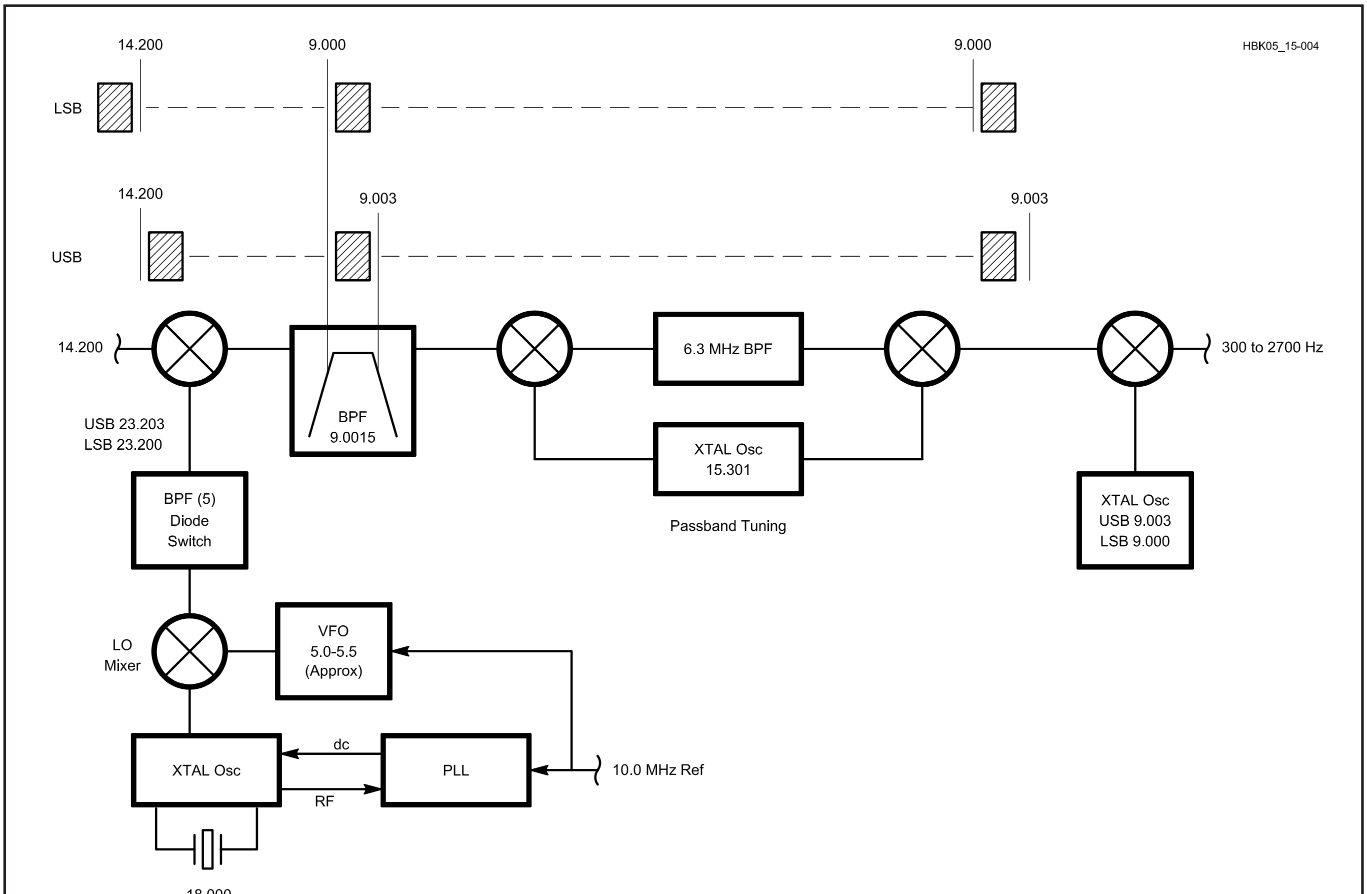


Fig 15.4 — LO frequency management in USB and LSB.

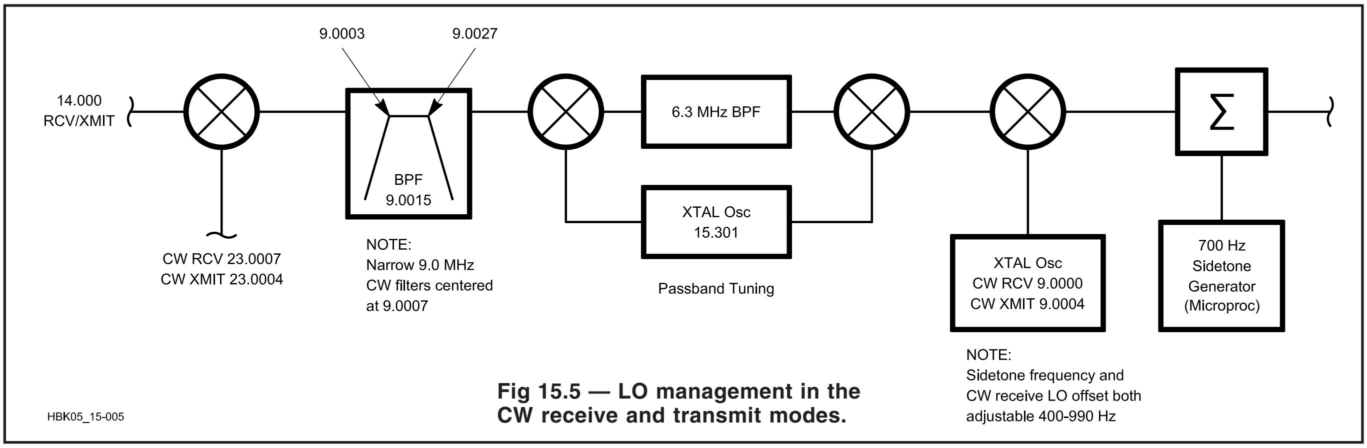


Fig 15.5 — LO management in the CW receive and transmit modes.

tion (300 to 2700 Hz) in either case falls within the passband of the 9.0015-MHz 8-pole crystal filter. For a USB signal this is accomplished by increasing the first LO 3 kHz, as indicated. Since the LO is on the high side of the signal frequency there is a sideband "inversion" at the first mixer. The passband tuning module does not change this relationship. At the product detector, the LO is increased 3 kHz in USB so that it is the same as the carrier (suppressed) frequency of the IF signal. Note that the designators "USB" or "LSB" at the product detector LO refer to the antenna signal, not the IF signal. The jog of the first mixer LO is accomplished partly within the crystal oscillator and partly within the VFO. The microprocessor sends the frequency instructions to both of these oscillators. Despite the frequency offsets, the digital readout displays the correct carrier frequency, in this example 14.20000 MHz. And, of course, the same procedures apply to the transmit mode.

Another interesting idea involves the first LO mixer. The 18-MHz crystal and the VFO are added to get 23.0 to 23.5 MHz, for the 20-m band. But the output of the LO mixer also contains the difference, 12.5 to 13.0 MHz, which is just right for the 80-m band. For the 20-m band one BPF selects 23.0 to 23.5 MHz. For the 80-m band the

12.5 to 13.0-MHz BPF is selected. A problem occurs, though, because now the direction of frequency tuning is reversed, from high to low. The microprocessor corrects this by reversing the direction of the tuning knob (an optical encoder). Other "book keeping" is performed so that the operation is transparent to the operator. A similar trick is used on the 17-m band and the 28.5 to 29.0-MHz segment of the 10-m band.

CW-Mode LO Frequencies

In CW mode the "transceiver problem" shows up. See **Fig 15.5** for a discussion of this problem. If the received carrier is on exactly 14.00000 MHz and if we want to transmit our carrier on that same exact frequency then the transmitter and the receiver are both "zero beat" at 14.00000 MHz. In receive we would have to retune the receiver, say up 700 Hz, to get an audible 700-Hz beat note. But then when we transmit we are no longer on 14.0000 MHz but are at 14.00070 MHz. We would then have to reset to 14.00000 when we transmit.

The transceiver's microprocessor performs all of these operations automatically. Fig 15.5 shows that in receive the first-LO frequency is increased 700 Hz. This puts the first IF at 9.0007 MHz, which is inside the passband of the 9.0 MHz IF filter. The BFO is at 9.0000 MHz and an audio beat note at 700 Hz is produced. This 700-Hz pitch is compared to a 700-Hz audio oscillator (from the microprocessor). When the two pitches coincide the signal frequency display of our transceiver coincides almost exactly with the frequency of the received signal. The digital frequency display reads "14.00000" at all times. The value of the 700-Hz reference beat can be adjusted between 400 and 950 Hz by the user. The receive LO shift matches that value.

When the optional 500/250 Hz CW 9.0 MHz IF filters are used, these are centered at 9.0007 MHz. These filters are used in receive but not in transmit.

When we transmit, the transmit frequency is that which the frequency display indicates, 14.00000 MHz. However, there is a slight problem. The 9.0-MHz transmit IF must be increased slightly to get the speech signal within the passband of the 9.0 MHz IF filter. The transmit BFO is therefore at 9.0004 MHz. The mixer LO is also moved up 400 Hz so that the transmit output frequency will be exactly 14.0000 MHz.

In addition to the above actions, the RIT (receive incremental tuning) and the XIT (transmit incremental tuning) knobs permit up to ±9.9 kHz of independent control of the receive and transmit frequencies, relative to the main frequency readout.

Local Oscillators

Fig 15.4 indicates that the crystal oscillator for the first mixer is phase locked. Each of the 10 crystals is locked to a 100-kHz reference inside the PLL chip. This reference is derived from a 10-MHz system reference.

Let's go into some detail regarding the very interesting 5.0 to 5.5 MHz VFO circuitry. **Fig 15.6** is a block diagram. The VCO output, 200 to 220 MHz, is divided by 40 to get 5.0 to 5.5 MHz. The reference frequency for the PLL loop is 10 kHz, so each increment of the final output is 10 kHz / 40, which is 250 Hz. Phase noise in the PLL is also divided by 40, which is equivalent to 32 dB (20 × log (40)).

To get 10-Hz steps at the output, the voltage-tuned crystal oscillator at 39.94 MHz is tuned in 200-Hz steps (the division ratio from oscillator to final output is 20 instead of 40 because of the frequency doubler). To get 200-Hz steps in this oscillator, serial data from the microprocessor is fed into a latch. This data is sent from a RAM lookup table that has the correct values to get the 200-Hz increments very accurately. The outputs of the latch are fed into an R/2R ladder (D/A conversion) and the dc voltage tunes the VCXO. Adjustment potentiometers calibrate the tuning range of the oscillator over 5000 Hz in 200-Hz increments. At the final output, this tuning range fills in the 10-Hz steps between the 250-Hz increments of the PLL. Although this circuit is not phase locked to a reference (it's an open-loop), the resulting frequency steps are very accurate, especially after the division by 20. This economical approach reduces the complexity and cost of the VFO considerably, but performs extremely well (very low levels of phase noise and frequency drift).

CW Break-In (Fast QSK) Keying

The radio is capable of break-in keying at rates up to 25 WPM when it is in the FAST QSK mode. This mode is also used

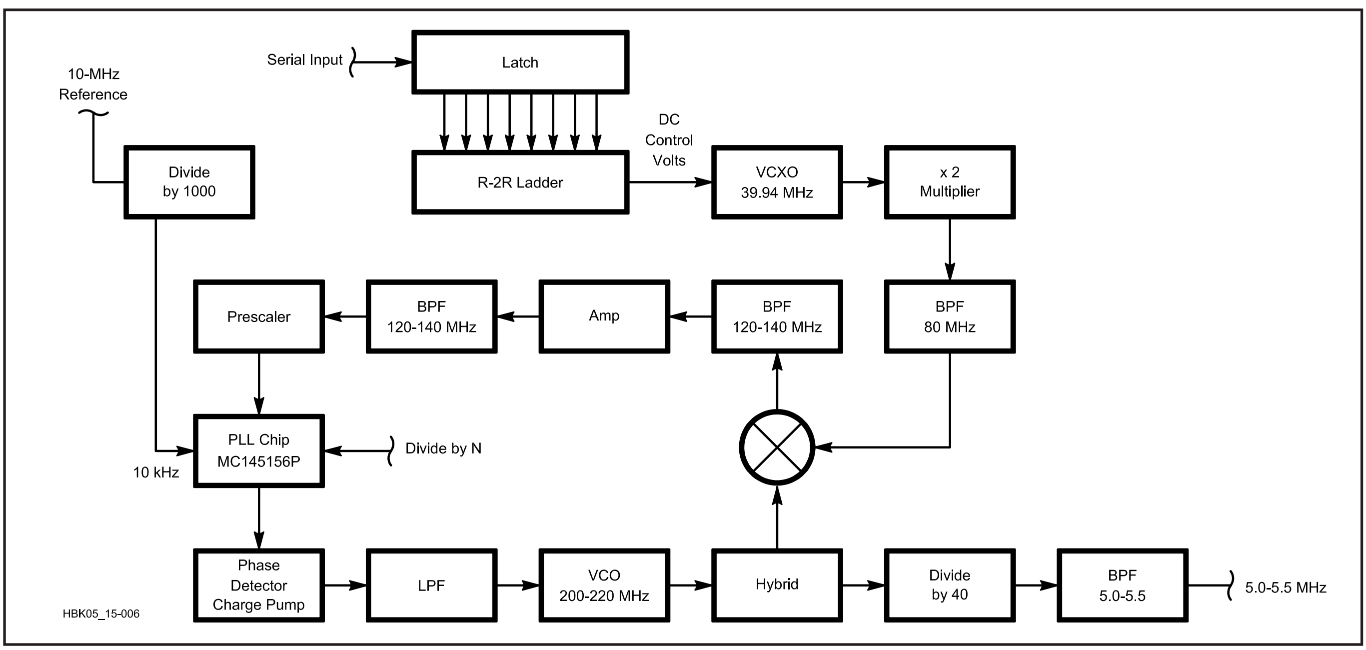


Fig 15.6 — Block diagram of the VFO.

