Contents

Chapter 14

Transceivers

Receivers and transmitters were covered in the previous two chapters. Putting them together creates a transceiver, the heart of the modern Amateur Radio station. This chapter will present some history and perspective on transceiver development, transceiver architecture and information on selecting a commercial transceiver. Then details of control and interconnection circuits needed to integrate a receiver and transmitter into a transceiver are presented. There are two transceiver projects at the end, and more projects and related information may be found on the *Handbook* CD-ROM. This chapter was updated and new material contributed by Joel R. Hallas, W1ZR.

Current Transceiver Overview

Previous editions included a section describing a range of commercial HF and VHF/UHF transceivers. Beginning with this edition, the transceiver overview section has been moved to the CD-ROM in PDF format. As subsequent editions are released, the overview will be updated and the previous version moved to the ARRL website for future reference.

14.1 The Transceiver Appears

In the beginning of the 20th century, from the days of spark transmitters through the early days of single-sideband (SSB) voice operation in the 1950s, the typical Amateur Radio station included a separate transmitter and receiver. In the mid- to late-1950s, it became clear that, unlike the earlier AM and CW radios, SSB receivers and transmitters used many of the same functional blocks and could be combined into a single unit sharing the common parts. This concept became well established with the 1957 introduction of the Collins Radio KWM-2 SSB and CW transceiver, shown in **Fig 14.1**.

Transceivers offered a number of key advantages to SSB operation. Perhaps the key operational benefit was that a single variable frequency oscillator (VFO) tuned both transmitter and receiver simultaneously. Thus, having tuned in another station properly, your transmit signal would be tuned for them to hear your signal properly as well — avoiding the need to make a separate operation of trying to *zero-beat* your transmitter to the receive frequency. Because they were not designed for full-carrier AM operation, SSB transceivers didn't require the heavy transformers of the typical AM transmitters of the day, making them compact and lightweight compared to their AM brethren.

The KWM-2 transceiver shared the appearance of the Collins 75S-1 and 32V-1 receiver and transmitter respectively, fitting into the same compact cabinet as either one of the separate units. Considerable flexibility was lost in the combined unit, however. The separate receiver and transmitter could be inter-cabled to transceive as a package, while still allowing split-frequency operation. CW operation was better supported in the separate units and multiple selectivity choices were provided in the separate receiver. Nonetheless, the compact single-unit transceiver offered excellent SSB operation in a single compact enclosure. A separate VFO was provided to allow the KWM-2 to use

Fig 14.1 — The 1957 vintage Collins KWM-2 transceiver, circa 1957, was one of the first in the move from separate receivers and transmitters to transceivers. The unit shown in this photo is a later version, the KWM-2A, which included some improvements to the original design. (*Photo courtesy Collins Radio Association, www.collinsra.com*)

separate transmit and receive frequencies for split-frequency operation, but this somewhat negated the single-unit benefit.

The successful Collins equipment was quickly followed by compact transceivers from R. L. Drake and Heathkit — two other very popular early manufacturers of the period. Their vacuum tube equipment carried on well into the 1970s, after which they (and many other manufacturers) moved to hybrid and finally all solid-state designs.

Since then, advanced design techniques, microminiaturization and competition have resulted in a range of available HF SSB transceivers ranging in price from around $500 to over $10,000 with a wide range of choices in features and performance. It is safe to say that, for the radio amateur, there is no longer anything to be given up by selecting a transceiver rather than a separate transmitter and receiver.

14.2 Early SSB Transceiver Architectures

Since the SSB transmitter and receiver are so similar, it is possible to combine them into a single package sharing many functions. In many transceivers, the sideband filter, some amplifiers, and other filters are shared between transmit and receive modes through the use of extensive switching. A simple example is illustrated in **Fig 14.2** in which common oscillators are used for transmitting and receiving. An advantage of this configuration in a two-way system is that the radios at both ends are set to transmit and receive on the same frequency at all times. This is particularly important for SSB operation in which a tuning error of even 50 Hz can be noticeable.

14.2.1 The Collins System

The KWM-2 had an additional conversion stage and the single-sideband filter was shared between transmit and receive. The suppressed-carrier oscillator frequencies were above and below the 455 kHz center frequency of the 2.1 kHz bandwidth mechanical filter — 453.65 kHz for lower sideband and 456.35 kHz for upper sideband. Note that the carrier frequency is 300 Hz outside each filter edge. This provides a voice bandwidth of 300 Hz to 2400 Hz, adequate for communication purposes, if not quite telephone “toll quality.” By placing the carrier frequency on the response skirt of the filter, the carrier suppression of the balanced modulator is enhanced by that amount of attenuation.

The first conversion stage used a variable oscillator with a tuning range of approximately 2.7 to 2.5 MHz (shifted depending on sideband selected) resulting in a variable intermediate frequency in the range of 3.155 to 2.955 MHz. The next conversion stage employed a choice of 14 crystal-controlled oscillator frequencies covering individual 200 kHz-wide bands over frequencies ranging from 3.4 to 5.0 and 6.5 to 30.0 MHz. (That was increased to 28 oscillator frequencies in the “A” model shown in Fig 14.1) This arrangement allowed an easy adaptation to use of the radio by other services merely by changing crystals. Note that 14 bands, each 200 kHz wide, in the basic unit did not quite cover all segments of even the 1957 amateur bands.

The HF circuits were all tuned simultaneously with the VFO using a mechanical slug rack that moved up and down with the tuning. This architecture is similar to that used in the earlier 75A, 51J and 32V series AM equipment and 75A-4 SSB receiver.

14.2.2 Other Early Transceivers

Drake and Heathkit provided transceivers that were functionally similar to the KWM-2, although they differed in some details in their design. A fundamental difference was that while Collins used its 455 kHz mechanical filter as a sideband filter, both Drake and Heathkit used crystal lattice filters in the low HF range for carrier and sideband suppression. Drake transceivers (but interestingly, not their separate units) used a single carrier frequency and switched between two filters for sideband selection — one on each side of the carrier frequency. Transceivers from both manufacturers were quite popular since they offered similar performance to the KWM-2 at a lower price.

14.2.3 Limitations of the Early Transceivers

FREQUENCY AGILITY

The first generation of SSB transceivers was quite usable for voice communication in which both ends of the link were on the same frequency. This is quite useful for net operations and casual conversations, but in many cases operators need the capability to operate split, with each operator transmitting on a different frequency. Sometimes the two stations are in different countries with different portions of the band allocated for voice operation, or sometimes a sought-after DX station might want to transmit on a different frequency so those calling would not interfere with the DX station’s transmissions. The

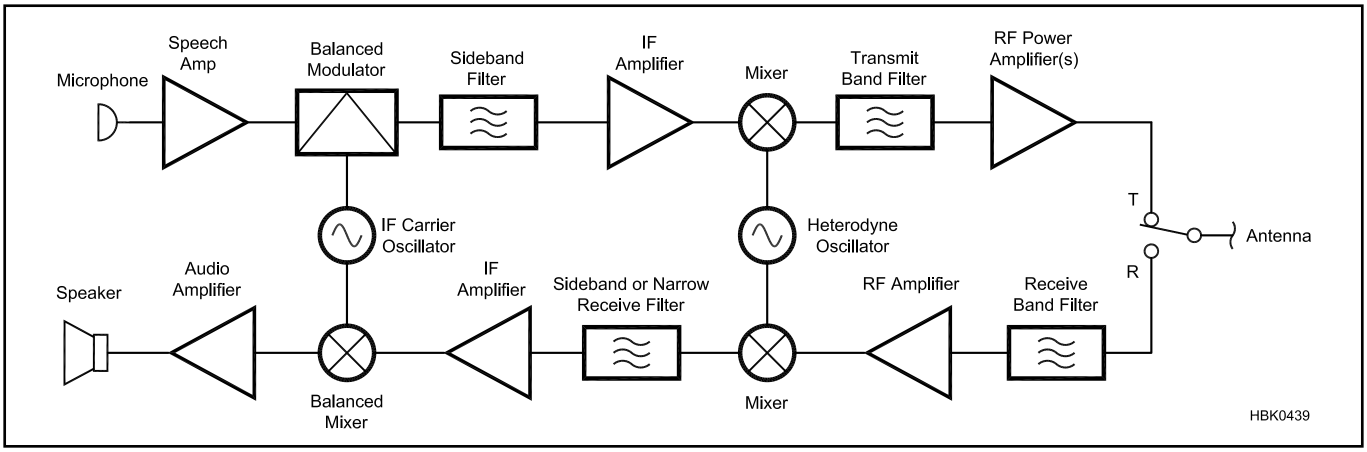


Fig 14.2 — Block diagram of a simple SSB transceiver sharing oscillator frequencies.

early transceivers could not do this.

Manufacturers eventually met this need with a second VFO for many models. This would allow transmission on one frequency and reception on another. Most were able to switch to a reverse mode (swapping transmit and receive VFOs) to simplify setting each frequency. While this was a workable solution, the need for an additional enclosure negated some of the benefits of having an "all in one" box.

Later versions began to offer *receive incremental tuning* (RIT) that allowed the receive frequency to be adjusted independently from the transmit frequency. (RIT is also called "clarify" by some manufacturers.) In some transceivers, RIT allowed sufficient separation of receive and transmit frequencies to be useful for limited split-frequency operation.

All the early transceivers were of the "downconverting" design (from the point of view of the receiver side). Multiple-conversion was employed to provide both a constant tuning rate, as defined in the Collins system (see the **Receivers** chapter), and sufficient image rejection. A limitation of this approach is that it makes *general-coverage receive* (continuous coverage from below 3 to 30 MHz or more) more complicated.

INTERFERENCE REJECTION

Early SSB transceivers generally were equipped with a sideband selection filter that provided appropriate selectivity for reception of SSB signals as well as *single-signal* CW reception if too many nearby channels weren't in use. Those with separate receivers generally enjoyed multiple filter bandwidths for different modes, as well as special filters to notch out interfering carriers.