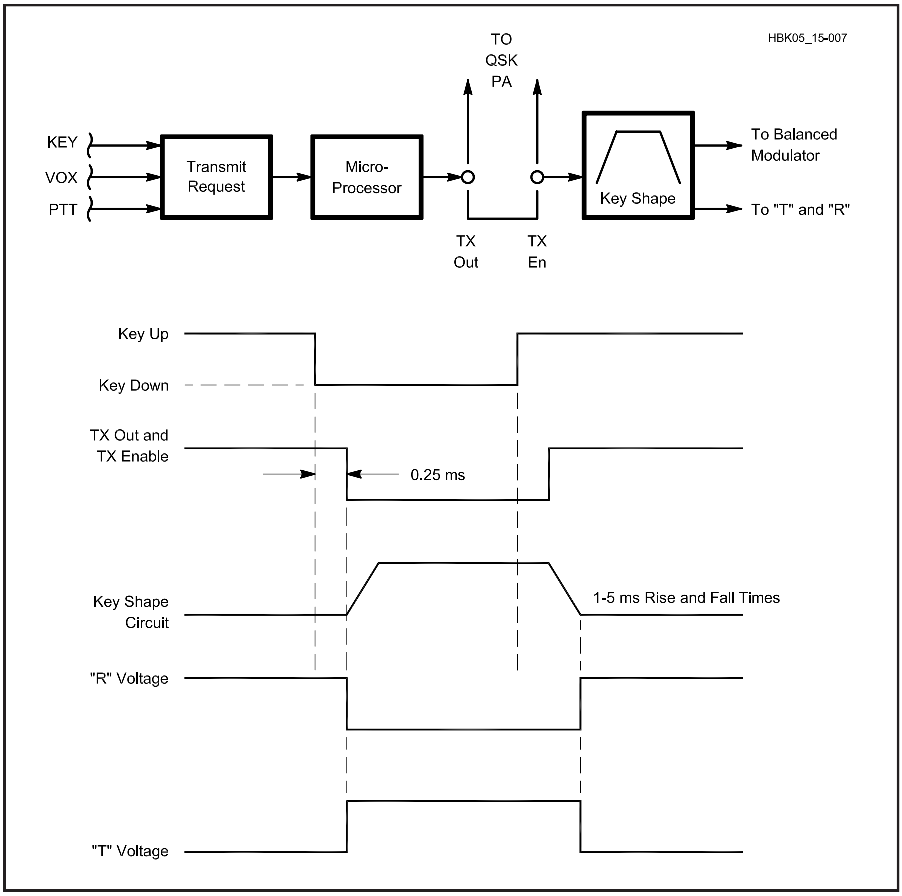


Fig 15.7 — Fast QSK operation of the Omni VI transceiver.

for AMTOR FSK. **Fig 15.7** explains the action and the timing involved in this T/R switching. The sequence of events is as follows:

1. The key is pressed.
2. A Transmit Request is sent to the microprocessor.
3. The microprocessor changes the LO and BFO to their transmit frequencies.
4. After a 0.25-ms delay a transmit out logic level is sent to a jack on the rear panel.
5. The Transmit Out signal is jumpered to the TRANSMIT ENABLE jack. If an external Fast QSK PA is being used, an additional short delay is introduced while it is being switched to the transmit mode.
6. The Transmit Enable signal starts the keying-waveform circuit, which ramps up in 3 ms.
7. Near the bottom of this ramp, the "T" (transmit B+) voltage goes high and the "R" (receive B+) voltage goes low. The T/R reed relay (very fast) at the Omni VI PA output switches to transmit.
8. The shaped keying waveform goes to the balanced modulator and the RF envelope builds up. There is a very brief delay from balanced modulator to Omni VI output. The T/R relay is switched before the RF arrives.
9. The key is opened.
10. The Transmit Out and Transmit Enable lines go high.
11. The keying waveform ramps down. RF ramps down to zero.
12. After 5 ms (a fixed delay set by the microprocessor) "T" goes low and "R" goes high and the microprocessor returns the LO and BFO to their receive frequencies.

Slow QSK

In the Slow QSK mode the action is as described above. The radio reverts quickly to the receive mode. However, the receive audio is muted until the end of an extended (adjustable) delay time.

There is also a relay in the Omni VI that can be used to T/R switch a conventional (not Fast QSK) external PA. This option is selected from the operator's menu and is available only in the Slow QSK mode. The relay is held closed for the duration of the delay time in the slow QSK mode. When using this option the operator must ensure that the external PA switches fast enough on the first "key-down" so that it is not "hot switched" or that the first dot is missed. Many older PAs do not respond well at high keying rates. If the PA is slow, we can still use the Fast QSK mode with the Omni VI ("barefoot") and the PA will be bypassed because the optional relay is not energized in the Fast QSK mode.

VOX

In SSB mode, VOX and PTT perform the same functions and in the same manner as the CW Slow QSK described above. The VOX hang-time adjustment is separate from the CW hang-time adjustment. A MUTE jack allows manual switching (foot switch, and so on) to enable the transmit mode without applying RF. The key or the VOX then subsequently applies RF to the system. This arrangement helps if the external PA has slow T/R switching.

Operating Features

Modern transceivers have, over the years, acquired a large ensemble of operator's aids that have become very popular. Here are some descriptions of them:

Key Pad

The front panel key pad is the means for configuring a wide assortment of operating preferences and for selecting bands and modes.

Frequency Change

1. Use the tuning knob. The tuning rate can be programmed to 5.12, 2.56, 1.71, 1.28, 1.02 or 0.85 kHz per revolution. The knob has adjustable drag.
2. UP and DOWN arrows give 100 kHz per step.
3. Band selection buttons.
4. Keyboard entry of an exact frequency.

Mode Selection

1. ***Tune***: Places the rig in CW mode, key down, for various "tune-up" operations.
2. ***CW***: An optional DSP low-pass filter can be selected. Cutoff frequencies of 600, 800, 1000, 1200 or 1400 Hz can be designated. A SPOT function generates a 700-Hz audio sidetone that can be used for precise frequency setting (the received signal pitch matches the 700-Hz tone). The pitch of the sidetone can be adjusted from 400 to 950 Hz. Audio level is adjustable also. FAST QSK and SLOW QSK are available as previously described. Cascaded CW filters are available, with passband tuning of one of the filters. CW filter options: 500/250 Hz at 6.3 MHz IF and 500 Hz at 9.0-MHz IF.
3. ***USB or LSB***: Standard SSB IF bandwidth is 2.4 kHz (two 8-pole filters in cascade). The second filter can be passband-

tuned ±1.5 kHz. Additional IF filters with 1.8-kHz BW are available.

4. ***FSK and AFSK***: Special FSK filter for receive. AMTOR operation with FAST QSK capability. AFSK generator can be plugged into microphone jack.

5. ***FM***: 15-kHz IF filters at 9.0 MHz and 455 kHz. Quadrature detection, RSSI output and squelch. Adjustable transmit deviation. FM transmit uses the direct method.

6. ***VOX***: VOX sensitivity and hang time adjustable via the key pad. Anti-VOX level adjustable.

Time of Day Clock

There is a digital readout on front panel.

Built-In Iambic Keyer

Curtis type A or B, front panel speed knob. Adjustable dot-dash ratio. Also external key or keyer.

Dimmer

Adjusts brightness of front panel display.

Dual VFOs

Select A or B. Independent frequency, mode, RIT and filter choices stored for each VFO. Used for split-frequency operation.

Receiver Incremental Tuning (RIT)

Each VFO has its own stored RIT value.

Frequency Offset Display

RIT value adjusted with knob. RIT can be toggled on and off, or cleared to zero.

Transmitter Incremental Tuning (XIT)

Same comments as RIT. Simultaneous RIT and XIT.

Cross-Band and Cross-Mode Operation

For cross-band operation, use PTT for SSB and manual switch for CW.

Scratch-Pad Memory

Stores a displayed frequency. Restores that frequency to the VFO on command.

Band Register

Allows toggling between two frequencies on each band.

Memory Store

Store 100 values of frequency, band, mode, filter, RIT, XIT. Memory channels can be recalled by channel number (key pad), "scrolling" the memory channels or "memory tune" using the main tuning knob.

Lock

Locks the main tuning dial.

User Option Menu

Enables configuration of the radio via the keypad.

Meter

Select between receive signal strength (on SSB/CW or NBFM), speech processor level, forward power, SWR and PA dc current.

AGC

Fast, slow, off and manual RF gain control.

FM Squelch Adjust

Passband Tuning Knob

Notch

Automatically notch out several heterodynes on SSB/FM or manually notch on CW/digital modes. Adjustable low-pass filter in CW mode.

Antenna Switch

Auxiliary antenna may be selected in receive mode.

Interface Port

25-pin D connector for interface to personal computer.

OTHER TRANSCEIVERS

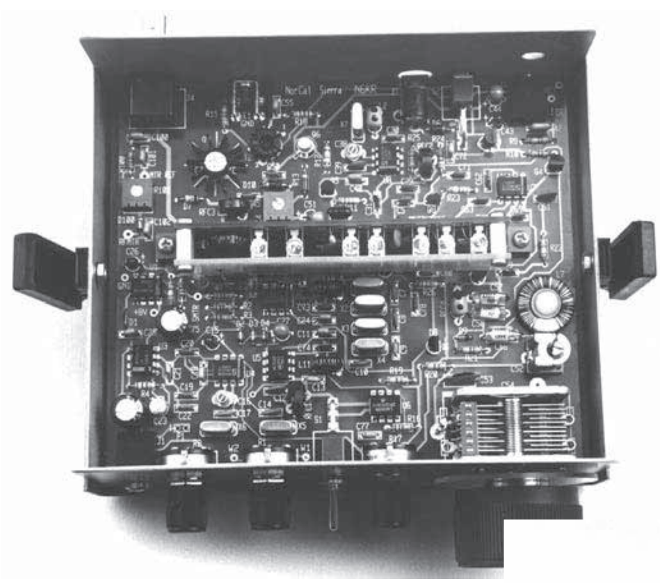
Other transceivers vary in cost, complexity and features. The one just described is certainly one of the best, at a reasonable price. For reviews of other transceivers (to see the differences in cost, features and performance specs) refer to the Product Reviews in *QST*.

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



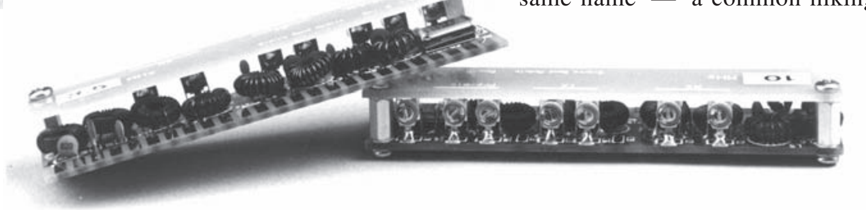


Fig 15.8 — The Sierra transceiver. One band module is plugged into the center of the main PC board; the remaining boards are shown below the rig. Quick-release latches on the top cover of the enclosure make it easy to change bands.

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.

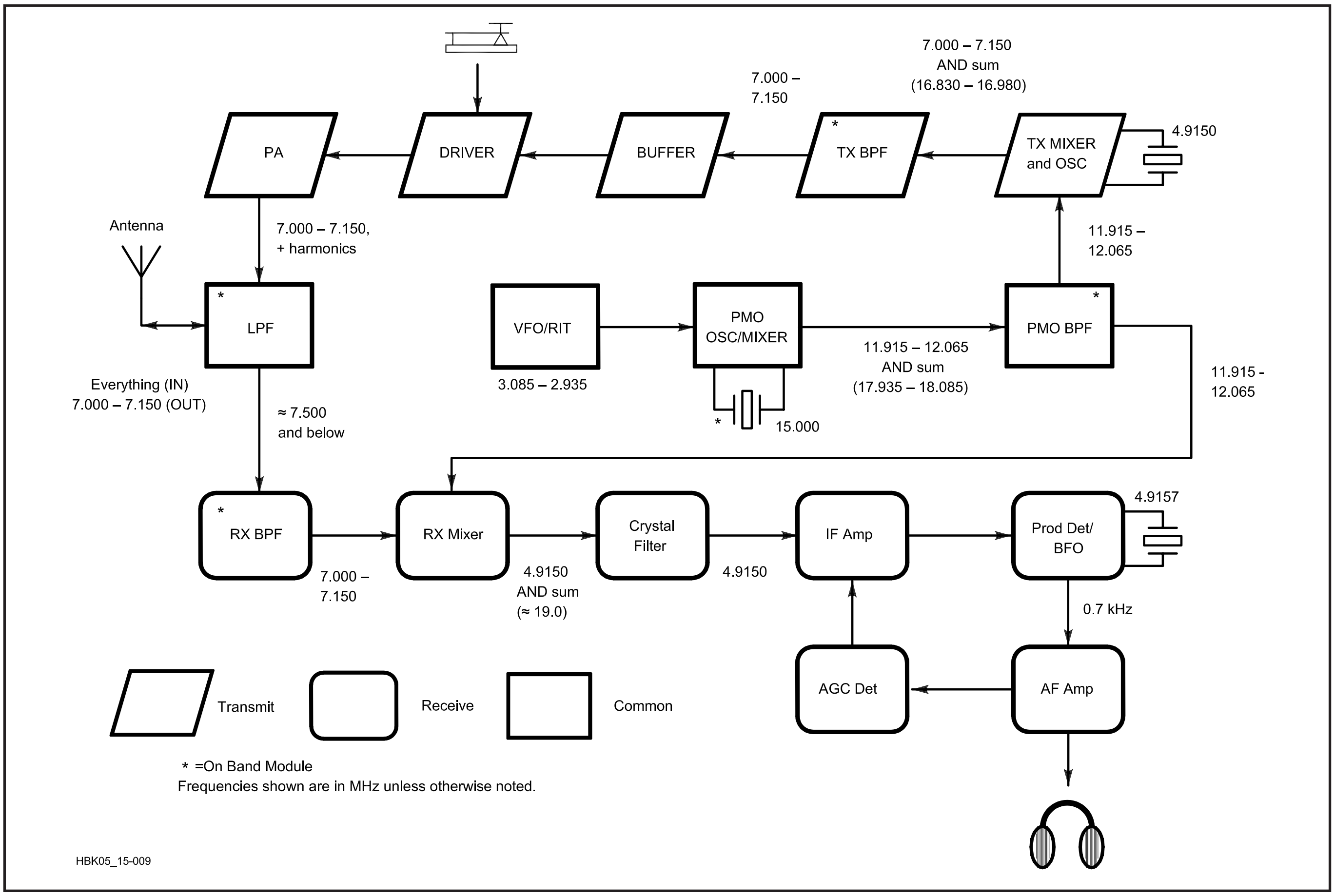


Fig 15.9 — Block diagram of the Sierra transceiver. Three different-shaped symbols are used to show transmit, receive and common blocks. Those blocks with an asterisk (*) are part of the band module. Signal frequencies shown are for 40 m; see Table 15.1 for a list of crystal oscillator and premix frequencies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