OPERATING MODES

Most early SSB transceivers made some accommodation to allow CW operation, but it was not always totally satisfactory. The general design architecture of the early transceivers was actually almost ideal for CW — the frequency stability and tuning rate of an SSB transceiver were very close to optimum for CW. In addition, the duty cycle of CW was a good match for transmitter power amplifiers and high-voltage power supplies designed for SSB.

The problem was that some designers seemed to add CW as an afterthought. The worst offender was probably the KWM-2, which generated CW by keying a 1750 Hz audio oscillator and sending its signal through the audio stages.[1] This arrangement resulted in a much higher than usual receive tone at the far end, often causing the receive operator to change frequency to provide for comfortable listening. If both operators in a contact were using KWM-2s (which unfortunately had no RIT), they would often chase each other across the band as each operator retuned for a more appropriate CW note.

Other radios generally injected an actual CW carrier into the transmitter on a frequency that would fall comfortably within the receiving filter's passband at an appropriate tone for comfortable listening. Initially, no additional selectivity was provided. Many radios eventually offered an additional filter, or a switchable position for an optional narrow bandwidth filter, typically 500 Hz, that could be used to provide a bandwidth appropriate for CW operation.

Other aspects of operation were not often optimum for CW. Transmit-receive switching tended to share the voice-operated delay circuitry used for SSB rather than provide timing appropriate for CW. Little attention was paid to shaping of the transmit waveform, nor were the choices offered for automatic gain control (AGC) time constants appropriate for CW.

Most early CW/SSB transmitters did not provide any facility for AM, FM or digital modes. These were the days before PCs and sound cards, so support of digital modes (RTTY) was not supported until later models added dedicated keying circuits that shifted the transmitter frequency to provide frequency-shift keying (FSK).

14.3 Modern Transceiver Architecture and Capabilities

With each generation of transceivers, in what has become a highly competitive marketplace, additional features were added as technology marched on. The deficiencies of early transceivers, in comparison to separate receivers and transmitters, quickly disappeared to the point that 100 W (or higher power) class transceivers exceeded the features of the best separate receivers and transmitters of the past.

The current generation of transceivers was designed using modern solid-state components that permit abundant functionality in a small enclosure. The designers and manufacturers have taken advantage of the possibilities of integrated electronics and microprocessors, incorporating many more functions into a transceiver than could have been envisioned in the early days. This is largely a function of improved technology becoming available at reduced cost.

Separate receivers and transmitters could be built with similar features and performance, but the required duplication of subsystems would make each unit cost about the same as a transceiver. Several manufacturers do make stand-alone receivers using components from transceivers, but they are generally aimed toward different markets such as shortwave listeners or military/commercial users.

14.3.1 Evolution of Transceiver Architectures

Getting from the early transceiver designs to what is currently available occurred in a number of steps, generally corresponding to availability of technology at prices that could be included in competitive radios that amateurs could afford, as well as applied in support of commercial and military product lines. Advances in transceiver technology can be divided up in a number of ways, the following discussion being one view of the march of technology as applied to amateur transceivers.

THE MOVE TO SOLID STATE

Early solid-state devices became available first as low-speed, low-power diodes and transistors. These began to creep into otherwise vacuum-tube-based transceiver designs right from the beginning. The move of major subsystems to solid state awaited the development of high-frequency transistors that could serve in receiver and low-level transmitter stages with comparable performance to the highly developed vacuum tube circuits of the day and with greatly reduced power consumption and heat.

This occurred in the early 1970s with so-called *hybrid* transceiver designs in which all active circuits with the exception of the transmit driver and final power amplifier stages were solid state. Such radios were still entirely analog in design, and required a power supply that delivered both low and high voltage dc for the different devices. These radios offered small benefits in comparison to the mostly vacuum tube counterparts: The hybrid designs were only slightly smaller, generated slightly less heat, and perhaps had less warm-up drift. They still required manual tuning of the transmitter output circuits.

In the late 1970s, both R. L. Drake and Ten-Tec offered 200 W dc power input (about 130 W PEP output, in today's terms) transceivers that were entirely solid state. The transceivers were still analog, with mechanical VFO tuning, although the Drake TR-7 included a digital frequency counter along with its mechanical dial display. The major advance of the solid-state transmitter was that no tuning was required at the output of the final transmit amplifier. This allowed instant frequency changing and even band-switching without retuning — if the antenna offered a low SWR at all the frequencies involved. The vacuum tube transceiver had a bit of an advantage here in that it could compensate for a wider level of antenna system mismatch with its manual tuning controls. Still, an external antenna tuner could be used to compensate for a mismatched antenna at the cost of some additional controls and desk space. These radios generated much less heat than their tube counterparts and could run from a single 12-V dc supply. This meant no additional hardware for portable or mobile operation, if a 12-V source were available.

DIGITAL TECHNOLOGY ARRIVES

The first application of note to utilize digital technology was frequency display, as mentioned above. In the next (1980s) generation of transceivers, virtually all included some form of digital display, sometimes as an option. Next, digital control logic was used to allow *soft* controls, such as electronically-switched PIN diode attenuators or filter selection, instead of hard-wired switches and rotary potentiometers.

As digital logic components became smaller and less expensive, they moved into more and more areas such as frequency synthesis, allowing wider tuning ranges and electronically simulating the dual external VFOs of the earlier era through the use of dual memories for a digitally controlled frequency generator. Variable analog oscillators tuned by a variable capacitor or inductor were replaced by programmable digital dividers in phase-locked loops (PLLs) and a single stable reference oscillator. PLL-based frequency synthesis is significantly more stable than analog frequency generation.

Other early features included memory registers to allow saving and recalling frequencies and operating modes and direct keypad entry of frequency. As technology continued to evolve, direct digital synthesis (DDS) replaced the PLL, offering faster frequency switching and eliminating the synthesizer design tradeoff of phase noise versus lock time. Soon embedded processor chips were controlling most aspects of transceiver operation.

DIGITAL SIGNAL PROCESSING

A major leap in capability occurred with the availability of reasonably priced digital signal processing (DSP) integrated circuits around the beginning of the 21st century. While the previous digital processing functions made operation convenient and allowed for an unprecedented level of automation, today DSP is applied directly in the signal path. The analog radio signals are sampled and converted into digital form many thousands of times a second in an *analog-to-digital converter* (ADC). The digital samples are processed at high speed using DSP algorithms designed to accomplish a number of benefits and then returned to analog form in a *digital-to-analog converter* (DAC) as if they never changed. (A complete discussion of this technology is provided in the **DSP and Software Radio Design** chapter.)

While in digital mode, a number of functions can be applied. Note that not all DSP systems provide all these functions, depending on their design objectives. Also while almost all current HF transceivers provide DSP functions inside the box, it is also possible to purchase external DSP processors that can be added to older transceivers or receivers, with significant limitations as noted below.

- *DSP selectivity* — DSP can do a marvelous job of setting the selectivity or bandwidth. If you like to compare curves, note how steep the skirts of **Figs 14.3** and **14.4** are compared to the response of analog filters. This was the selectivity of an outboard audio DSP filter made by SGC and reviewed in the January 2004 issue of *QST*. It has far sharper skirts than any pre-DSP analog filter. While this is most important for interference rejection, sharp selectivity will also reduce random noise. More recent internal IF-based DSP filters are sometimes even sharper and often provide for adjustable skirt slopes so signals don't suddenly appear (and disappear) while tuning. DSP filters are also immune to the inaccuracies of analog filters, which are subject to drift over time and temperature as capacitor and inductor values shift or crystals age.

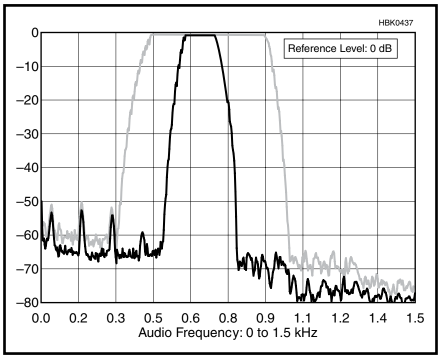


Fig 14.3 — The selectivity provided by a DSP processor is far closer to rectangular perfection than an analog filter. This shows narrow and wide CW bandwidths.

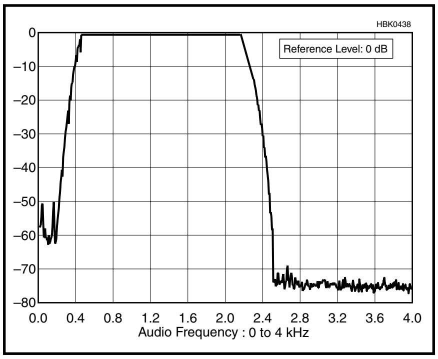


Fig 14.4 — The SSB bandwidth from the same DSP filter as in Fig 14.3.

- *DSP notch filtering* — A steady carrier signal, either from an operator adjusting an antenna tuner, or the carrier of a shortwave broadcast station on a shared band, is more interference than noise, but perhaps even more annoying. DSP can do an incredible job of eliminating narrow-band steady carriers, and can even track carriers that drift slowly — something that would require manual re-adjustment of an analog notch filter.
- *DSP noise reduction* — Analog filtering and notching has been used for years, although current DSP technology can generally do it better. On the other hand, DSP can also do something that analog systems can't. DSP noise reduction can actually look at the statistics of the signal and noise and figure out which is which. The DSP can then reduce the noise significantly. It can't quite eliminate the noise, and it needs enough of the signal to figure out what's happening, so it won't work if the signal is far below the noise. DSP may also help with some kinds of impulse noise, but the impulse noise may look like a signal to the DSP and not get reduced, depending on the software. It's always worth trying the feature to find out.

The first DSP systems and aftermarket DSP processors, operated at audio frequencies. As processors and sampling speeds got faster and faster, DSPs were able to operate at intermediate radio frequencies within a radio. Initially the frequencies were in or just above the audio range in the tens of kilohertz, although this is rapidly advancing with higher-speed technology.

DSP at the IF allows the processing of signals before they get into the AGC system, a significant advantage. Otherwise, a signal that gets through the radio's early filtering but isn't "heard" by the outboard DSP filter can cause the AGC to reduce the gain of the receiver, reducing the level of both the desired and undesired signals.

UPCONVERTING RECEIVER ARCHITECTURE

A significant change in the architecture of receivers and transceivers became popular in the 1980s and, with a few notable exceptions became almost universal in commercial products over the following decade. A limitation of the architecture shown in Fig 14.2 is that it is not trivial to provide operation on frequencies near the first IF. The typical transceiver designer selected a first IF frequency away from the desired operating frequencies and proceeded on that basis.

A Move to Flexibility

Amateur bands at 30, 17 and 24 meters were approved at the 1979 ITU World Administrative Radio Conference (WARC) and opened to hams over the following years. The difficulties of managing image rejection on the new bands and the desire for continuous receiver coverage of LF, MF and HF bands (called general-coverage receive as noted earlier) required a change in receiver conversion architecture.

The solution was to move to the upconverting architecture shown in **Fig 14.5**. By selecting a first IF well above the highest receive frequency, the first local oscillator can cover the entire receive range without any gaps. With the 70 MHz IF shown, the full range from 0 to 30 MHz can be covered by an LO covering 70 to 100 MHz, less than a 1.5:1 range, making it easy to implement with modern PLL or DDS technology. Note that the high IF makes image rejection very easy and, rather than the usual tuned bandpass front end, we can use more universal low-pass filtering. The low-pass filter is generally shared with the transmit side and designed with octave cutoff frequencies to reduce transmitter harmonic content. A typical set of HF transceiver low-pass filter cut-off frequencies would be 1, 2, 4, 8, 16 and 32 MHz.

This architecture offers significant benefits. By merely changing the control system programming, any frequency range or ranges can be provided with no change to the architecture or hardware implementation. Unlike the more traditional transceiver architecture (Fig 14.2), continuous receive frequency coverage over the range is actually easier to provide than to not provide, offering a marketing advantage for those who like to also do shortwave or broadcast listening.

An Achille's Heel

Almost every design choice offers both advantages and disadvantages, and the generally beneficial upconverting architecture is no exception. The primary limitation is not in the design itself, but rather in the characteristics of crystal filters in the low VHF range combined with the manufacturer's desire to maintain maximum flexibility. Early upconverting radios had a first IF bandwidth of typically 15 to 20 kHz. This allowed signals with narrow to wide bandwidth to pass through this portion of the receiver with the operating bandwidth set by the DSP filter, typically in the third IF stages, accommodating FM, AM and CW as well as SSB.

The result was that very strong signals within the first IF passband would travel all the way through the receiver's gain and mixing stages until they reached the ADC of the DSP system. The hope was that signals outside the operating DSP bandwidth, generally narrower than the initial first IF roofing filter bandwidth, would be eliminated in the DSP. Unfortunately, if the signals were strong enough they could exceed the dynamic range of the ADC. This could result in both reduction in receiver gain for the desired signal (blocking) or, if there were multiple signals, third-order intermodulation distortion (IMD) products *within* the desired DSP bandwidth due to two or more signals *outside* the DSP bandwidth. These effects can be a major limitation in a band crowded with strong signals.

In the architecture of Fig 14.2, the first IF bandwidth can be set as narrow as HF crystal filters can be made, typically down to 200 Hz, eliminating the problem but also eliminating continuous coverage below 30 MHz. Narrower VHF crystal filters have started to become available, and some top-end upconverting radios now offer selectable VHF first IF filters at 10, 6 and 3 kHz bandwidths, although their skirts are considerably wider than good HF filters. It wasn't long ago that such filters were unheard of, but they keep getting better and better, so perhaps it will become a moot point in the future.

Distributed Roofing Filters

The architectures discussed so far have applied narrow filtering at either the front (Fig 14.2) or the back (Fig 14.5) of the receiver chain. One manufacturer observed that there is a middle ground that could be used to maintain the near-in dynamic performance almost as well as radios with an HF first IF, yet maintain the advantages of upconverting. The Ten-Tec Omni VII has spread the filter-

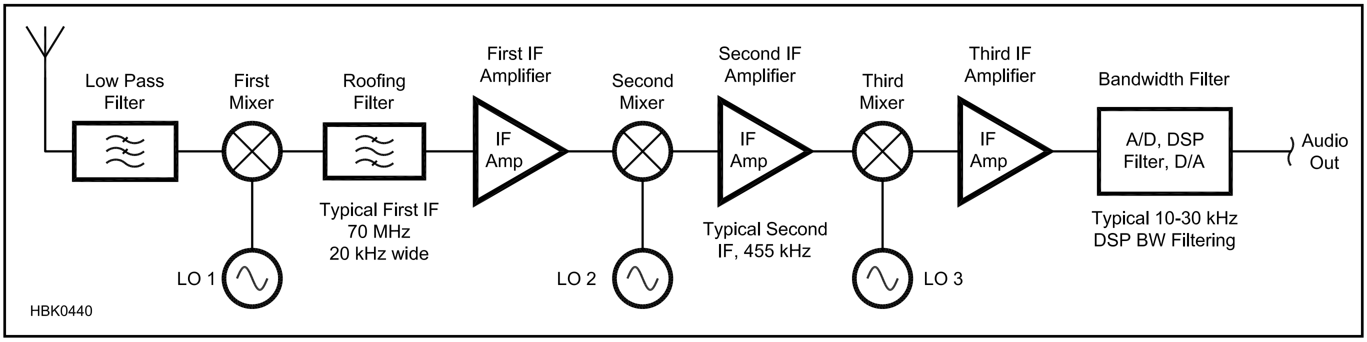


Fig 14.5 — Simplified block diagram of upconverting general coverage transceiver, receiver section shown.

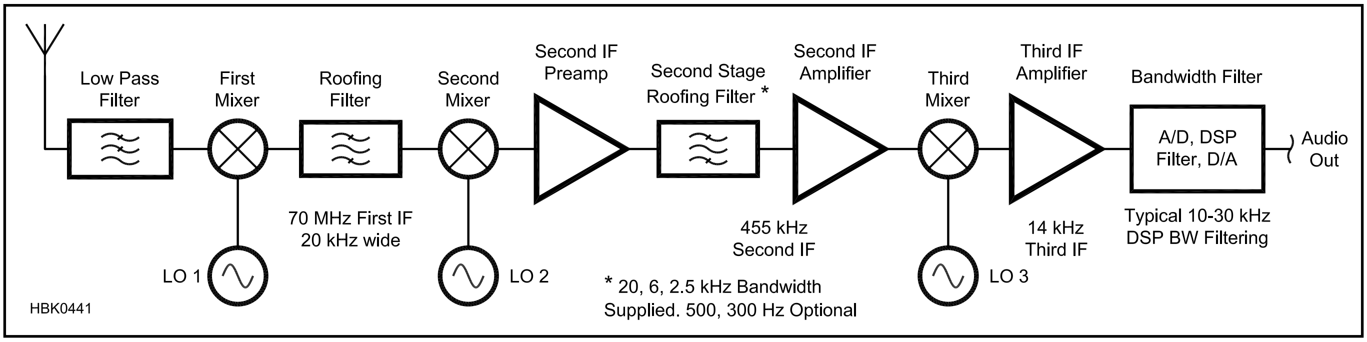


Fig 14.6 — Simplified block diagram of Ten-Tec's distributed roofing filter architecture.

ing to all three IFs as shown in **Fig 14.6.** The Omni VII achieves good dynamic receiver performance through an architecture that is worth a few words of explanation.

The problems resulting from strong unwanted signals near a desired one are minimized if the unwanted signals are kept out of stages in the receiver where they can cause the nonlinear effects that we try to avoid. Note that in Fig 14.2, the only place where the desired and undesired signals all coexist is in the first mixer. In top performing transceivers, the "sideband filter," shown on the receive side in Fig 14.2, can be switched to a much narrower sharp filter for narrow bandwidth modes such as CW or data. If the first mixer has sufficient strong-signal handling capability, the undesired signals will be eliminated in the filter immediately behind the first mixer. The later amplifier, mixer and DSP circuits only have to deal with the desired signal.

The Omni VII has effectively combined two technologies. The first IF has a 20-kHz-wide roofing filter at 70 MHz, plus selectable steep-skirted 455 kHz Collins mechanical filters at the second IF and then DSP filters at the third IF. Careful attention to the gain in stages between the filters maintains desired sensitivity, but not so much sensitivity that the undesired signals have a chance to become a serious problem. With bandwidths of 20, 6 and 2.5 kHz supplied, and 500 and 300 Hz as accessories, the undesired close-in signals are eliminated before they have an opportunity to cause serious trouble in the DSP, usually a key limitation for dynamic range. Some representative ARRL Lab receiver test results are shown in **Table 14.1**. The downconverting data shown is based on *QST* Product Review data on the Elecraft K3; the 20 kHz upconverting data from the ICOM IC-756 ProIII; the 3 kHz upconverting data from the ICOM IC-7700 and the distributed data from the Ten-Tec Omni VII.[2-5] It should be noted that there are significant price differences between the transceivers, but they are representative of the difference in the performance that one can expect from the distinct architectures in 2010.

14.3.2 Features of Current Transceivers

Current 100-W (or higher) transceivers tend to include the following features. Some features tend to appear in transceivers of different price ranges, thus the features have been placed in generic groups based generally on price class.

BASIC FEATURES

Even the lowest price entry-level transceivers of every generation have features never even considered in earlier higher-end units. The following is not an exhaustive list but should provide an indication of the benefits of some of the more popular features.