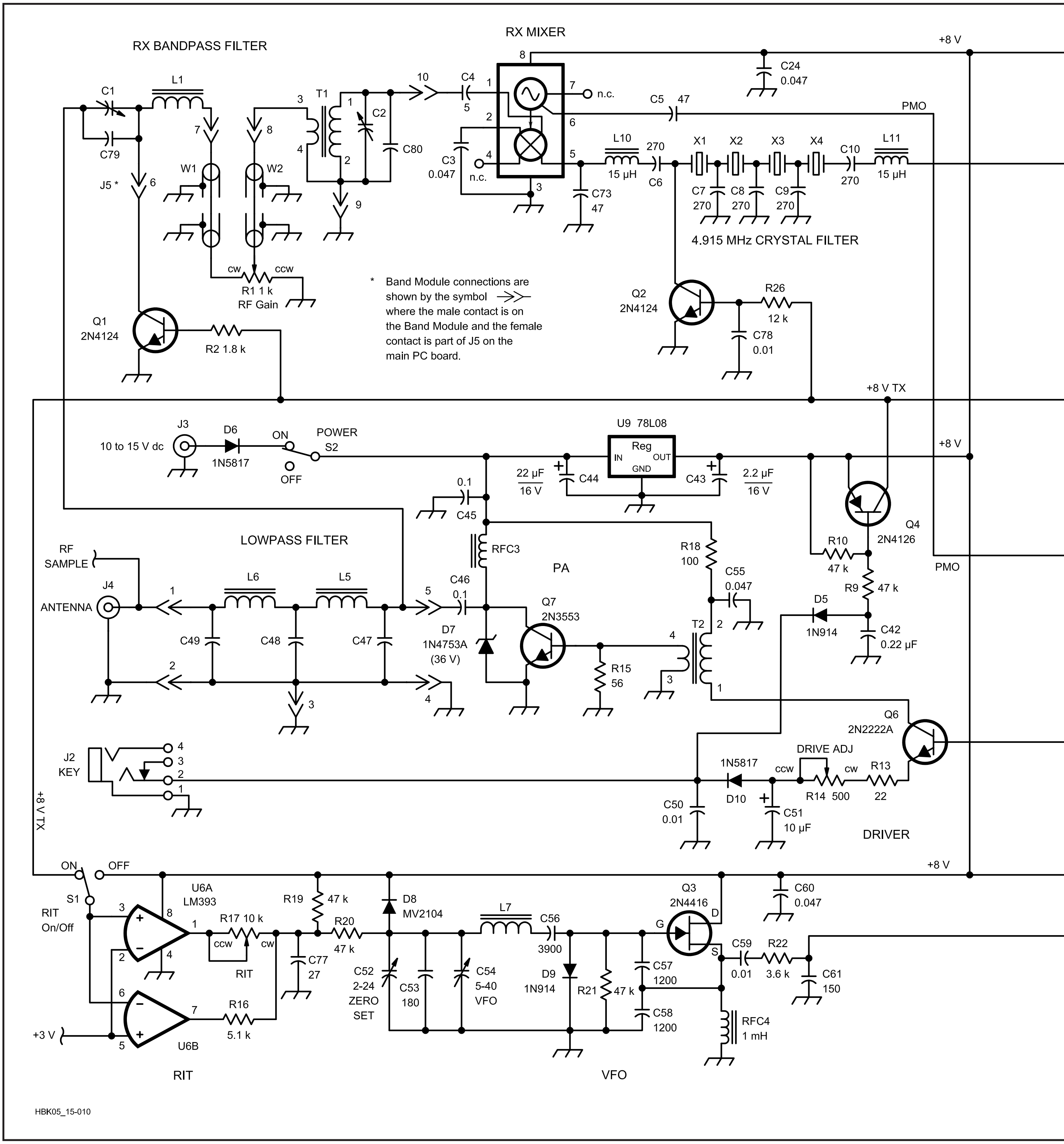
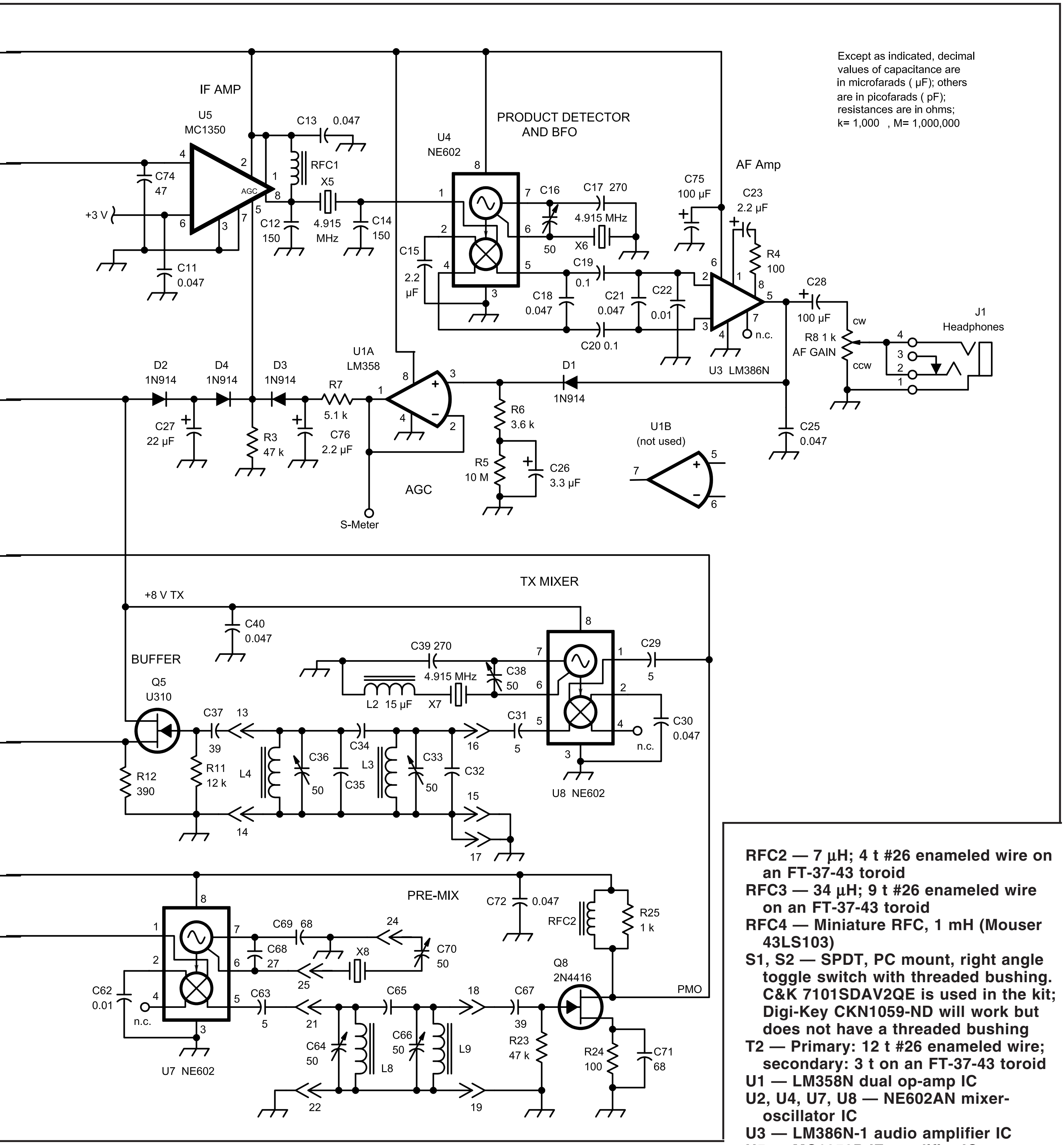


Fig 15.10 — Schematic of the Sierra transceiver. Parts that change for each band are shown in Table 15.2.

C1, C2, C33, C36, C64, C66, C70 — 9-50 pF right-angle-mount ceramic trimmer (same for all band modules, Mouser 24AA084)
C16, C38 — Ceramic trimmer, 8-50 pF (Mouser 24AA024)
C52 — Air variable, 2-24 pF (Mouser 530-189-0509-5)
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 (Mouser 333-1N4753A)
D8 — MV2104 varactor diode, or equivalent
J1, J2 — PC-mount 3.5-mm stereo jack with switch (Mouser 161-3500)
J3 — 2.1-mm dc power jack (Mouser 16PJ031)
J4 — PC-mount BNC jack (Mouser 177-3138)
J5 — 50 pin, dual-row edgeboard connector with 0.156-inch spacing (Digi-Key S5253-ND)



L10, L11 — 18 µH; 18 t #28 enameled wire on an FT-37-61 toroid
L2 — Miniature RFC, 15 µH (Mouser, 43LS185)
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 (Mouser 31CW301)
R14, R101 — 500 Ω trimmer (Mouser 323-4295P-500)
R17 — PC-mount 10-kΩ pot (Mouser 31CW401)
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 (Mouser 43LS103)
S1, S2 — SPDT, PC mount, right angle toggle switch with threaded bushing. C&K 7101SDAV2QE is used in the kit; Digi-Key CKN1059-ND will work but does not have a 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 — NE602AN 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 (Digi-Key AN78L08-ND)
W1, W2 — RG-174 coaxial jumper, about 3 inches long (see text)
X1-X7 — 4.915 MHz, HC-49 (Digi-Key CTX050). X1 through X5 should be matched (their series-resonant frequencies within 50 Hz)

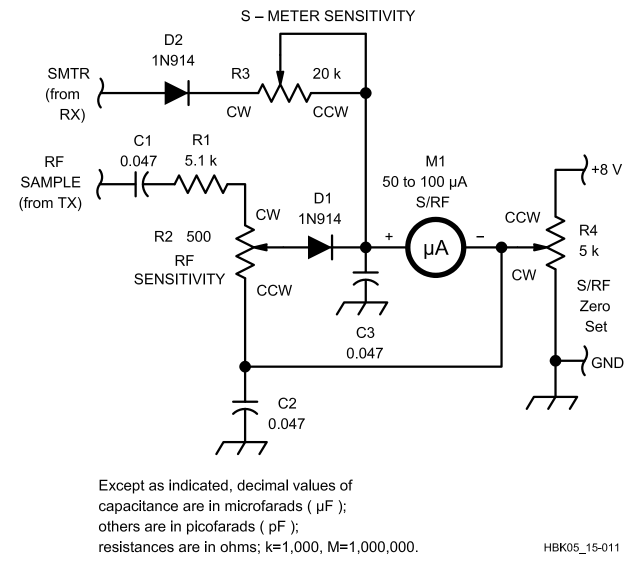


Fig 15.11 — Metering circuitry for the Sierra transceiver.

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 homemade 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. Construction details for these bands are provided in the Sierra information packet available from the ARRL. Go to the ARRL Web page: **www.arrl.org/notes/** to download a template package or write to the ARRL Technical Department Secretary and request the '96 *Handbook* Sierra template package.

[3]For information about NorCal, write to Jim Cates, WA6GER. Please include an SASE.

[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.

[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 in Los Altos, CA.

[7]The alignment procedure given here is necessarily brief. More complete instructions are provided with the ARRL template package and the kit. See note 2 to obtain a template.

[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.

A 10-WATT SSB TRANSCEIVER FOR THE 60-METER BAND

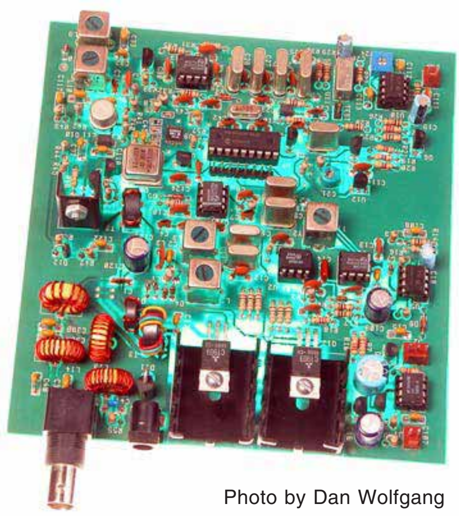


Photo by Dan Wolfgang

It is not often we get a new amateur allocation in the HF spectrum! This 60-m transceiver design provides the builder with an approach that emphasizes a minimum number of adjustments during construction. This should be considered an advanced homebrew project. It makes use of a select number of surface-mount (SMT) components not readily duplicated using traditional construction techniques.[1] This project was designed by Dave Benson, K1SWL (ex-NN1G).

The new 60-Meter band departs from the traditional amateur allocations in that operation is channelized on five discrete frequencies. Operation is restricted to Upper sideband (USB), voice only. These channels are specified as being within a 2.8-kHz window centered on 5332, 5348, 5368, 5373 and 5405 kHz.

The multiple fixed-channel allocation suggests that the traditional analog Local Oscillator (LO) scheme would be unattractive from repeatability and stability standpoints. While a crystal-controlled LO approach is perfectly feasible, cost and complexity increase rapidly for more than several channels. This design makes use of the Direct-Digital-Synthesis (DDS) approach. It uses a MicroChip 16F628A, a 2K × 14 CMOS microcontroller that performs DDS frequency management, channel selection and fine-tuning (RIT) control and channel indication. Microcontroller source code and hex files for this project are both available.[2] **Fig 15.12** shows the schematic diagram and parts list for this 60-m project. The DDS IC (U14) contains two sets of frequency registers, loaded at power-up with two copies of the LO frequency. One is used during *transmit* and is fixed in frequency. The second frequency register set is used during *receive* and is fine-tuned by use of the RIT function. RIT is mechanized using an inexpensive electromechanical shaft encoder. Each detented step of the encoder yields a 10 Hz frequency step, with limit stops in firmware at ±500 Hz, sufficient to fine-tune stations slightly off-frequency within the channel window. The microcontroller steers the DDS IC between the two register sets via the T/R* signal (U14, pin 10).

Each time the frequency is initialized or changed, the DDS IC receives a sync signal and a burst of 40 clock pulses and corresponding serial data. This data is in the form of an 8-bit control word and a 32-bit frequency control word. The IC generates a sinusoidal waveform with 10 bits of D/AC resolution. This is an accuracy of 1 part in 1024 (2^{10}) — maximum error is one part in 2048, which corresponds to roughly 66 dB below the desired output. The LO frequency varies by channel and is at approximately 2.3 MHz. The output of the DDS is applied to a low-pass filter to removed unwanted high-frequency energy. This consists of both the 25-MHz clock energy and an alias signal. The alias signal is at the difference of the system clock and desired outputs, i.e., ~22.7 MHz. The resulting spectrum at the output of this filter is quite clean. Other components (spurs) of this waveform are present at low levels and their presence establishes the Spurious-Free Dynamic Range (SFDR). Those close-in spurs, i.e., nearest the desired LO frequency are of most interest. Spurs farther from the desired frequency are less critical, as their effect on receiver performance is mitigated by receiver front-end selectivity. This SFDR is reasonable for the application, but would normally be augmented with a cleanup loop (PLL) for higher-performance applications.

The microcontroller and DDS use their own local voltage regulator (U12). The primary contributor to digital noise in the

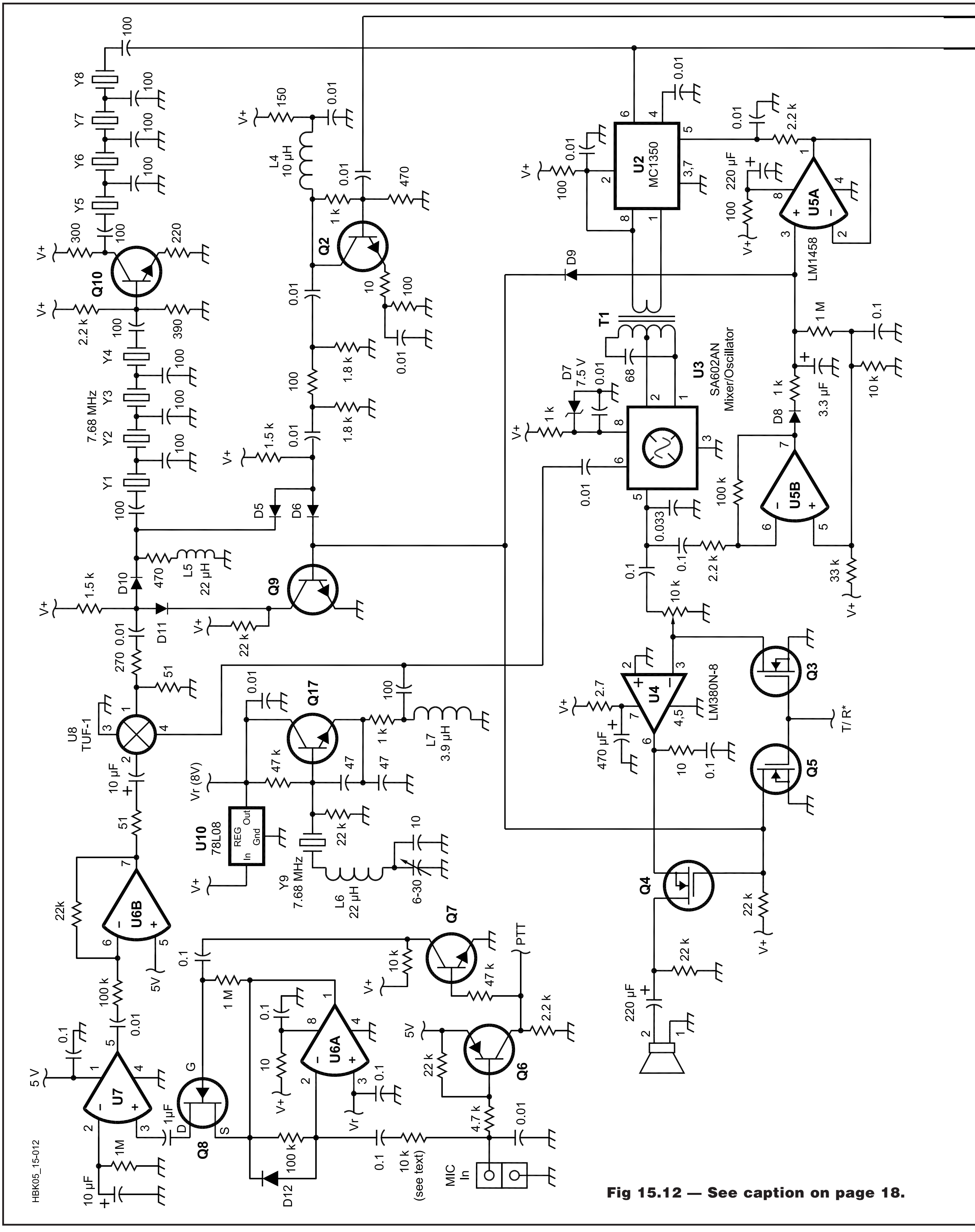
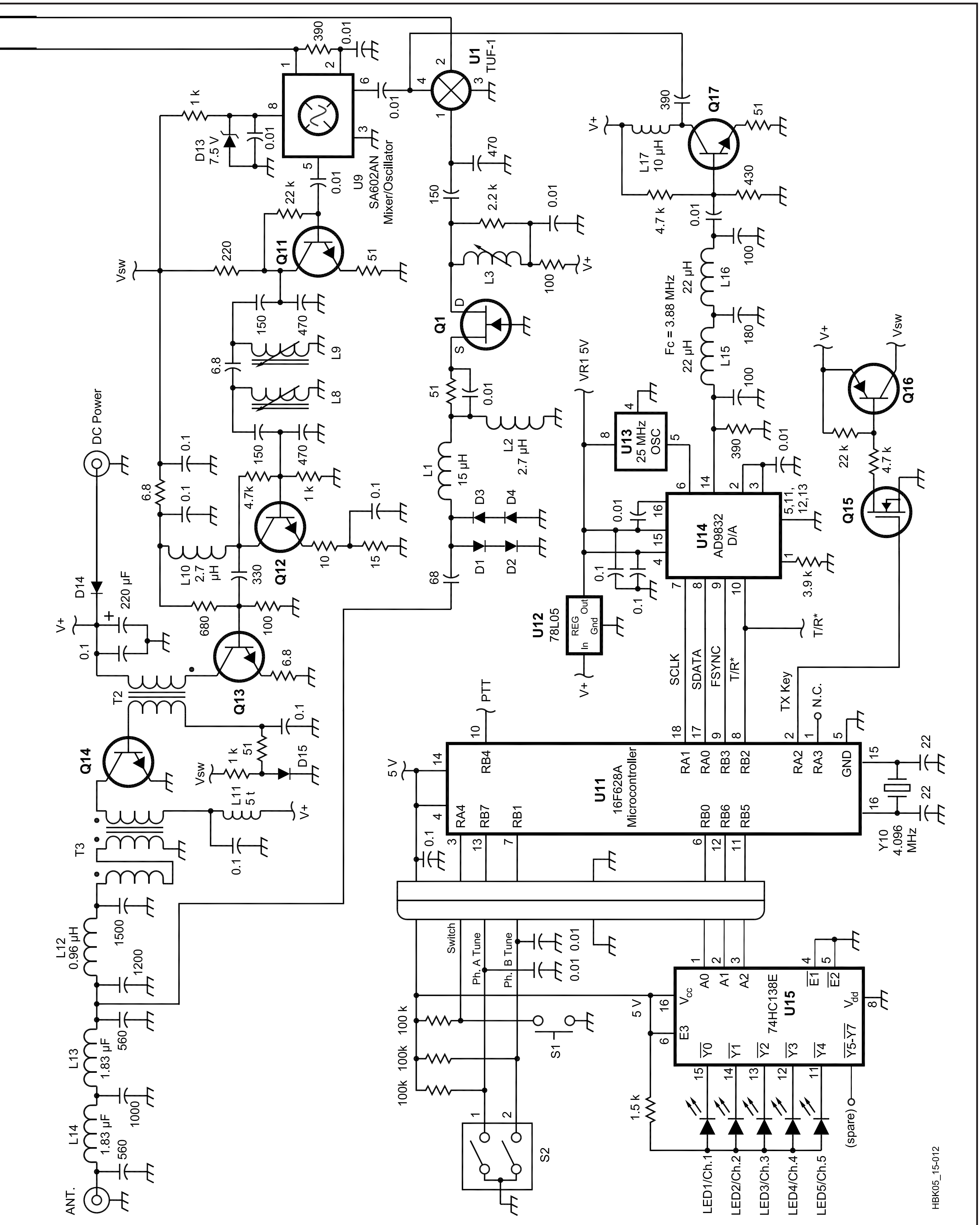


Fig 15.12 — See caption on page 18.



U1
TUF-1
U9
SA602AN
Mixer/Oscillator
D13
7.5 V
Q11
Q12
Q13
Q14
Q1
Q15
Q16
Q17
L1
15 µH
L2
2.7 µH
L3
L8
L9
L10
2.7
µH
L11
5 t
L12
0.96 µH
L13
1.83 µF
L14
1.83 µF
L15
22 µH
L16
22 µH
L17
10 µH
Fc = 3.88 MHz
T2
T3
D1
D2
D3
D4
D14
D15
220 µF
DC Power
ANT.
Vsw
V+
VR1 5V
U12
78L05
REG
In
Gnd
Out
U13
25 MHz
OSC
U14
AD9832
D/A
SCLK
SDATA
FSYNC
T/R*
TX Key
N.C.
PTT
U11
16F628A
Microcontroller
RA4
RB7
RB1
RB4
RA1
RA0
RB3
RB2
RA2
RA3
GND
RB0
RB6
RB5
Y10
4.096
MHz
5 V
Switch
Ph. A Tune
Ph. B Tune
S1
S2
U15
74HC138E
A0
A1
A2
E3
Y0
Y1
Y2
Y3
Y4
Y5-Y7
(spare)
LED1/Ch.1
LED2/Ch.2
LED3/Ch.3
LED4/Ch.4
LED5/Ch.5
HBK05_15-012

Fig 15.12 — Schematic of the 10-W, USB Transceiver for the new 60-m band. All resistors are ¼-W, 5% carbon film. Small value (<.01 uF) fixed capacitors are NPO/C0G characteristic; polarized capacitors are aluminum electrolytic. One possible source of RF power transistors is RF Parts Company, San Marcos, CA.

D1-D6, D8-D12 — 1N4148 small-signal diode
D7, D13 — 7.5V Zener diode, Mouser 625-1N5236B
D14 — 1N5822, 3A Schottky rectifier diode
D15 — 1N4001, 1A rectifier diode
L1 — 15 uH submin. RF choke, Mouser 434-22-150
L2 — 2.7 uH submin. RF choke, Mouser 434-22-2R7
L3, L8, L9 — 10.7 MHz IF transformer, secondary unused, Mouser 42IF123
L4, L17 — 10 uH submin. RF choke, Mouser 434-22-100
L5, L6 — 22 uH submin. RF choke, Mouser 434-22-220
L7 — 3.9 uH submin. RF choke, Mouser 434-22-3R9
L10 — 2.7 uH submin. RF choke, Mouser 434-22-2R7
L11 — 5 turns #22 AWG on FT37-43 core
L12 — 0.96 uH, 14 turns #22 AWG on T50-2 core
L13, L14 — 1.83 uH, 19 turns #22 AWG on T50-2 core
L15, L16 — 22 uH submin. RF choke, Mouser 434-22-220
Q1 — J309 or J310 FET
Q2 — 2N2222A transistor
Q3, Q4, Q5, Q15 — 2N7000 MOSFET
Q6, Q16 — 2N3906 PNP transistor
Q7, Q9, Q10,Q11, Q17 — 2N4401 transistor
Q8 — 2N5485 FET
Q12 — 2N2219A transistor
Q13 — 2SC2078 or 2SC2166 transistor
Q14 — 2SC2312C transistor
S1 — pushbutton switch, single pole-normally open
S2 — rotary shaft encoder, Mouser 318 ENC16024P
T1 — 10.7 MHz IF transformer, Mouser 42IF123
T2 — 4 turns #22 AWG bifilar on FT50-43 core
T3 — 4 turns #22 AWG trifilar on FT50-43 core, observe polarity indications on schematic
U1, U8 — TUF-1, +7 dBm mixer, Minicircuits Labs
U2 — MC1350P IF Amplifier, Jameco Electronics 24942CF
U3, U9 — SA602AN Mixer/Oscillator IC, Future Electronics
U4 — LM380N-8, AF Amplifier, 8-pin. DigiKey LM380N-8
U5, U6 — LM1458, MC1458, or equivalent, dual operational amplifier
U7 — Speech Amplifier IC, AN6123. Digikey AN6123MSTXLCT
U10 — 8V, 100 mA 3-terminal voltage reg., Mouser 511-L78L08ACZ
U11 — 16F628A Microcontroller, Digikey PIC16F628A-04/P. Note: this is a blank (unprogrammed) device requires programming. See notes
U12 — 5V, 100 mA 3-terminal voltage reg, Mouser 511-L78L05ACZ
U13 — CMOS Clock oscillator, 25.00 MHz, Mouser 73-X052B2500
U14 — 10-bit Direct-digital synthesis (DDS) IC, Analog Devices AD9832BRU, Avnet Electronics Marketing
U15 — 74HC138E IC, 3:8 Demultiplexer
Y1-Y9 — 7.68 MHz microprocessor crystal, 20-pF load calibration group within 100 Hz. Mouser. 520-HCA768-20

receiver proved to be those ICs — this separation was necessary to keep the receive quiet.

The crystal (IF) filter is central to the transceiver. The IF is 7.68 MHz, a frequency chosen over several others based on spurious emissions consideration based on a birdy analysis. The filter (Y1-Y8 and associated capacitors) is mechanized as a pair of 4-pole filters for a total of 8 poles of filtering. Although the filter skirt slope is steeper on the high-frequency side, the slope is sufficient for good residual-carrier and alternate sideband suppression with oscillator injection on the low-frequency side. This has the important result of permitting upper-sideband generation at a much lower (2.3 MHz) LO frequency. This considerably eases the frequency-accuracy issue.

The IF passband width is 1.9 kHz. Although somewhat narrow for ragchewing, it is representative of the filter widths used for contesting. This narrow width proved necessary to provide sufficient suppression of out-of-channel energy, and also eased the frequency-tolerance issue by guard-banding both edges of the frequency window. Loss through the filter is minimal; passband ripple is a maximum of 2.4 dB. The source and termination impedances are 330 Ω. The crystals are readily-available microprocessor types (see the parts list in Fig 15.12) and should be selected by frequency within a grouping of 100 Hz in frequency.

The IF filter is shared between transmit and receive functions to avoid a significant duplication of hardware. Diodes D10/D11 (transmit side) and D5/D6 (receive) serve to isolate Receive and Transmit circuit functions as needed. For the network that is turned off, the series diode is back-biased (non-conducting) and the shunt diode is conducting (low-impedance) for good isolation performance. Rather than replicate this hardware at the downstream end of the filter, the filter drives both receiver product detector and transmit second mixer in parallel. This is a tradeoff based on the cost of the associated components (the two mixers) and printed circuit-board layout complexity. While the SA602A IC used for the transmit second mixer is inferior to the diode-ring mixers for 3rd-order intercept and balance (suppression between ports), it is well adequate in this narrow-band application.

The receiver design uses a +7dBm diode-ring mixer for its first mixer. This yields higher odd-order intercept performance than the popular SA602/SA12 mixer found in many minimum-parts-count designs. Grounded-gate JFET Q1 provides modest gain ahead of the mixer. While not necessary for signal-to-noise ratio purposes, it provides additional isolation between antenna and any LO leakage from the receive first mixer. Note that the presence of this preamp stage degrades the receiver intercept to reduce the superiority of the diode-ring mixer over the SA602/SA612 — a mixed blessing.

This transceiver design uses the readily-available HT speaker-mics simply to afford a standardized approach. Any of a number of ICOM/Yaesu-compatible products is usable — you'll want the twin-plug (2.5mm and 3.5mm) version with two contacts on each prong. Aftermarket offerings include the Pryme SPM-100 and the RadioShack 291-314, among others. This choice of microphone has several ramifications to the design, discussed below.