- A general coverage receiver — Typical coverage is from below the medium-wave broadcast band (sometimes with reduced sensitivity) to the top of HF, sometimes well into VHF, depending on transceiver frequency coverage. While this is useful to allow listening to international broadcast stations or other services, it may be even more useful as an adjunct to an amateur's workbench as a test instrument.
- Wide transmit frequency coverage — While this section has so far addressed "HF" transceivers, it is important to note that all current models extend downward to MF (160 meters) and most extend into VHF as well. Many provide coverage through 6 meters, and some go further into VHF and even UHF. In some cases the additional coverage may obviate the need for one or more additional radios in the station, making for a more compact, and sometimes less expensive, station.
- Multiple modes of operation — Most current transceivers offer SSB, CW, AM and FM modulation and detection. Some offer provision for digital modes, including both modulation and demodulation. Depending on frequency coverage, some "HF+" transceivers can also serve as VHF FM transceivers, offering standard repeater frequency offsets, squelch and tone encoding.
- Choices of selectivity — All current generation transceivers offer DSP-based variable selectivity. In lower-cost models it tends to be a small but adequate number of discrete choices, while in higher priced units selectivity is often continuously variable in 50 or 100 Hz steps. Advanced units allow shaping of the passband as well as high- and low-frequency rolloff adjustment. Some offer a dual-passband filter, designed to separately pass each tone of an FSK signal and not the frequencies between them.
- Dual VFO operation — All current designs offer instant selection of either of two operating frequencies to allow split-frequency operation. This allows the setting of one frequency for transmit and another for receive. A single switch or button can be used to toggle between the two so that the transmit frequency can be monitored before transmitting.
- DSP impulse, noise and carrier reduction — Most DSP-equipped transceivers provide for the reduction of impulse noise such as that from ignition systems or appliances.
- CW keyer — Most current model transceivers include the capability to connect keyer paddles for sending CW via an internal keyer. Some also include memories to allow one-button transmission of short messages.
- Removable front panel — Transceivers designed for mobile operation often have a removable front panel. This allows a compact control head to be mounted near the operator, while the radio's main chassis can be located in the trunk or other out-of-the-way spot.

FEATURES FOUND IN ADVANCED TRANSCEIVERS

More advanced transceivers tend to have additional features for their increased price. Most are larger than the basic units so that the front panels can accommodate additional controls and displays to support the extra features.

- Multiple roofing filter bandwidth — Most basic transceivers incorporate a single roofing filter with sufficient width to permit use on all modes. A typical value is 15 to 20 kHz. Improved close-in dynamic range performance can be obtained by having narrower roofing filters for narrow bandwidth modes as discussed previously and as described in the **Receivers** chapter.
- Adjustable noise blanking — Some transceivers include a separate wideband receive channel designed to detect and blank the main receiver in the presence of impulse noise. This capability is often independent of the similar DSP-based function. One or the other may be found to be better at eliminating noise from particular sources, while sometimes using both is even more helpful. Some transceivers offer two separate methods

Table 14.1
Comparison of Dynamic Performance of Samples of Three Architectures

Performance Data	*Downconverting (500 Hz)*	*Upconverting (20 kHz)*	*Upconverting (3 kHz)*	*Distributed*
BDR (20/5/2 kHz) dB	142/140/139	122/102/98	133/120/108	137/134/134
IMD DR (20/5/2 kHz) dB	106/105/103	102/78/70	108/99/87	91/84/82

*BDR = Blocking Dynamic Range
** IMD DR = Intermodulation Distortion Dynamic Range

of noise blanking, each suited for different common types of impulse noise.

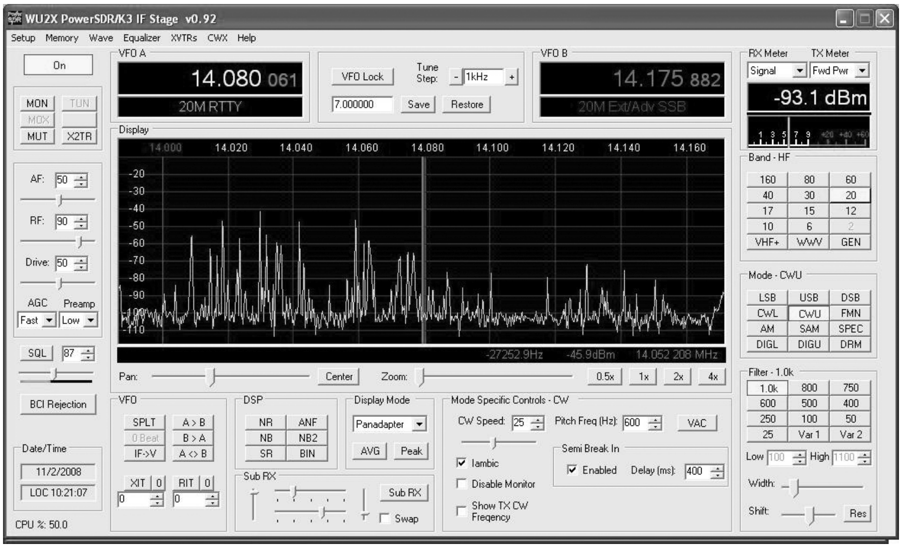
- Choices of AGC parameters — Most transceivers provide automatic AGC settings for different operating modes. Some advanced transceivers provide additional choices to allow optimization for different kinds of operation and different ambient noise levels. For example, to maximize sensitivity for weak signals, the AGC operating threshold should generally be set above the external noise level. This will vary depending on ionospheric conditions. Other parameters include the slope of the AGC curve and hold and attack times.
- Frequency memories — Advanced (and some basic) transceivers include the capability to store operating frequencies and other settings in memory. "Band-stacking registers" are multiple memories for each band that are typically accessed by pressing the band selection button multiple times. Typically they will store two or three frequencies per band, along with mode, filter and other settings, in a last-in, first-out register stack.
- Dual receive — Some higher-end transceivers include two independent receive channels. Dual receive channels can be useful to monitor two frequencies simultaneously. For example, you could listen simultaneously to transmit and receive frequencies being used by a DX station operating in split mode.

There are some subtle differences between the *sub-receiver* capabilities of different model transceivers. In some transceivers, the sub-receiver can only be used in the same band as the main receiver. This is not a limitation for normal split operation, but it does not permit monitoring a different band for openings or other activity. While some transceivers offer a duplicate receiver system for the sub-receiver, others have sub-receivers with lower dynamic range performance or fewer filter options than the main receiver.

Some sub-receivers have independent antenna input connections that allow operation with two different antennas. If the tuning of the two receivers can be locked together, that can provide a kind of diversity operation to reduce fading. Typically that might entail polarization diversity (one horizontal antenna, one vertical); space diversity with two antennas separated by a wavelength or so; or arrival angle diversity, using antennas at different heights.

- Panadapter — While a visual view of the received spectrum has been possible for decades with a station accessory called a *panadapter*, these devices were not too common in amateur stations until manufacturers started building display screens into transceivers. Many current transceivers offer panadapters in different forms. Often they offer views of signals on a band, adjustable over a range from the immediate vicinity of the operating frequency to the whole band. Some transceivers with dual receivers provide either dual panadapters or the ability to use one on the second receiver to keep track of band openings while communicating on the main band. In some cases, the receive circuitry is shared with the panadapter so that the audio is disabled during the time of the scan.

A *real-time* panadapter scans the frequency segment and repeats the scan over and over, giving an appearance of continuous updates. Thus newly arrived signals will show up during each scan. Some panadapters offer a single-pass or *one-shot* functionality in which a button press initiates a single scan over the selected range. The display retains the same snapshot of band activity until the next time the button is depressed. While this can provide a sample of band activity, it does not provide the same level of information as a real-time display.



Tune Step: 1kHz
7.000000
AF: 50
RF: 90
Drive: 50
AGC: Fast
Preamp: Low
SQL: 87
XIT 0: 0
RIT 0: 0
Date/Time
11/2/2008
LOC 10:21:07
CPU %: 50.0
Display Mode: Panadapter
RX Meter: Signal
TX Meter: Fwd Pwr
CW Speed: 25
Pitch Freq (Hz): 600
☑ Iambic
☐ Disable Monitor
☐ Show TX CW Freqency
Semi Break In: ☑ Enabled Delay (ms): 400
Low 100 High 1100

Fig 14.7 — Wideband view of the CW portion of 20 meters during a contest, using the K3 with LP-Pan software defined IQ panadapter.

Some transceivers provide a wideband IF output ahead of roofing filters so that an external panadapter can be used to monitor the received band. **Fig 14.7** shows the display of a TelePost LP-Pan IQ Panadapter connected to the output of an Elecraft K-3 transceiver. This system provides a highly capable real time spectrum analysis capability as well as interactive operation with the transceiver. The wideband IF output can also be used by other external signal processing equipment.

- Higher power — Transceivers are available at many power levels, from the very compact and portable low power (QRP) transceivers to medium power output sets. While we have been focusing on the usual 100 W PEP output transceivers that are the most popular, some transceivers provide 200 W PEP output or more.
- AF equalization — Long a capability of amateurs interested in broadcast-quality voice signals, newer transceivers provide a DSP-based audio equalization capability similar to professional studio control consoles. This is often available in both transmit and receive. In receive mode, it functions largely as a higher resolution tone control. In transmit mode, equalization can be used to shape audio response to provide higher fidelity. Or it can be used to focus the response to best punch through a DX pileup or compensate for individual voice or microphone response.
- Memory voice recorder — Sometimes called a *voice keyer* because of the similarity to a CW memory keyer, this function allows you to record and play back short messages. Voice keyers use digital technology and store the voice signal into memory. Different radios have different numbers of such memories, and some also can record received audio for playback on the air or to record a contact.
- RTTY and PSK31 decode — Some transceivers, generally at the upper end of the price spectrum, include the capability to decode RTTY and PSK31 transmissions on the display screen, eliminating the need for a separate PC and sound card. There usually is a limited amount of screen space for decoded messages, but it is usually plenty for contest exchanges or occasional contacts. A few transceivers, notably recent ICOM transceivers, provide connections for a computer keyboard to allow sending without an attached PC. The Elecraft K3 offers the ability to use the CW keyer or to send information as CW; the radio then converts the CW to RTTY or PSK31 for transmission.
- Flexible configuration — Two recent transceivers allow the purchaser to custom-order the configuration of features. The Elecraft K3 and Yaesu FTdx9000 Contest transceivers are each available with multiple feature sets spanning around a 2:1 price range, depending on options selected.

14.4 Transceiver Control and Interconnection

In the early days of Amateur Radio, there was a logical sequence to the process of switching from receive to transmit. We used separate receivers and transmitters with minimal automation. Upon hearing the distant station say "over" or send "K", the process would begin:

- Switch the receiver from receive to standby.
- Switch the antenna from the receiver to the transmitter.
- Switch the transmitter from standby to transmit.

To go the other way you went through the sequence in reverse, with the switches changed the opposite way. If the sequence were not followed, you risked damage to your ears, equipment or both.

14.4.1 Automated Transceivers

The better equipment of the mid-1950s provided capability to allow for the automation of this process. The Johnson Viking II transmitter, for example, included a socket on the rear panel with 120 V ac applied whenever the standby/transmit switch was moved to the transmit position. By connecting this socket to an antenna relay, the antenna could be switched from the receiver to the transmitter each time the transmitter was switched to transmit. Note that many coaxial relays of the day provided a pair of *auxiliary* contacts that were actuated whenever the relay was energized. These contacts could be used to disable or *mute* the receiver upon switching to transmit. With this arrangement, the station was set up for "one-switch operation," a goal of most early amateurs!

This arrangement worked for both voice and CW operation. Note that in those days, most amateurs used full-carrier AM for voice, rather than the modern suppressed-carrier single-sideband (SSB). With AM operation, the carrier was switched on and the transmitter started putting out power as soon as the operator switched to transmit, whether or not he or she was talking. With a properly adjusted SSB transmitter, there is virtually no signal transmitted except when the operator is actually speaking into the microphone (or the dog barks!). In a similar manner, most CW transmitters only transmit when the key is depressed, so some operators would leave the transmitter turned on and count on the key to determine when a signal would be transmitted.

14.4.2 Break-In CW Operation

Some top-flight CW operators were not quite satisfied with "one-switch operation," but would prefer to just transmit when the key is down and receive when it's up. A simple way that early amateurs accomplished this was to use separate antennas for transmit and receive (to avoid the requirement to switch) and run low enough power so that the transmitter would not overload the receiver.

If the receiver recovered fast enough to hear distant signals between transmitted dits, the configuration was called "break-in keying." This allowed the sending operator to listen to the frequency while transmitting and thus take appropriate action if there was interference. The distant operator could also hit the key a few times to alert the transmitting station that information needed to be repeated. The Q signal QSK (meaning "I can hear between dits") is often used to designate "full break-in" operation.

Fortunately technology has solved this problem, and QSK operators aren't limited to running low power and separate transmit and receive antennas. Most current 100 W class HF transceivers use high-speed relays (with the relay actually following the CW keying) or solid-state PIN diodes to implement full break-in CW. Some RF power amplifiers use high-speed vacuum relays for the TR switching function.

The term "semi-break-in" is used to designate a CW switching system in which closing the key initiates transmission, but switching back to receive happens between words, not between individual dits. Some operators find this less distracting than full break-in, and it is easier to implement with less-expensive relays for the TR switching.

14.4.3 Push-To-Talk for Voice Operators

Another advance in amateur station switching followed longstanding practices of aircraft and mobile voice operators who had other things to contend with besides radio switches. Microphones in those services included built-in switches to activate TR switching. Called push-to-talk (PTT), this function is perhaps the most self-explanatory description in our acronym studded environment.

Relays controlled the various switching functions when the operator pressed the PTT switch. Some top-of-the-line transmitters of the period included at least some of the relays internally and had a socket designed for PTT microphones. **Fig 14.8** is a view of the ubiquitous Astatic D-104 microphone with PTT stand, produced from the 1930s to 2004, and still popular at flea markets and auction sites. PTT operation allowed the operator to be out of reach of the radio equipment while operating, permitting "easy chair" operation for the first time.

Modern transceivers include some form of PTT (or "one switch operation"). Relays, diodes, transistors and other components seamlessly handle myriad transmit-receive changeover functions inside the transceiver. Most transceivers have additional provisions for manually activating PTT via a front-panel switch. And many have one or more jacks for external PTT control via foot switches, computer interfaces or other devices.

14.4.4 Voice-Operated Transmit-Receive Switching (VOX)

How about break-in for voice operators? SSB operation enabled the development of voice operated transmit/receive switching, or VOX. During VOX operation, speaking into the microphone causes the station to switch from receive to transmit; a pause in speaking results in switching back to receive mode. Although VOX technology can work with AM or FM, rapidly turning the carrier signal on and off to follow speech does not provide the smooth operation possible with SSB. (During SSB transmission, no carrier or signal is sent while the operator is silent.)

VOX OPERATION

VOX is built into current HF SSB transceivers. In most, but not all, cases they also provide for PTT operation, with switches

Fig 14.8 — A classic Astatic D-104 mic with PTT stand.

or menu settings to switch among the various control methods. Some operators prefer VOX, some prefer PTT and some switch back and forth depending on the operating environment.

VOX controls are often considered to be in the "set and forget" category and thus may be controlled by a software meu or by controls on the rear panel, under the top lid or behind an access panel. The following sections discuss the operation and adjustment of radio controls associated with VOX operation. Check your transceiver's operating manual for the specifics for your radio.

Before adjusting your radio's VOX controls, it's important to understand how your particular mic operates. If it has no PTT switch, you can go on to the next section! Some mics with PTT switches turn off the audio signal if the PTT switch is released, while some just open the control contacts. If your mic does the former, you will need to lock the PTT switch closed, have a different mic for VOX or possibly modify the internal mic connections to make it operate with the VOX. If no audio is provided to the VOX control circuit, it will never activate. If the mic came with your radio, or from its manufacturer, you can probably find out in the radio or mic manual.

VOX Gain

Fig 14.9 shows some typical transceiver VOX controls. The VOX GAIN setting determines how loud speech must be to initiate switchover, called "tripping the VOX." With a dummy load on the radio, experiment with the setting and see what happens. You should be able to advance it so far that it switches with your breathing. That is obviously too sensitive or you will have to hold your breath while receiving! If not sensitive enough, it may cause the transmitter to switch off during softly spoken syllables. Notice that the setting depends on how close you are to the microphone, as well as how loud you talk. A headset-type microphone (a "boom set") has an advantage here in that you can set the microphone distance the same every time you use it.

Fig 14.9 — The function of VOX controls is described in the text. They require adjustment for different types of operating, so front-panel knobs make the most convenient control arrangement. In some radios, VOX settings are adjusted through the menu system.

The optimum setting is one that switches to transmit whenever you start talking, but isn't so sensitive that it switches when the mic picks up other sounds such as a cooling fan turning on or normal household noises.

VOX Delay

As soon as you stop talking, the radio can switch back to receive. Generally, if that happens too quickly, it will switch back and forth between syllables causing a lot of extra and distracting relay clatter. The VOX DELAY control determines how long the radio stays in the transmit position once you stop talking. If set too short, it can be annoying. If set too long, you may find that you miss a response to a question because the other station started talking while you were still waiting to switch over.

You may find that different delay settings work well for different types of operation. For example, in a contest the responses come quickly and a short delay is good. For casual conversation, longer delays may be appropriate. Again, experiment with these settings with your radio connected to a dummy load.

Anti-VOX

This is a control with a name that may mystify you at first glance! While you are receiving, your loudspeaker is also talking to your mic — and tripping your VOX — even if you aren't! Early VOX users often needed to use headphones to avoid this problem. Someone finally figured out that if a sample of the speaker's audio signal were fed back to the mic input, out-of-phase and at the appropriate amplitude, the signal from the speaker could be cancelled out and would not cause the VOX circuit to activate the transmitter. The ANTI-VOX (called ANTI-TRIP in the photo) controls the amplitude of the sampled speaker audio, while the phase is set by the transceiver design.

As you tune in signals on your receiver with the audio output going to the speaker, you may find that the VOX triggers from time to time. This will depend on how far you turn up the volume, which way the speaker is pointed and how far it is from the mic. You should be able to set the ANTI-VOX so that the speaker doesn't trip the VOX during normal operation.

Generally, setting ANTI-VOX to higher values allows the speaker audio to be louder without activating the VOX circuit. Keep in mind that once you find a good setting, it may need to be changed if you relocate your mic or speaker. With most radios, you should find a spot to set the speaker, mic and ANTI-VOX so that the speaker can be used without difficulty.

14.4.5 TR Switching With a Linear Amplifier

Virtually every amateur HF transceiver includes a rear panel jack called something along the lines of KEY OUT intended to provide a contact closure while in transmit mode. This jack is intended to connect to a corresponding jack on a linear amplifier called something like KEY IN. Check the transceiver and amplifier manuals to find out what they are called on your units. A diagram of the proper cabling to connect the transceiver and amplifier will be provided in the manual.

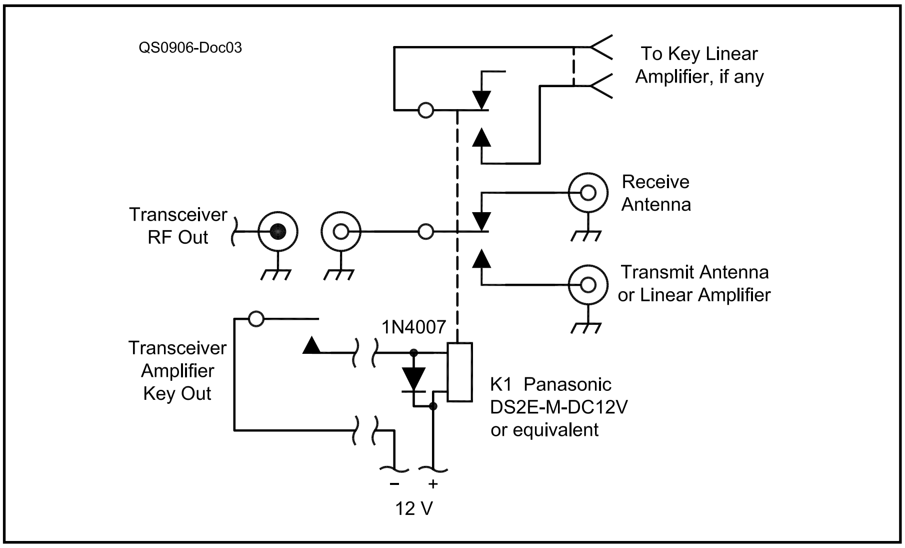


Fig 14.10 — Schematic of an external box that allows a modern transceiver to key a linear amplifier with TR switch voltage or current requirements that exceed the transceiver's ratings. As a bonus, it can also be used to allow reception from a low-noise receiving antenna.