Both microphone element and PTT switch are combined in series (single-signal and ground) on the 2.5-mm connector plug. Although it reduces the number of connections to a speaker/mic, its practical effect is to introduce a sizable audio transient into the speech-amplifier circuitry on key-down. Op-amp U6, section A, provides some gain but also serves to clamp this audio transient to within one diode drop of reference voltage V_r via D12. Q7 is configured as a one-shot and provides a brief gating pulse to FET Q8 to open the audio path briefly during key-down to avoid upsetting subsequent speech-amplifier stages.

U7 is a speech-amplifier IC recently available, and designed with the cell-phone industry in mind. It features approximately 45 dB of AGC action, reducing that variation in input signal range into a peak output range of about 2 dB with modest distortion figures.

The remaining section of U6 serves to buffer this ICs output and provide the necessary low-source impedance to the transmit first mixer. Speaker/mics vary noticeably in terms of microphone output level. The value shown at the microphone input path (see schematic) assumes a fairly low microphone output level. This resistance value should be revised upwards, reducing gain, if you receive reports of excessive audio background noise while transmitting.

The speaker/mic approach also requires high isolation between receive and transmit audio signals. During receive, the microphone element is physically disconnected and the speech amplifier circuitry is further isolated by the filter-switching network (D10/D11). During transmit, the receiver output must be positively disconnected from the speaker to prevent audio feedback through the speaker/mic. This is typically manifested as a hollow sound or by squealing at higher feedback levels. Several MOSFET switches around the audio amplifier IC provide the function. Transistor Q3 provides a low-resistance shunt to ground during transmit. Additionally, Q4 is employed as a series switch to disconnect the path between AF amplifier and speaker. A variation of configurations was tested in the quest for high isolation, this one proving the most successful. Upstream, i.e., IF gain control was tried unsuccessfully — the supply feed to the audio amp IC itself proved to be a source of unwanted feedback via power-supply sag under high-current conditions.

For a channelized frequency allocation, the task of frequency annunciation is considerably simplified. Five LED indicators corresponding to the 5 allocated channels accomplish this. The three LED logic signals are binary encoded and are expanded into one-of-eight to illuminate individual LEDs. Three spare lines are available in the event that additional channels become available. For the advanced homebrewer, firmware for several of these three signals could be recoded as serial data to an LCD or LED display. Jameco Electronics offers a serial-to-parallel-port expansion IC compatible with many parallel-LCD display modules. While the LCD has largely overtaken the LED display in popularity for reasons of power consumption, the recent availability of super-bright, 7-segment LED displays renders that approach worthy of reconsideration. (The incentive to upgrade in this way would of course be strengthened by any assignment of additional frequencies within the 60-meter band.)

Alignment is straightforward due to the low number of adjustments in this design. The receiver is peaked via L3 and T1 for maximum signal level. The firmware contains a built-in calibration mode for fine-tuning the LO frequency. Powering up the transceiver with the channel-select switch depressed yields a loud audio tone. Its frequency is adjusted to 800 Hz using a frequency counter applied to the transceiver speaker output. If a frequency counter is not available, this critical step must still be performed and can be easily accomplished using currently-available computer soundcard applications.[3] The transceiver stays in this mode until power is removed. Upon key-down into a dummy load, inductors L8 and L9 are adjusted for maximum indicated output power.

Going *on the air* is as simple as one could hope for. The transceiver powers up at the lowest frequency channel and illuminates one of five LEDs. Depressing pushbutton switch S1 advances the tuning to the next channel. If the switch is held down, the channel selection scans through the bank of five frequencies until the switch is released. With each change in channel selection, the RIT function offset is reset to the neutral position.

Spectral purity measurements taken at a 10-W carrier show spur content at –50dBc or better. Harmonic content at the second harmonic is –46 dBc and –50 dBc or better for all higher harmonics.

Notes

[1]A double-sided printed-circuit board is available from the author with SMT components preinstalled and functional-tested. $35 US ($40 DX) includes shipping. See **www.smallwonderlabs.com/projects.htm** for ordering information.

[2]Documented source code for the 16CF628 microcontroller, as well as hex (programming) files are available for free download. See **www.smallwonderlabs.com/projects.htm**.

[3]A variety of Amateur-Radio applications with soundcard/spectrographic displays are available. See **www.psk31.com** software links. DigiPan, among others, is freeware. See also **www.visualizationsoftware.com** for the popular Spectrogram application. This has a registration fee but provides a free trial period.

Transverters

At VHF, UHF and microwave frequencies, transverters that interact with factory-made transceivers in the HF or VHF range are common and are often home-built. These units convert the transceiver transmit signal up to a higher frequency and convert the receive frequency down to the transceiver receive frequency. The resulting performance and signal quality at the higher frequencies are enhanced by the frequency stability and the signal processing capabilities of the transceiver. For example, SSB and narrowband CW from 1.2 to 10 GHz are feasible, and becoming more popular. Some HF and VHF transceivers have special provisions such as connectors, signal-path switching and T/R switching that facilitate use with a transverter.

VHF TRANSVERTERS

The methods of individual circuit design for a transverter are not much different than methods that have already been described. The most informative approach would be to study carefully an actual project description.

The interface between the transceiver and transverter requires some careful planning. For example, the transceiver power output must be compatible with the transverter's input requirements. This may require an attenuator or some modifications to a particular transverter or transceiver.

When receiving, the gain of the transverter must not be so large that the transceiver front-end is overdriven (system IMD is seriously degraded). On the other hand, the transverter gain must be high enough and its noise figure low enough so that the overall system noise figure is within a dB or so of the transverter's own noise figure. The formulas in the **Receivers and Transmitters** chapter for cascaded noise figure and cascaded third-order intercept points should be used during the design process to assure good system performance. The transceiver's performance should be either known or measured to assist in this effort.

MICROWAVE TRANSVERTERS

The microwave receiver section of the **Receivers and Transmitters** chapter in this *Handbook* discusses a 10-GHz transverter project and provides references to the *QST* articles that give a detailed description. The reader is encouraged to refer to these articles and to review the previous material in that chapter.

Other Information

The ARRL UHF/Microwave Experimenter's Manual and ARRL's *Microwave Projects* contain additional interesting and valuable descriptions of transverter and transponder requirements.

Repeaters

This section was written by Paul M. Danzer, N1II.

In the late 1960s two events occurred that changed the way radio amateurs communicated. The first was the explosive advance in solid-state components — transistors and integrated circuits. A number of new "designed for communications" integrated circuits became available, as well as improved high-power transistors for RF power amplifiers. Vacuum tube-based equipment, expensive to maintain and subject to vibration damage, was becoming obsolete.

At about the same time, in one of its periodic reviews of spectrum usage, the Federal Communications Commission (FCC) mandated that commercial users of the VHF spectrum reduce the deviation of truck, taxi, police, fire and all other commercial services from 15 kHz to 5 kHz. This meant that thousands of new narrowband FM radios were put into service and an equal number of wideband radios were no longer needed.

As the new radios arrived at the front door of the commercial users, the old radios that weren't modified went out the back door, and hams lined up to take advantage of the newly available "commercial surplus." Not since the end of World War II had so many radios been made available to the ham community at very low or at least acceptable prices. With a little tweaking, the transmitters and receivers were modified for ham use, and the great repeater boom was on.

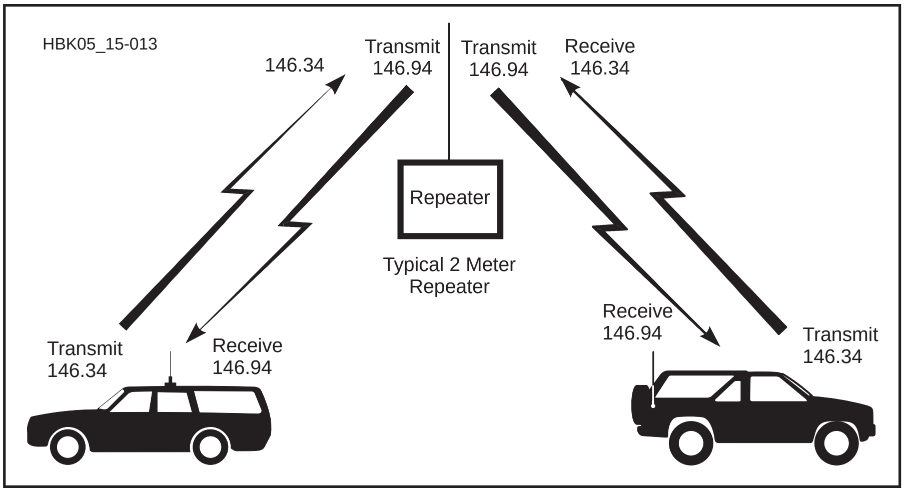


Fig 15.13 — Typical 2-m repeater, showing mobile-to-mobile communication through a repeater station. Usually located on a hill or tall building, the repeater amplifies and retransmits the received signal on a different frequency.

Table 15.3
Types of Repeaters

ATV — **Amateur TV** — Same coverage advantages as voice repeaters to hams using wideband TV in the VHF and UHF bands. Often consist of pairs of repeaters — one for the ATV and the other for the voice coordination.

AM and SSB — There is no reason to limit repeaters to FM. There are a number of other modulation-type repeaters, some experimental and some long-established.

Digipeaters — Digital repeaters used primarily for packet communications. Can use a single channel (single port) or several channels (multi-port) on one or more VHF and UHF bands.

Multi-channel (wideband) — Amateur satellites are best-known examples. Wide bandwidth (perhaps 50 to 200 kHz) is selected to be received and transmitted so all signals in bandwidth are heard by the satellite (repeater) and retransmitted, usually on a different VHF or UHF band. Satellites are discussed elsewhere in this chapter.

Although not permitted or practical for terrestrial use in the VHF or UHF spectrum, there is no reason wideband repeaters cannot be established in the microwave region where wide bandwidths are allowed. This would be known as frequency multiplexing.

WHAT IS A REPEATER?

Trucking companies and police departments learned long ago that they could get much better use from their mobile radios by using an automated relay station called a *repeater*. Not all radio dispatchers are located near the highest point in town or have access to a 300-ft tower. But a repeater, whose basic idea is shown in **Fig 15.13**, can be more readily located where the antenna system is as high as possible and can therefore cover a much greater area.

Types of Repeaters

The most popular and well-known type of amateur repeater is an FM voice system on the 29, 144, 222 or 440-MHz bands. Tens of thousands of hams use small 12-V powered radios in their vehicles for both casual ragchewing and staying in touch with what is going on during heavy traffic or commuting times. Others have low-power battery-operated handheld units for 144, 222 or 440 MHz. Some mobile and handheld transceivers operate on two bands. But there are several other types of ham radio repeaters. **Table 15.3** describes them.

FM is the mode of choice, as it was in commercial service, since it provides a high degree of immunity to mobile noise pulses. Operations are *channelized* — all stations operate on the same transmit frequency and receive on the same receive frequency. In addition, since the repeater receives signals from mobile or fixed stations and retransmits these signals simultaneously, the transmit and receive frequencies are different, or *split.* Direct contact between two or more stations that listen and transmit on the same frequency is called operating *simplex.*

Individuals, clubs, amateur civil defense support groups and other organizations all sponsor repeaters. Anyone with a valid amateur license for the band can establish a repeater in conformance with the FCC rules. No one owns specific repeater frequencies, but nearly all repeaters are *coordinated* to minimize repeater-to-repeater interference. Frequency coordination and interference are discussed later in this chapter.

Block Diagrams

Repeaters normally contain at least the sections shown in **Fig 15.14**. After this, the sky is the limit on imagination. As an example, a remote receiver site can be used to try to eliminate interference (**Fig 15.15**).

The two sites can be linked either by telephone ("hard wire") or a VHF or UHF link. Once you have one remote receiver site it is natural to consider a second site to better hear those "weak mobiles" on the other side of town (**Fig 15.16**). Some of the stations using the repeater are on 2 m while others are on 440. Just link the two repeaters! (**Fig 15.17**).

Want to help the local Civil Air Patrol (CAP)? Add a receiver for aircraft emergency transmitters (ELT). Tornados? It is now legal to add a weather channel receiver (**Fig 15.18**).

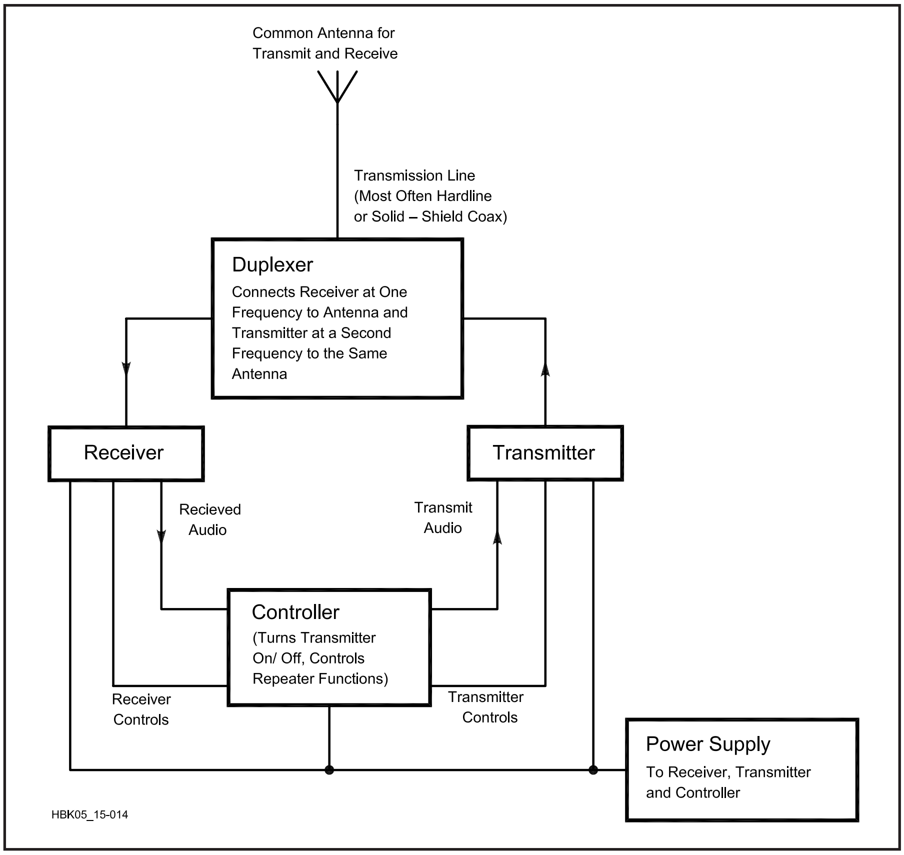


Fig 15.14 — The basic components of a repeater station. In the early days of repeaters, many were home-built. Today, most are commercial, and are far more complex than this diagram suggests.