ENSURING AMPLIFIER-TRANSCEIVER COMPATIBILITY

While you're there, check the ratings to find out how much voltage and current the transceiver can safely switch. In earlier days, this switching was usually accomplished by relay contacts. More modern radios tend to use solid-state devices to perform the function. Although recent amplifiers are usually compatible with the switching capabilities of current transceivers, the voltage and/or current required to switch the relays in an older linear amplifier may exceed the ratings. Fortunately, it is pretty easy to find out what your amplifier requires, and almost as easy to fix if it's not compatible with your radio.

If your amplifier manual doesn't say what the switching voltage is, you can find out with a multimeter or DMM. Set the meter to read voltage in a range safe for 250 V dc or higher. Connect the positive meter probe to amplifier key jack's center conductor, and connect the negative meter probe to the chassis ground (or other key jack terminal if it's not grounded). This will tell you what the open circuit voltage is on the amplifier key jack. You may need to try a lower voltage range, or an ac range, or switch the probes (if the key line is a negative dc voltage) to get a reading.

Now set the meter to read current. Start with a range that can read 1 A dc, and with the leads connected as before, you should hear the amplifier relay close and observe the current needed to operate the TR relay or circuit. Adjust the meter range, if needed, to get an accurate reading.

These two levels, voltage and current, are what the transceiver will be asked to switch. If *either* reading is higher than the transceiver specification, do not connect the transceiver and amplifier together. Doing so will likely damage your transceiver. You will need a simple interface circuit to handle the amplifier's switching voltage and current.

The simple, low-cost relay circuit shown in **Fig 14.10** can be used to switch an older amplifier with a modern transceiver. It offers an added benefit: Another potential use of the transceiver KEY OUT jack is to switch to a separate low-noise receive antenna on the lower bands. While most high-end transceivers have a separate receive-only antenna connection built in, many transceivers don't. If you don't need one of the extra functions, just leave off those wires.

14.5 Transceiver Projects

There are many transceiver designs available, aimed mainly at the advanced builder. We will provide two. One describes the construction of a 5-W single-band SSB/CW transceiver with many features. The other is the description of the design and construction process that resulted in a 100 W transceiver for all HF bands with performance (confirmed in the ARRL Lab) that is as good as some of the best commercial products. Construction details for these projects and support files are available on the ARRL Web site. Additional projects may be found on the *Handbook* CD-ROM.

Fig 14.11 — MFJ Cub QRP transceiver built from a kit.

Fig 14.12 — MFJ Cub QRP transceiver kit showing parts supplied.

14.5.1 Transceiver Kits

One of the simplest kits to build, is also one of the least expensive. The ARRL offers the MFJ Enterprises (**www.mfjenterprises.com**) Cub 40 meter transceiver kit (**Figs 14.11** and **14.12**) bundled with *ARRL's Low Power Communication — The Art and Science of QRP* for less than $100 as we write this.[6] Other kits are available from many manufacturers.

Ten-Tec, maker of some of the best HF transceivers, offers single band CW QRP kits for less than $100 for your choice of 80, 40, 30 or 20 meters. Elecraft offers a range of kits from tiny travel radios to the K2 high performance multiband CW and SSB transceiver as well as the top performing K3 semi-kit (mechanical assembly only, no soldering required). The K2 and K3 can both start out as 10 W models and be upgraded to 100 W, if desired. DZkit, the company founded by Brian Wood, W0DZ to produce Heathkit-style radio kits offers modular transmitter and receiver kit sections that can be combined to form a high performance transceiver.

If your interest is strictly QRP transceiver kits, there are many small and specialty manufacturers. The QRP Amateur Radio Club, Inc. (QRP ARCI) maintains a manufacturer list on their Web site at **www.qrparci.org**, available in the "QRP Links" section of the site.

14.5.2 *Project:* The TAK-40 SSB CW Transceiver

Jim Veatch, WA2EUJ, was one of two winners of the first ARRL *Homebrew Challenge* with his TAK-40 transceiver shown in **Fig 14.13**. This challenge was to build a homebrew 5 W minimum output voice and CW transceiver using all new parts for under $50. The resulting radio had to meet FCC spurious signal requirements. The submitted radios were evaluated as to operational features and capabilities by a panel of ARRL technical staff. Jim's transceiver met the requirements for a transceiver that required a connected PC for setup — to load the PIC controller. This information was presented in May 2008 *QST* in an article provided by Jim as a challenge requirement.

The following is a list of the criteria for the Homebrew Challenge and a brief description of how the TAK-40 meets the requirements:

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

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

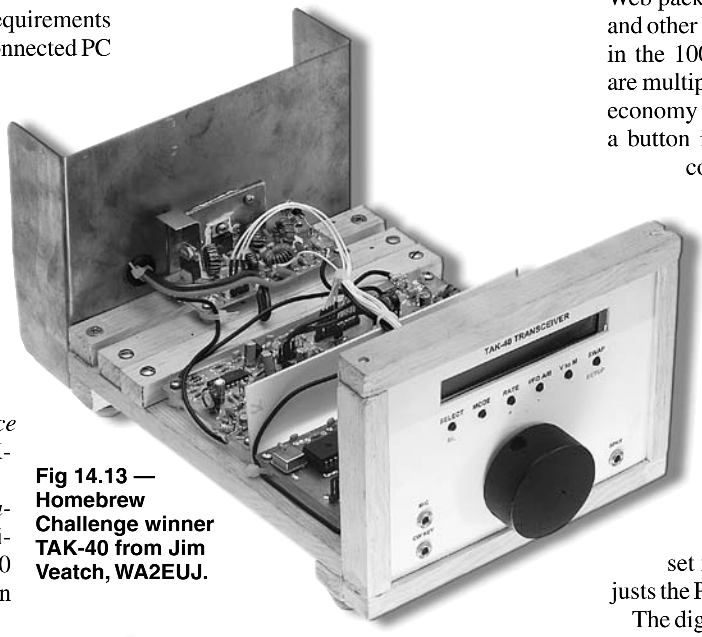


Fig 14.13 — Homebrew Challenge winner TAK-40 from Jim Veatch, WA2EUJ.

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

CIRCUIT DESCRIPTION

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

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

The overall design is a classic superheterodyne with a 4-MHz IF and a 3- to 3.3-MHz VFO. The same IF chain is used for transmitting and receiving by switching the oscillator signals between the two mixers. **Fig 14.14** shows the block diagram of the TAK-40 transceiver. Each board is described below with a detailed parts list on the *QST* binaries Web site.[7]

Digital Board

The digital board contains the microprocessor, front panel controls, liquid crystal display (LCD), the digital to analog converter for the VFO, the beat frequency oscillator (BFO) and the oscillator switching matrix. See the Web package for detailed schematics of this and other boards. Components are numbered in the 100 range. The front panel switches are multiplexed on the LCD control lines for economy so the display will not update when a button is pressed. The BFO is a voltage controlled oscillator (VFO) using a ceramic resonator (Y101) as a tuned circuit. The pulse width modulator (PWM) output from the microprocessor is filtered (R124, C114, R131, C108) and used as the control voltage for the BFO. The microprocessor (U105) varies the BFO frequency for upper or lower sideband modulation. The microprocessor is also used to stabilize the BFO, if the BFO varies more than 10 Hz from the set frequency; the microprocessor adjusts the PWM to correct the BFO frequency.

The digital board also contains the switching matrix for the VFO and BFO (U106, U107). The NE-612 mixers on the IF board work nicely when driven with square waves and aren't sensitive to duty cycle. One section of each tri-state buffer (74HC125s) is used to convert the output of the VFO and BFO to a square wave. The remaining sections control which oscillator goes to which mixer and which oscillator is applied to the frequency counter. The counter counts the VFO then the BFO and adds the result to calculate the operating frequency. The 20 MHz oscillator (OSC101) that runs the microprocessor is only accurate to 100 PPM, so the frequency displayed may be as much a 1 kHz off. Don't operate within 1 kHz of the band/segment edge just to be sure. A commercial transceiver or frequency counter can be used to calibrate your operating frequency.

The digital-to-analog converter (DAC) (U103) used to drive the VFO is a Microchip

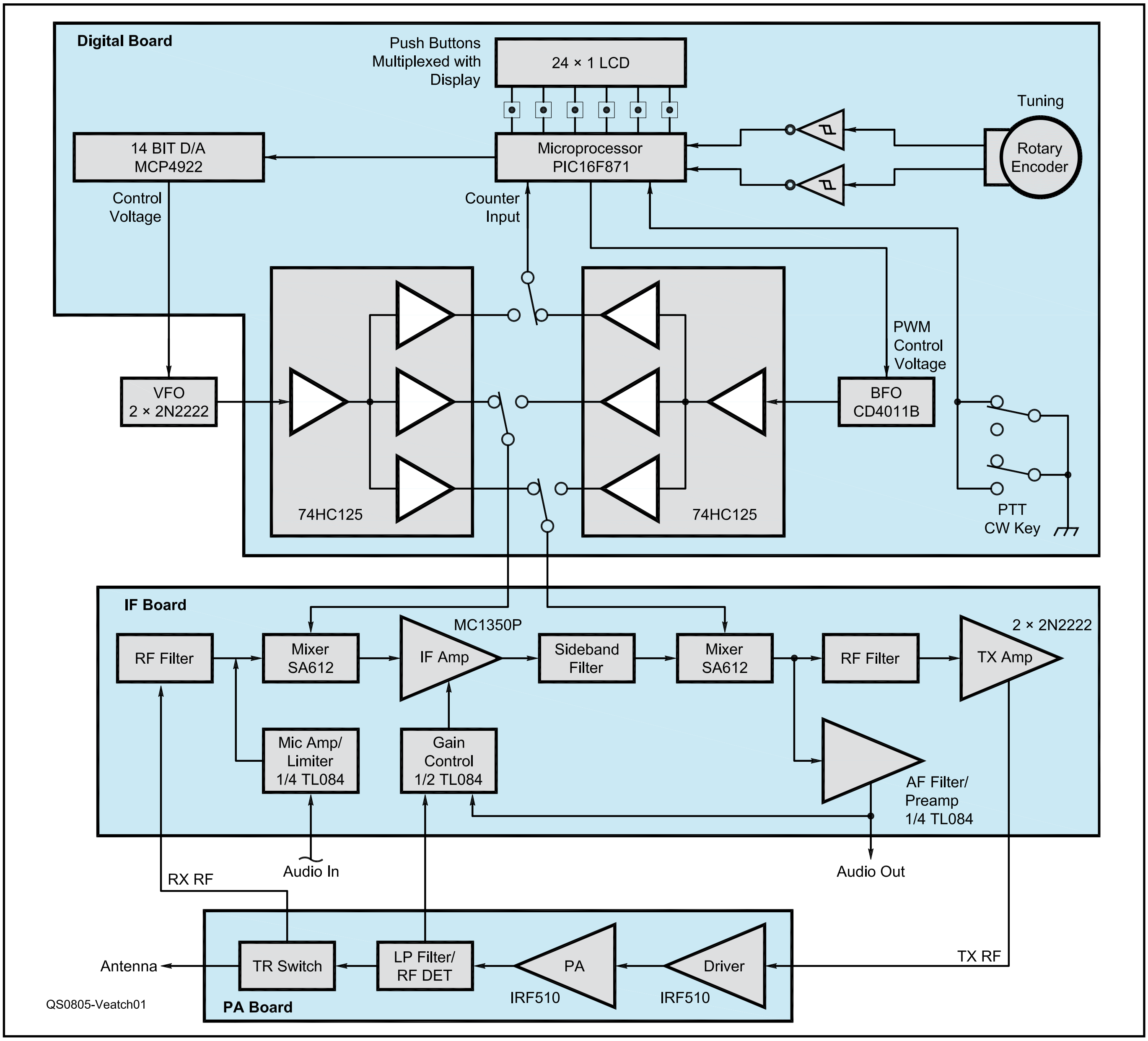


Fig 14.14 — Block diagram of TAK-40, homebrew challenge winner. This radio included many more features and capabilities than we expected to find in a $50 radio! Complete schematics, parts lists and firmware can be found at www.arrl.org/QST-in-depth. Look in the 2008 section for QS0508Veatch.zip.

MCP4922 dual 12-bit DAC. The outputs of each converter are coupled with an 8:1 resistive divider (R116, R117) effectively creating a 15-bit DAC. Since the band is split into two 150 kHz sections this results in approximately 10 Hz steps. Tuning is not linear, so frequency steps at the bottom of each band are slightly larger than steps at the top.

IF Board

In receive mode, RF is filtered in an impedance matching RF filter (C254, L208, C240, C235, L207, C234, C226), applied to the first mixer and mixed (U201) with the VFO signal to result in a 4 MHz IF. This signal is filtered in a 6-element crystal ladder filter (Y201-Y206) with a bandwidth of a bit more than 2 kHz. The signal is then amplified by an MC1350P IF amplifier (U202). The amplified signal is applied to the second mixer (U203) and mixed with the BFO signal to produce the receive audio.

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

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

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

VFO Board

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

Power Amplifier Board

The PA board includes the driver (Q401) and PA (Q402). Both stages use an IRF-510 MOSFET, which is overkill for the driver but very inexpensive. The gate voltage is pulled down during receive to reduce current draw and heat. The PA is biased class A and can produce 7 to 8 W output. The RF detector (R405, R406, D403 and C413) simply measures the RF voltage at the output so it's only accurate into a 50-Ω load. No protection is provided for excessive SWR conditions, thus it is possible to damage the PA transistor with prolonged operation into a poorly matched antenna system. A tuned TR switch (C412, D404, D405 and L405) isolate the receiver input during transmissions. Parts on the PA board are numbered in the 400 range.

Chassis

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

CONSTRUCTION

The best way to build this radio would be to buy the printed circuit boards (PCB) but it won't fit in the $50 budget. Files included in the Web *QST* binaries package that can be sent to **www.expresspcb.com** and they will send you two complete sets of boards for just over $100. (If you order more, the pre-set price decreases.) By ordering the PCBs you would complete the radio sooner than if you built it using any other technique and with a higher probability of success. To build the TAK-40 for less than $50 we'll have to resort to more creative techniques. Perfboard is expensive! "Dead bug" or "ugly" style construction is messy and difficult to rework/troubleshoot so a different approach is used in the prototype.

Print out the mechanical files for each board. Each drawing includes a parts placement, hole position, top copper and bottom copper drawing. Cut out the hole drawing and stick it to the copper side of the copper clad PCB using glue stick or print it on a self-ticking label. Make sure that the printer is printing a 1:1 size ratio using the dimensions of the board shown on the drawings. (Print out a test copy and check it against the actual parts to be sure.) Mark each hole with a center punch (hammer and a small, sharp nail works fine) then remove the drawing and drill all of the holes. Then refer to the top copper drawing and mark every hole that does not connect to the ground plane with a Sharpie pen. Next touch each hole with a larger diameter drill bit to remove the copper but don't go all the way through.

Using the parts placement drawing, the bottom copper drawing and the schematic, build the board. Take care not to short the non-grounded component leads to the copper and directly solder component leads that need to be grounded. The technique results in a good ground, short signal runs and solid mounting.

The prototype is built on a wooden frame and the front panel printed on photo paper in an inkjet printer. The tuning knob was made by using a hole-saw to make a circular wooden slug, drilling and tapping the sides for set screws and cutting off 6-32 screws to use as set screws. The encoder is made from rebuilding a potentiometer with the guts of a wheel mouse (see binaries package). The author mounted the VFO board in an Altoids tin for three reasons; mechanical stability, electrical shielding and it's not really a cool home-brew radio unless part of it is in a food container.

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

ADJUSTMENTS

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

LSB BFO Setup

The left portion of the display shows the frequency of the BFO at 100 Hz and the right portion shows the BFO setting at 10 Hz resolution. The main tuning knob adjusts the BFO setting (right display). Pressing SELECT stores the setting and updates the BFO. The microprocessor stabilizes the BFO frequency by counting the frequency with 10 Hz resolution and adjusting the BFO as necessary. USB/CW BFO setup is the same as the LSB setup, but adjusts the setting for USB and CW modes.

VFO A Range Test

The left portion of the display shows the VFO frequency and the main tuning knob adjusts the VFO frequency. This is useful when adjusting the VFO circuit and verifying the tuning range. VFO B Range Test is the same as VFO A test but displays the upper frequency range.

BFO Range Test

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

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

FINAL ASSEMBLY

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

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

Final Tune Up

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

VR-102 — sets the BFO range use setup

mode 5 above to display frequency of the BFO and rotate the MAIN TUNING knob CW until the frequency stops increasing. Set VR102 for a BFO frequency of 4.006 MHz. Rotate the MAIN TUNING knob counterclockwise until the BFO stops decreasing and verify that the BFO tunes below 3.995 MHz.

VR201 — Sets the AGC threshold. With no signal applied to the TAK-40 adjust VR201 for 2.5 VDC at pin 4 of the microprocessor (U105).

VR401 — Sets the PA bias. Adjust for 600 mA current draw LSB mode key down, VR 203 set to minimum.

VR203 — Sets the transmit drive level. Set for 7 W (3.7 V dc at pin 7 of U105) into 50 Ω on CW mode with VR202 set to minimum (wiper toward R227).

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

OPERATION

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

On the air most operators can't believe that it's only 5 W. The author worked 15 states on LSB in about a two-week period. Lots of phone operators use more than 100 W, but you can work then as well and they are usually excited about working a QRP station especially one that is homebrew. CW is even easier. The radio should give good results on PSK31, as well. Don't expect to sit on a frequency, call CQ and rake in the DX, but practice, patience, good operating skills and lots of listening, will be rewarded with plenty of ham radio action.

Controls

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

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

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

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

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

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

V to M — Stores the current frequency in memory.

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

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

14.5.3 *Project:* A Homebrew High Performance HF Transceiver — the HBR-2000

Markus Hansen, VE7CA, shows us that it's still possible to roll your own full feature HF transceiver — and get competitive performance! This project is a condensed version of an article that appeared in March 2006 *QST* and should provide an inspiration to all homebrewers. (The full original article is available in PDF format on the CD-ROM included with this book.)

Have you ever dreamed of building an Amateur Radio transceiver? Have you thought how good it would feel to say, "The rig here is homebrew"? The author is the proud owner of a homebrew, high performance, 100 W HF transceiver named the HBR-2000 (see **Fig 14.15**).

The secret to being able to successfully build a major project such as this is to divide it into many small modules, as indicated in the block diagram (**Fig 14.16**). Each module represents a part of the whole, with each module built and tested before starting on the next. To choose the actual circuits that were to be built into each module, the author searched past issues of *QST*, *QEX*, *The ARRL Handbook* and publications dedicated to home brewing such as *Experimental Methods in RF Design*, published by ARRL. It's import to learn by reading, building a circuit and then taking measurements. After you build a particular circuit and measure the voltage at different points, you begin to understand how that particular circuit works.

Do not go on to the next module until finishing the previous module, including testing it to make sure it worked as expected. After building a module, follow the same process to decide on the circuit and build the next module. Then connect the two modules together and check to make sure that, when combined together, they performed as expected. It is really that simple, one step at a time. Anyone who has had some building experience can build a receiver and transmitter using this procedure.

For a receiver, begin by building the audio amplifier and product detector module, then the BFO circuit, testing each separately and then the growing receiver, step by step. From there, build the IF/AGC module, then the VFO and the heterodyne LO system, then the receiver mixer and on and on until reaching the antenna. At that point you have a functioning receiver. It is a thrilling day when you hook up an antenna to the receiver and tune across the Amateur Radio bands listening to signals emanating from the speaker.