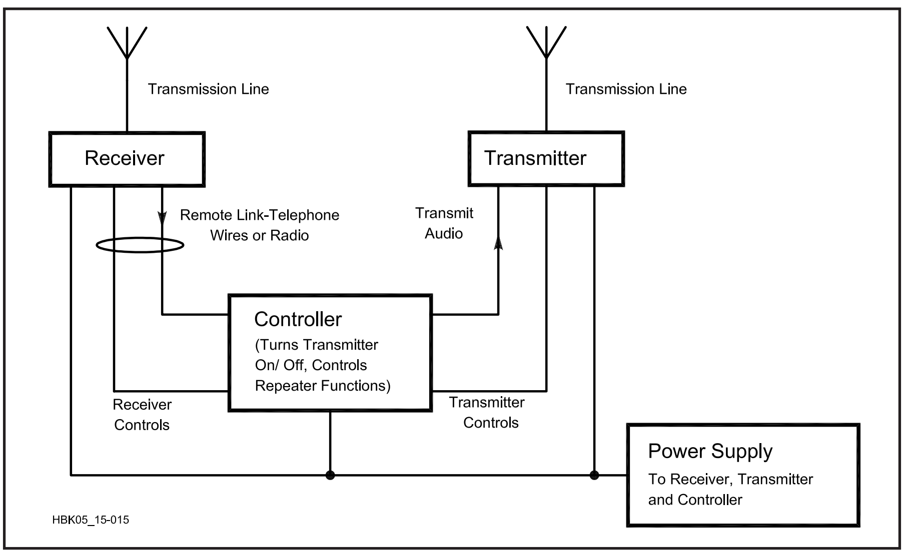


Fig 15.15 — Separating the transmitter from the receiver helps eliminate certain types of interference. The remote receiver can be located on a different building or hill, or consist of a second antenna at a different height on the tower.

The list goes on and on. Perhaps that is why so many hams have put up repeaters.

Repeater Terminology

Here are some definitions of terms used in the world of Amateur Radio FM and repeaters:

access code — one or more numbers and/ or symbols that are keyed into the repeater with a DTMF tone pad to activate a repeater function, such as an autopatch.

autopatch — a device that interfaces a repeater to the telephone system to permit repeater users to make telephone calls. Often just called a "patch."

break — the word used to interrupt a conversation on a repeater *only* to indicate that there is an emergency.

carrier-operated relay (COR) — a device that causes the repeater to transmit in response to a received signal.

channel — the pair of frequencies (input and output) used by a repeater.

closed repeater — a repeater whose access is limited to a select group (see ***open repeater***).

control operator — the Amateur Radio operator who is designated to "control" the operation of the repeater, as required by FCC regulations.

courtesy beep — an audible indication that a repeater user may go ahead and transmit.

coverage — the geographic area within which the repeater provides communications.

CTCSS — abbreviation for continuous tone-controlled squelch system, a series of subaudible tones that some repeaters use to restrict access. (see **closed repeater**).

digipeater — a packet radio (digital) repeater.

DTMF — abbreviation for dual-tone multifrequency, the series of tones generated from a keypad on a ham radio transceiver (or a regular telephone).

duplex or **full duplex** — a mode of communication in which a user transmits on one frequency and receives on another frequency simultaneously (see ***half duplex***).

duplexer — a device that allows the repeater transmitter and receiver to use the same antenna simultaneously.

frequency coordinator — an individual or group responsible for assigning frequencies to new repeaters without causing interference to existing repeaters.

full quieting — a received signal that contains no noise.

half duplex — a mode of communication in which a user transmits at one time and receives at another time.

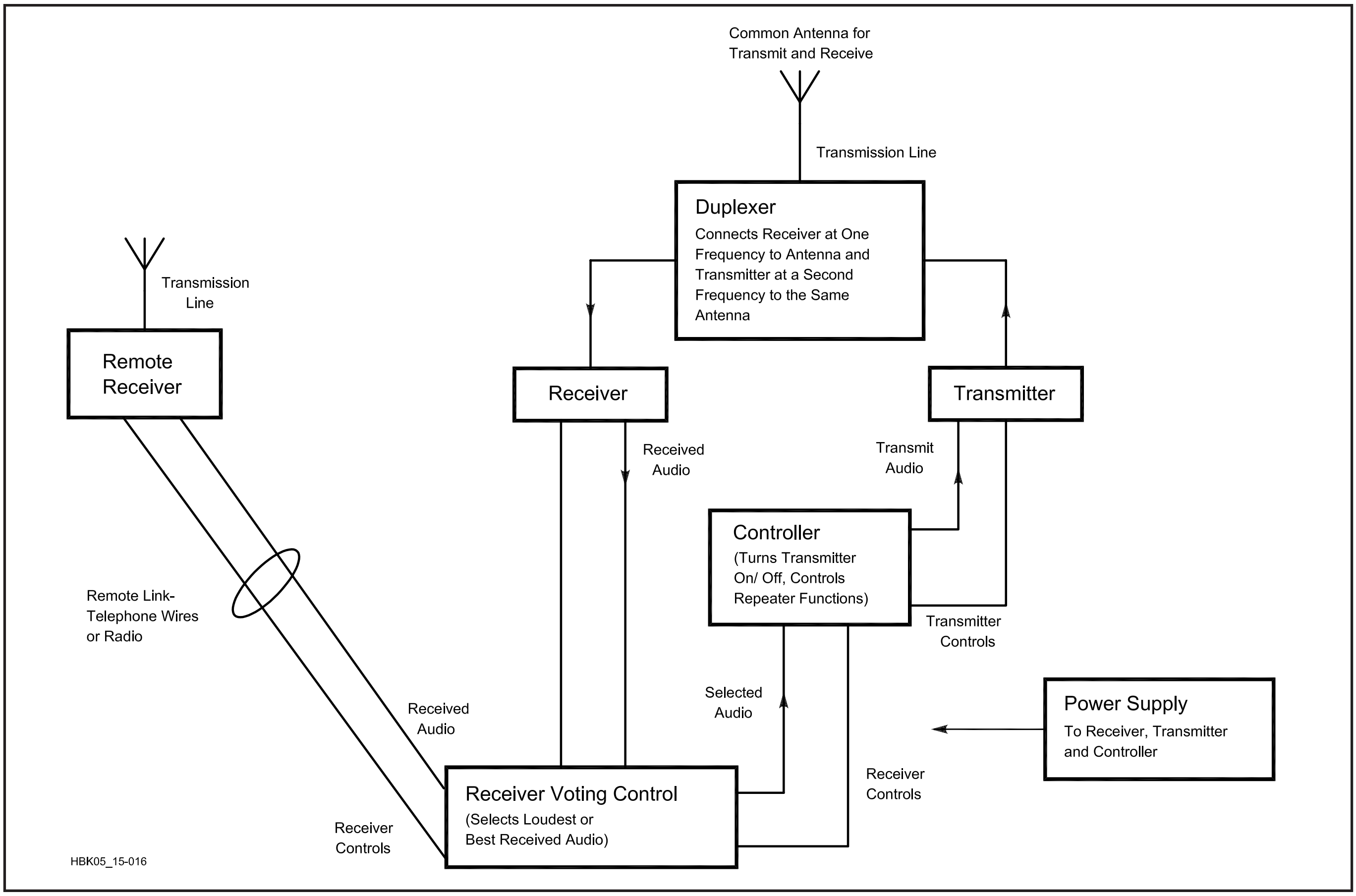


Fig 15.16 — A second remote receiver site can provide solid coverage on the other side of town.

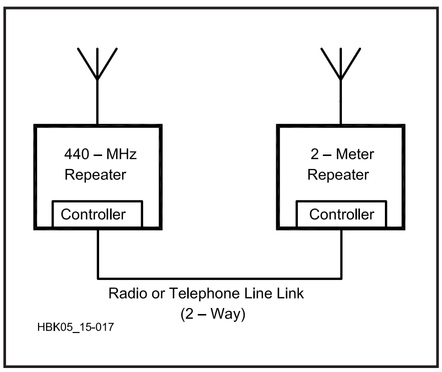


Fig 15.17 — Two repeaters using different bands can be linked for added convenience.

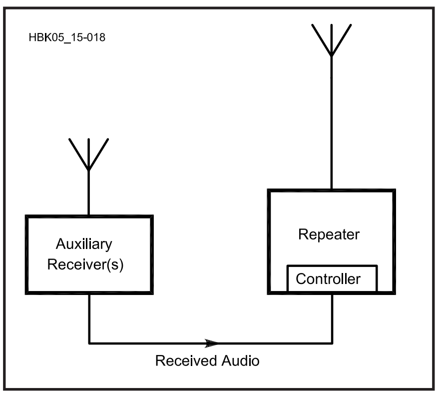


Fig 15.18 — For even greater flexibility, you can add an auxiliary receiver.

handheld — a small, lightweight portable transceiver small enough to be carried easily.

hang time — the short period following a transmission that allows others who want to access the repeater a chance to do so; a *courtesy beep* sounds when the repeater is ready to accept another transmission.

input frequency — the frequency of the repeater's receiver (and your transceiver's transmitter).

intermodulation distortion (IMD) — the unwanted mixing of two strong RF signals that causes a signal to be transmitted on an unintended frequency.

key up — to turn on a repeater by transmitting on its input frequency.

machine — a repeater system.

magnetic mount or **mag-mount** — an antenna with a magnetic base that permits quick installation and removal from a motor vehicle or other metal surface.

NiCd — a nickel-cadmium battery that may be recharged many times; often used to power portable transceivers. Pronounced "NYE-cad."

open repeater — a repeater whose access is not limited.

output frequency — the frequency of the repeater's transmitter (and your transceiver's receiver).

over — a word used to indicate the end of a voice transmission.

Repeater Directory — an annual ARRL publication that lists repeaters in the US, Canada and other areas.

separation or **split** — the difference (in kHz) between a repeater's transmitter and receiver frequencies. Repeaters that use unusual separations, such as 1 MHz on 2 m, are sometimes said to have "oddball splits."

simplex — a mode of communication in which users transmit and receive on the same frequency.

time-out — to cause the repeater or a repeater function to turn off because you have transmitted for too long.

timer — a device that measures the length of each transmission and causes the repeater or a repeater function to turn off after a transmission has exceeded a certain length.

tone pad — an array of 12 or 16 numbered keys that generate the standard telephone dual-tone multifrequency (***DTMF***) dialing signals. Resembles a standard telephone keypad. (see ***autopatch***).

Advantages of Using a Repeater

When we use the term *repeater* we are almost always talking about transmitters and receivers on VHF or higher bands, where radio-wave propagation is normally line of sight. Sometimes a hill or building in the path will allow refraction or other types of edge effects, reflections and bending. But for high quality, consistently solid communications, line of sight is the primary mode.

We know that the effective range of VHF and UHF signals is related to the height of each antenna. Since repeaters can usually be located at high points, one great advantage of repeaters is the extension of coverage area from low-powered mobile and portable transceivers.

Fig 15.19 illustrates the effect of using a repeater in areas with hills or mountains. The same effect is found in metropolitan areas, where buildings provide the primary blocking structures.

Siting repeaters at high points can also have disadvantages. When two nearby repeaters use the same frequencies, your transceiver might be able to receive both. But since it operates FM, the *capture effect* usually ensures that the stronger signal will capture your receiver and the weaker signal will not be heard — at least as long as the stronger repeater is in use.

It is also simpler to provide a very sensitive receiver, a good antenna system, and a slightly higher power transmitter at just one location — the repeater — than at each mobile, portable or home location. A superior repeater system compensates for the low power (5 W or less), and small, inefficient antennas that many hams use to operate through them. The repeater maintains the range or coverage we want, despite our equipment deficiencies. If both the handheld transceiver and the repeater are at high elevations, for example, communication is possible over great distances, despite the low output power and inefficient antenna of the transceiver (see **Fig 15.20**).

Repeaters also provide a convenient meeting place for hams with a common interest. It might be geographic — your town — or it might be a particular interest such as DX or passing traffic. Operation is channelized, and usually in any area you can find out which channel — or repeater — to pick to ragchew, get highway information, or whatever your need or interest is. The fact that operation is channelized also provides an increased measure of driving safety — you don't have to tune around and call CQ to make a contact, as on the HF bands. Simply call on a repeater frequency — if someone is there and they want to talk, they will answer you.

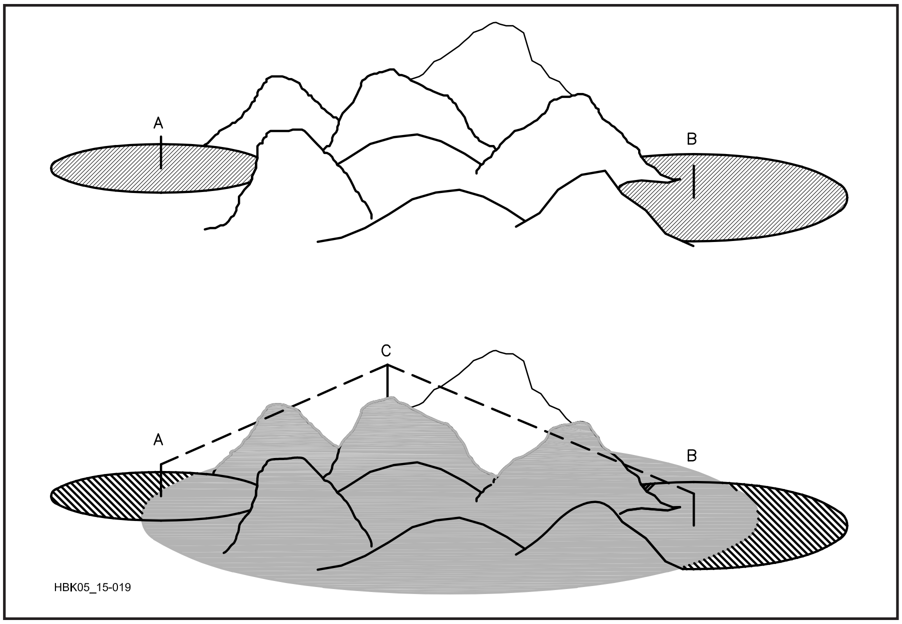


Fig 15.19 — In the upper diagram, stations A and B cannot communicate because their mutual coverage is limited by the mountains between them. In the lower diagram, stations A and B can communicate because the coverage of each station falls within the coverage of repeater C, which is on a mountaintop.

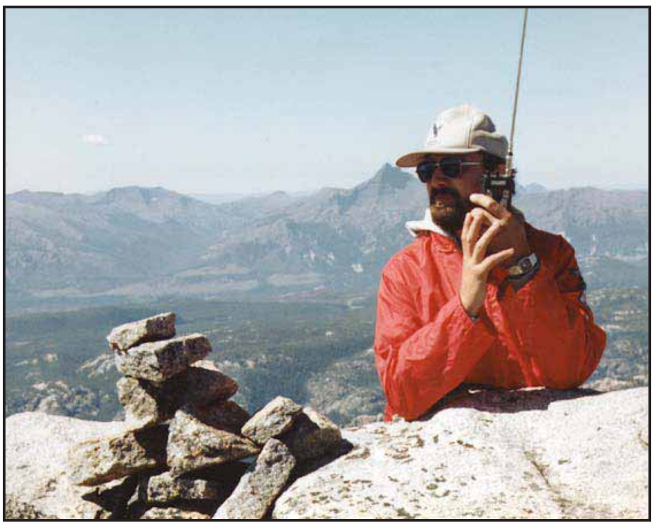


Fig 15.20 — In the Rocky Mountain west, handheld transceivers can often cover great distances, thanks to repeaters located atop high mountains. *(photo courtesy WBØKRX and NØIET)*

EMERGENCY OPERATIONS

When there is a weather-related emergency or a disaster (or one is threatening), most repeaters in the affected area immediately spring to life. Emergency operation and traffic always take priority over other ham activities, and many repeaters are equipped with emergency power sources just for these occasions.

Almost all Amateur Radio emergency organizations use repeaters to take advantage of their extended range, uniformly good coverage and visibility. Most repeat-

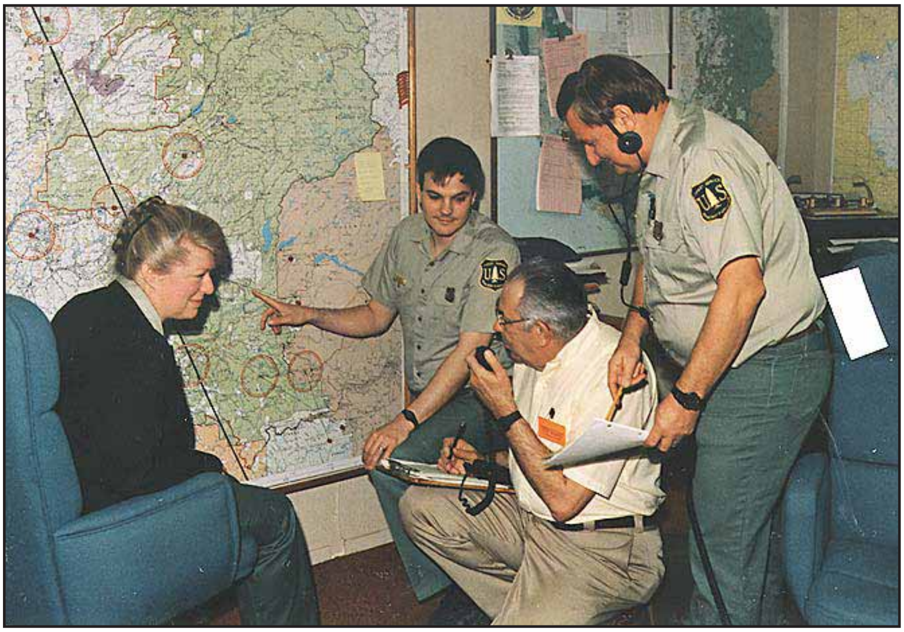


Fig 15.21 — During disasters like the Mississippi River floods of 1993, repeaters over a wide area are used solely for emergency-related communication until the danger to life and property is past. ***(photo courtesy WA9TZL)***

ers are well known — everyone active in an area with suitable equipment knows the local repeater frequencies. For those who don't, many transceivers provide the ability to scan for a busy frequency. See **Fig 15.21**.

REPEATERS AND THE FCC

The law in the United States changes over time to adapt to new technology and changing times. Since the early 1980s, the trend has been toward deregulation, or more accurately in the case of radio amateurs, self-regulation. Hams have established band plans, calling frequencies, digital protocols and rules that promote efficient communication and interchange of information.

Originally, repeaters were licensed separately with detailed applications and control rules. Repeater users were forbidden to use their equipment in any way that could be interpreted as commercial. In some cases, even calling a friend at an office where the receptionist answered with the company name was interpreted as a problem.

The rules have changed, and now most nonprofit groups and public service events can be supported and businesses can be called — as long as the participating radio amateurs are not earning a living from this specific activity.

We can expect this trend to continue. For the latest rules and how to interpret them, see *QST* and *The FCC Rule Book*, published by the ARRL.

FM REPEATER OPERATION AND EQUIPMENT

Operating Techniques

There are almost as many operating procedures in use on repeaters as there are repeaters. Only by listening can you determine the customary procedures on a particular machine. A number of common operating techniques are found on many repeaters, however.

One such common technique is the transmission of *courtesy tones*. Suppose several stations are talking in rotation — one following another. The repeater detects the end of a transmission of one user, waits a few seconds, and then transmits a short tone or beep. The next station in the rotation waits until the beep before transmitting, thus giving any other station wanting to join in a brief period to transmit their call sign. Thus the term *courtesy tone* — you are politely pausing to allow other stations to join in the conversation.

Another common repeater feature that encourages polite operation is the *repeater timer*. Since repeater operation is channelized — allowing many stations to use the same frequency — it is polite to keep your transmissions short. If you forget this little politeness many repeaters simply cut off your transmission after 2 or 3 minutes of continuous talking. After the repeater "times out," the timer is reset and the repeater is ready for the next transmission. The timer length is often set to 3 minutes or so during most times of the day and 1 or 1 1/2 minutes during commuter rush hours when many mobile stations want to use the repeater.

A general rule, in fact law — both internationally and in areas regulated by the FCC — is that emergency transmissions always have priority. These are defined as relating to life, safety and property damage. Many repeaters are voluntarily set up to give mobile stations priority, at least in checking onto the repeater. If there is going to be a problem requiring help, the request will usually come from a mobile station. This is particularly true during rush hours; some repeater owners request that fixed stations refrain from using the repeater during these hours. Since fixed stations usually have the advantages of fixed antennas and higher power, they can operate simplex more easily. This frees the repeater for mobile stations that need it.

A chart of suggested operating priorities is given in **Fig 15.22**. Many but not all repeaters conform to this concept, so it can be used as a general guideline.

The figure includes a suggested priority control for *closed repeaters*. These are repeaters whose owners wish, for any number of reasons, not to have them listed as available for general use. Often they require transmission of a *subaudible* or *CTCSS* tone (discussed later). Not all repeaters requiring a CTCSS tone are closed. Other closed repeaters require the transmission of a coded telephone push-button *(DTMF)* tone sequence to turn on. It is desirable that all repeaters, including generally closed repeaters, be made available at least long enough for the presence of emergency information to be made known.

Repeaters have many uses. In some areas they are commonly used for formal traffic nets, replacing or supplementing the nets usually found on 75-m SSB. In other areas they are used with tone alerting for severe-weather nets. Even when a particular repeater is generally used for ragchewing it can be linked for a special purpose. As an example, an ARRL volunteer official may hold a periodic section meeting across her state, with linked repeaters allowing both announcements and questions directed back to her.

One of the most common and important uses of a repeater is to aid visiting hams. Since repeaters are listed in the *ARRL Repeater Directory* and other directories, hams traveling across the country with

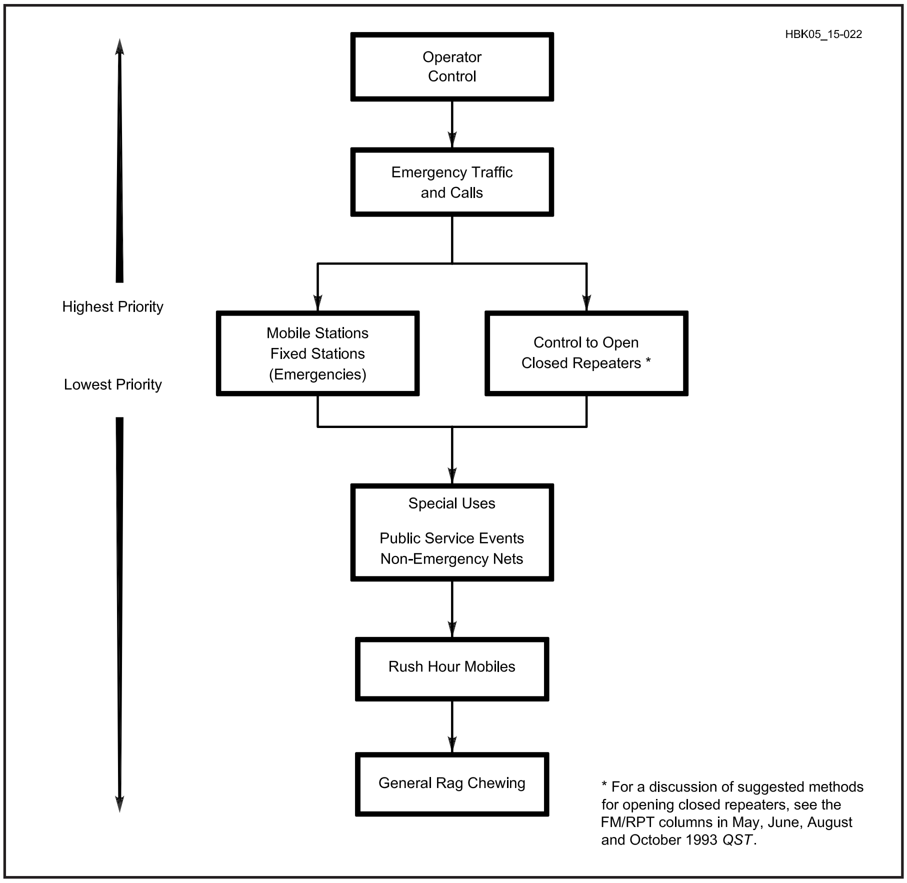


Fig 15.22 — The chart shows recommended repeater operating priorities. Note that, in general, priority goes to mobile stations.

mobile or handheld radios often check into local repeaters asking for travel route, restaurant or lodging information. Others just come on the repeater to say hello to the local group. In most areas courtesy prevails — the visitor is given priority to say hello or get the needed help.

Detailed information on repeater operating techniques is included in a full chapter of the *ARRL Operating Manual*.

Home and Mobile Equipment

There are many options available in equipment used on repeaters — both home-built and commercial. It is common to use the same radio for both home station and mobile, or mobile and handheld use. A number of these options are shown in **Fig 15.23**.

Handheld Transceivers

A basic handheld radio with 100 mW to 5 W output can be mounted in an automobile with or without a booster amplifier or "brick."

Several types of antennas can be used in the handheld mode. The smallest and most convenient is a rubber flex antenna, known as a "rubber duckie," a helically wound antenna encased in a flexible tube. Unfortunately, to obtain the small size the use of a wire helix or coil often produces a very low efficiency.

A quarter-wave whip, which is about 19 inches long for the 2-m band, is a good choice for enhanced performance. The rig and your hand act as a ground plane and a reasonably efficient result is obtained. A longer antenna, consisting of several electrical quarter-wave sections in series, is also commercially available. Although this antenna usually produces extended coverage, the mechanical strain of 30 or more inches of antenna mounted on the radio's antenna connector can cause problems. After several months, the strain may require replacement of the connector.

Selection of batteries will change the output power from the lowest generally available — 0.1 or 0.5 W — to the 5-W level. Charging is accomplished either with a "quick" charger in an hour or less or with a trickle charger overnight.

Power levels higher than 7 W may cause a safety problem on handheld units, since the antenna is usually close to the operator's head and eyes. See the **Safety** chapter for more information.

For mobile operation, a 12-V power cord plugs into the auto cigarette lighter. In addition, commercially available brick amplifiers — available either assembled or as kits — can be used to raise the output power level of the handheld radio to 10 to 70 W. These amplifiers often come with transmit-receive sensing and optional preamplifiers. One such unit is shown in block form in **Fig 15.24**.

Mobile Equipment

Mobile antennas range from quick and easy "clip-it-on" mounting to "drill through the car roof" assemblies. The four general classes of mobile antennas shown in the center section of Fig 15.23 are the most popular choices. Before experimenting with antennas for your vehicle, there are some precautions to be taken.

Through-the-glass antennas: Rather than trying to get the information from your dealer or car manufacturer, test any such antenna first using masking tape or some other temporary technique to hold the antenna in place. Some windshields are metallicized for defrosting, tinting and car radio reception. Having this metal in the way of your through-the-glass antenna will seriously decrease its efficiency.

Magnet-mount antennas are convenient, but only if your car has a metal roof. The metal roof serves as the ground plane.

Through-the-roof antenna mounting: Drilling a hole in your car roof may not be the best option unless you intend to keep the car for the foreseeable future. This mounting method provides the best efficiency, however, since the (metal) roof serves as a ground plane. Before you drill, carefully plan and measure how you intend to get the antenna cable down under the interior car headliner to the radio.

Trunk lid and clip-on antennas: These antennas are good compromises. They are usually easy to mount and they perform acceptably. Cable routing must be planned. If you are going to run more than a few watts, do not mount the antenna close to one of the car windows — a significant portion of the radiated power may enter the car interior.

Mobile rigs used at home can be powered either from rechargeable 12-V batteries or fixed power supplied from the 120-V ac line. Use of 12-V batteries has the advantage of providing back-up communications ability in the event of a power interruption. When a storm knocks down power lines and telephone service, it is common to hear hams using their mobile or 12-V powered rigs making autopatch calls to the power and telephone company to advise them of loss of service.

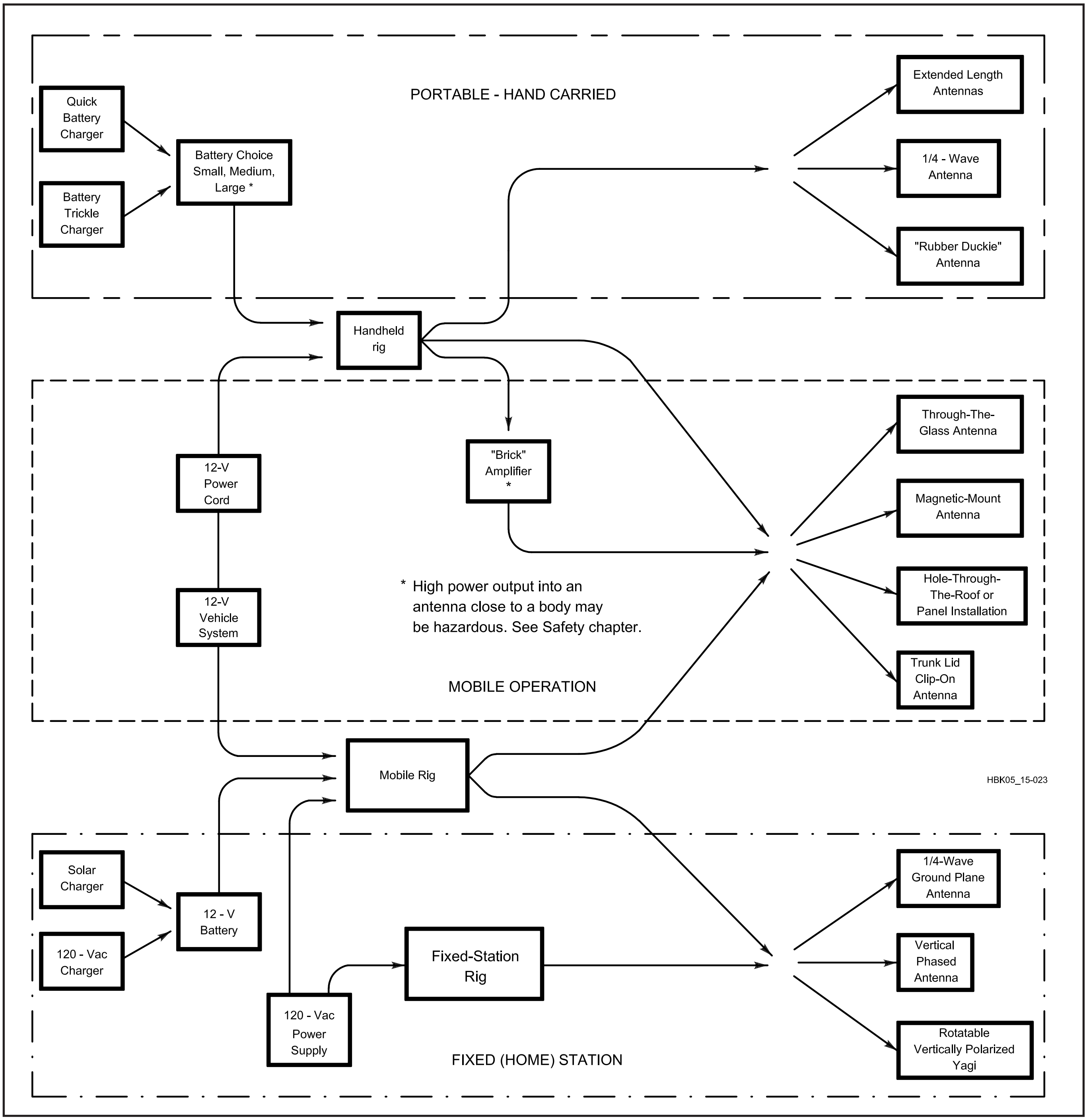


Fig 15.23 — Equipment choices for use with repeaters are varied. A handheld transceiver is perhaps the most versatile type of radio, as it can be operated from home, from a vehicle and from a mountaintop.

Home Station Equipment

The general choice of fixed-location antennas is also shown in Fig 15.23. A rotatable Yagi is normally not only unnecessary but undesirable for repeater use, since it has the potential of extending your transmit range into adjacent area repeaters on the same frequency pair. All antennas used to communicate through repeaters should be vertically polarized for best performance.

Both commercial and homemade $^1/_4$-λ and larger antennas are popular for home use. A number of these are shown in the **Antennas** chapter. Generally speaking, $^1/_4$-λ sections may be stacked up to provide more gain on any band. As you do so, however, more and more power is concentrated toward the horizon. This may be desirable if you live in a flat area. See **Fig 15.25**.

While most hams do not to try to build transceivers for use on repeaters, accessories provide a fertile area for construction and experimentation. What mobile operator has not wished that there was no need to hold the microphone continuously?

A single-pole, single-throw switch can be mounted in a small box and Velcro used to attach it temporarily to your seat.

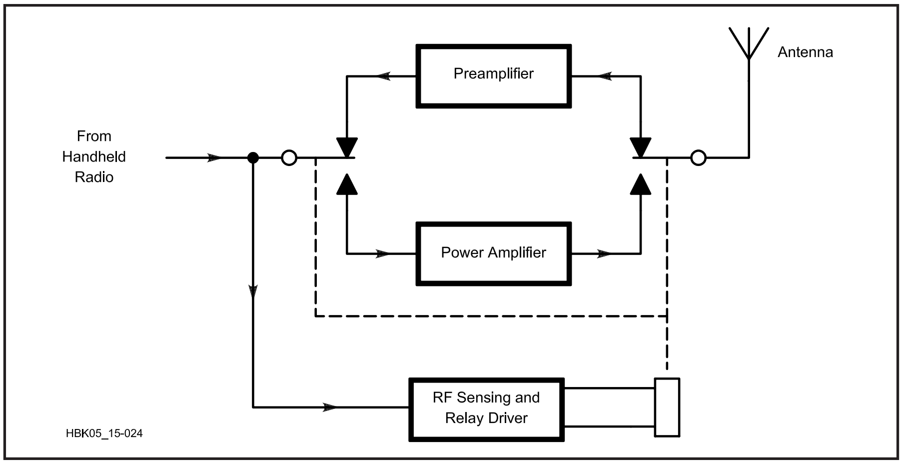


Fig 15.24 — This block diagram shows how a "brick" amplifier can be used with a receiver preamplifier. RF energy from the transceiver is detected, turns on the relay, and puts the RF power amplifier in line with the antenna. When no RF is sensed from the transceiver, the receiving preamp is in line.

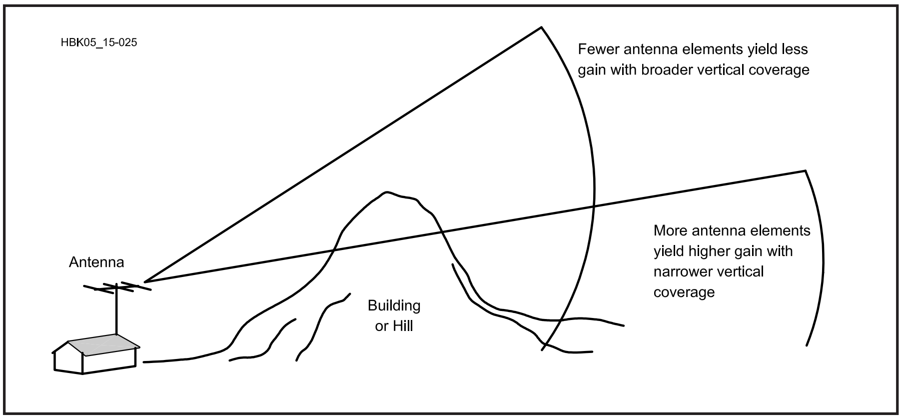


Fig 15.25 — As with all line-of-sight communications, terrain plays an important role in how your signal gets out.

Table 15.4
Standard Telephone (DTMF) Tones

	Low Tone Group		*High Tone Group*	
	1209 Hz	*1336 Hz*	*1477 Hz*	*1633 Hz*
697 Hz	1	2	3	A
770 Hz	4	5	6	B
852 Hz	7	8	9	C
941 Hz	*	0	#	D

Flip the lever on to transmit and flip it off to listen — in the meantime your hands are free.

Autopatches and Tones

One of the most attractive features of repeaters is the availability of autopatch services. This allows the mobile or portable station to use a standard telephone key pad to connect the repeater to the local telephone line and make outgoing calls.

Table 15.4 shows the tones used for these services. Some keyboards provide the standard 12 sets of tones corresponding to the digits 0 through 9 and the special signs # and *. Others include the full set of 16 pairs, providing special keys A through D. The tones are arranged in two groups, usually called the low tones and high tones. Two tones, one from each group, are required to define a key or digit. For example, pressing 5 will generate a 770-Hz tone and a 1336-Hz tone simultaneously.

The standards used by the telephone company require the amplitudes of these two tones to have a certain relationship. Fortunately, most tone generators used for this purpose have the amplitude relationship as part of their construction. Initially, many hams used surplus telephone company keypads. These units were easily installed — usually just two or three wires were connected. Unfortunately they were constructed with wire contacts and their reliability was not great when used in a moving vehicle.

Many repeaters require pressing a code number sequence or the special figures * or # to turn the autopatch on and off. Out-of-area calls are usually locked out, as are services requiring the dialing of the prefix 0 or 1. "Speed dial" is often available, although occasionally this can conflict with the use of * or # for repeater control, since these special symbols are used by the telephone company for its own purposes.

Some repeaters require the use of *subaudible* or CTCSS tones to utilize the autopatch, while others require these tones just to access the repeater in normal use. Taken from the commercial services, subaudible tones are not generally used to keep others from using a repeater but rather are a method of minimizing interference from users of the same repeater frequency.

For example, in **Fig 15.26** a mobile station on hill A is nominally within the normal coverage area of the Jonestown repeater (146.16/76). The Smithtown repeater, also on the same frequency pair, usually cannot hear stations 150 miles away but since the mobile is on a hill he is in the coverage area of both Jonestown and Smithtown. Whenever the mobile transmits both repeaters hear him.

The common solution to this problem, assuming it happens often enough, is to equip the Smithtown repeater with a CTCSS decoder and require all users of the repeater to transmit a CTCSS tone to access the repeater. Thus, the mobile station on the hill does not come through the Smithtown repeater, since he is not transmitting the required CTCSS tone.

Table 15.5 shows the available CTCSS tones. They are usually transmitted by adding them to the transmitter audio but at an amplitude such that they are not readily heard by the receiving station. It is common to hear the tones described by their code designators — a carryover from their use by Motorola in their commercial communications equipment.

Listings in the *ARRL Repeater Directory* include the CTCSS tone required, if any.

Frequency Coordination and Band Plans

Since repeater operation is channelized, with many stations sharing the same frequency pairs, the amateur community has

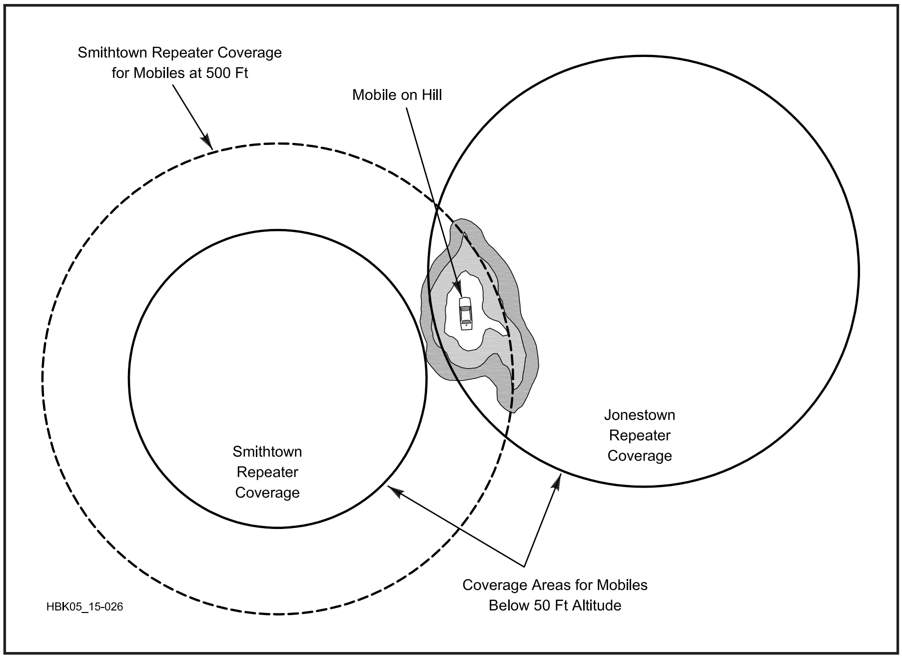


Fig 15.26 — When two repeaters operate on the same frequencies, a well-situated operator can key up both repeaters simultaneously. Frequency coordination prevents this occurrence.

Table 15.5
CTCSS (PL) Tone Frequencies

The purpose of CTCSS (PL) is to reduce cochannel interference during band openings. CTCSS (PL) equipped repeaters would respond only to signals having the CTCSS tone required for that repeater. These repeaters would not respond to weak distant signals on their inputs and correspondingly not transmit and repeat to add to the congestion.

The standard ANSI/EIA frequency codes, in hertz, with their Motorola alphanumeric designators, are as follows:

67.0 — XZ	91.5 — ZZ	118.8 — 2B	156.7 — 5A	179.9 — 6B	210.7 — M2
69.3 — WZ	94.8 — ZA	123.0 — 3Z	159.8	183.5	218.1 — M3
71.9 — XA	97.4 — ZB	127.3 — 3A	162.2 — 5B	186.2 — 7Z	225.7 — M4
74.4 — WA	100.0 — 1Z	131.8 — 3B	165.5	189.9	229.1 — 9Z
77.0 — XB	103.5 — 1A	136.5 — 4Z	167.9 — 6Z	192.8 — 7A	233.6 — M5
79.7 — WB	107.2 — 1B	141.3 — 4A	171.3	199.5	241.8 — M6
82.5 — YZ	110.9 — 2Z	146.2 — 4B	173.8 — 6A	203.5 — M1	250.3 — M7
85.4 — YA	114.8 — 2A	151.4 — 5Z	177.3	206.5 — 8Z	254.1 — 0Z
88.5 — YB					

Table 15.6
Standard Frequency Offsets for Repeaters

Band	*Offset*
29 MHz	100 kHz
52 MHz	1 MHz
144 MHz	600 kHz
222 MHz	1.6 MHz
440 MHz	5 MHz
902 MHz	12 MHz
1240 MHz	12 MHz

Table 15.7
10-M CTCSS Frequencies

In 1980 the ARRL Board of Directors adopted the 10-m CTCSS (PL) tone-controlled squelch frequencies listed below for voluntary incorporation into 10-m repeater systems to provide a uniform national system.

Call Area	*Tone 1*		*Tone 2*	
W1	131.8 Hz	-3B	91.5 Hz	-ZZ
W2	136.5	-4Z	94.8	-ZA
W3	141.3	-4A	97.4	-ZB
W4	146.2	-4B	100.0	-1Z
W5	151.4	-5Z	103.5	-1A
W6	156.7	-5A	107.2	-1B
W7	162.2	-5B	110.9	-2Z
W8	167.9	-6Z	114.8	-2A
W9	173.8	-6A	118.8	-2B
WØ	179.9	-6B	123.0	-3Z
VE	127.3	-3A	88.5	-YB

formed coordinating groups to help minimize conflicts between repeaters and among repeaters and other modes. Over the years, the VHF bands have been divided into repeater and nonrepeater subbands. These frequency-coordination groups maintain lists of available frequency pairs in their areas. A complete list of frequency coordinators, band plans and repeater pairs is included in the *ARRL Repeater Directory*.

Each VHF and UHF repeater band has been subdivided into repeater and nonrepeater channels. In addition, each band has a specific *offset* — the difference between the transmit frequency and the receive frequency for the repeater. While most repeaters use these standard offsets, others use "oddball splits." These nonstandard repeaters are generally also coordinated through the local frequency coordinator. **Table 15.6** shows the standard frequency offsets for each repeater band.

The 10-m repeater band offers an additional challenge for repeater users. It is the only repeater band where ionospheric propagation is a regular factor. Coupled with the limited number of repeater frequency assignments available, the standard in this band is to use CTCSS tones on a regional basis. **Table 15.7** lists the coordinated tone assignments. As can be seen, 10-m repeaters in the 4th call area will use either the 146.2 or 100.0 (4B or 1Z) CTCSS tone.