After you build a particular module, you don't want RF from outside sources to get into the modules you build and you don't want RF signals produced inside the modules to travel to other parts of the receiver, other than through shielded coaxial lines. The reason that you don't want RF floating around the receiver is that stray RF can produce unwanted birdies in the receiver, adversely affect the AGC system or cause other subtle forms of mischief. To prevent this from happening enclose each module in a separate RF tight

Fig 14.15 — Head on view of the HBR-2000. This looks a lot like a commercial transceiver.

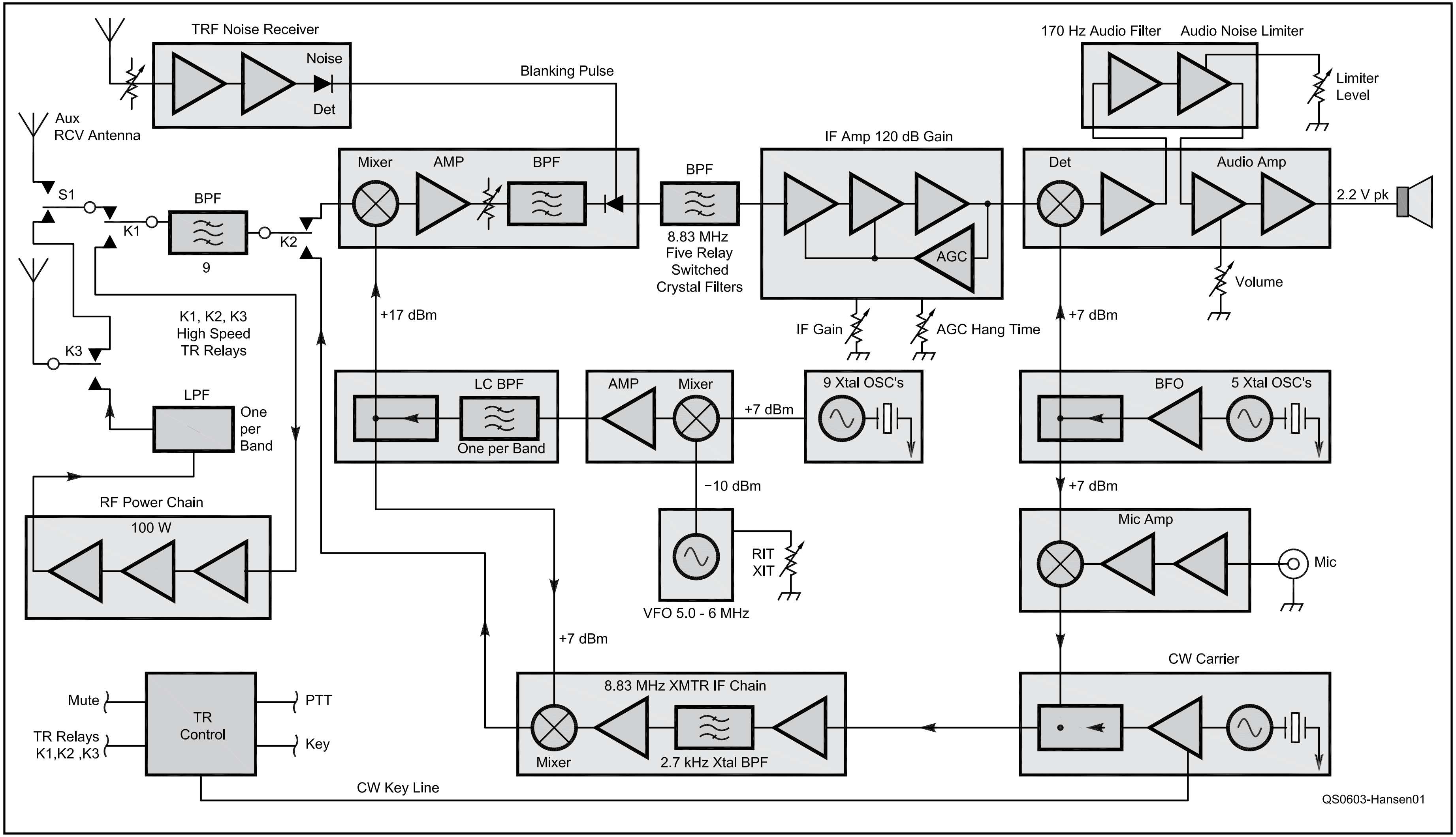


Fig 14.16 — Block diagram of the HBR-2000.

Fig 14.17 — Sample of a box made with PC board with a sheet brass cover overlapping all four sides. Note the BNC connectors and feed thru insulator.

box and used coax for all the RF lines with BNC or phono connectors on each end. All dc and control lines are connected via feed thru insulators.

Modules are enclosed in boxes made from unetched copper clad material. For the covers, cut sheet brass ½ inch wider and longer than the size of the PC box. Then lay the box on top of the brass and center the box so that there is about ¼ inch overlap around the perimeter of the box and draw a line around the box with a felt pen. Then cut the corners out with tin snips and bend the edges of the brass cover over in a vise. By drilling small holes around the perimeter of the box, inserting wires through the holes, soldering the wires to the inside of the box and to the overlapping edges, you produce an RF-tight enclosure. See **Fig 14.17** for an example of this technique.

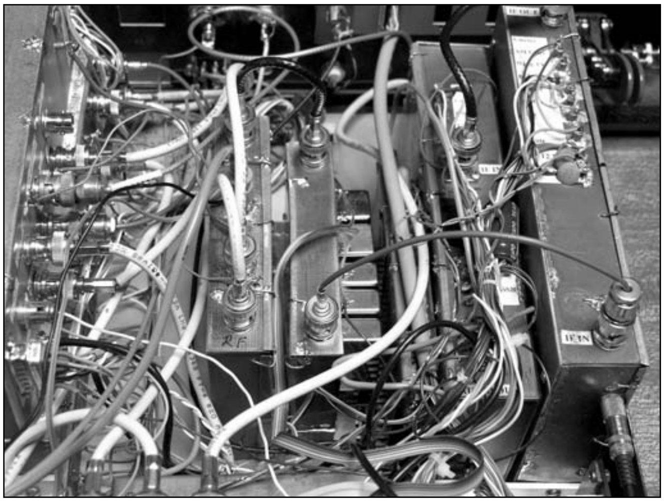


Fig 14.18 — The inside of the HBR-2000. All the boxes are connected together with 50 Ω coax and BNC connectors for the RF runs. All dc power and control leads, in and out of the boxes, are through feed through insulators.

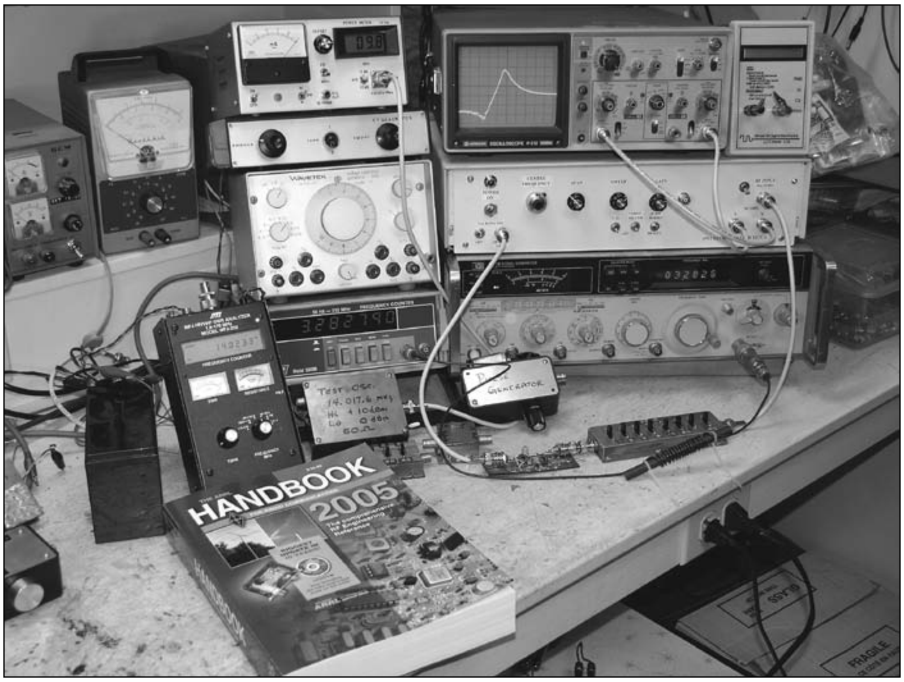


Fig 14.19 — The VE7CA work shop shows some of the home built and surplus test equipment used in the construction and evaluation of the HBR-2000.

TYPES OF CONSTRUCTION

The audio board and IF board are etched PC boards purchased from Far Circuits. The construction method the author learned to appreciate the most is "ugly construction," discussed in the **Circuit Construction** chapter. Each module is designed for an input and output impedance of 50 Ω except for the audio output (8 Ω for speaker connection). Thus 50-Ω coax cable with BNC connectors can be employed to connect the RF paths between the different modules. The concept is shown in **Fig 14.18**.

MEASUREMENTS AND TEST EQUIPMENT

Making meaningful and accurate measurements is a major part of producing a successful project. You must make measurements as you progress or you have no way of knowing whether a module is performing according to design specifications.

One of the specifications chosen for the HBR-2000 was that it should have a very strong front end. To accomplish this, the design uses a mixer that requires that the LO port be fed with +17 dBm at 50 Ω. Having the test equipment to measure these parameters confirms the expected results.

To help in the construction of this project, the author purchased surplus test instruments including an oscilloscope and signal generator. He also built test equipment such as crystal-controlled, very low power, oscillators and attenuators to measure receiver sensitivity, and high-power oscillators and a combiner to measure receiver blocking and dynamic range. He also built a spectrum analyzer, which turned out to be one of the most useful instruments because the HBR-2000 has 19 band-pass filters and 22 low-pass filters. (This instrument was described in August and September 1998 *QST* by Wes Hayward, W7ZOI, and Terry White, K7TAU.) Later he built the RF power meter featured in June 2001 *QST*, authored by W7ZOI and Bob Larkin, W7PUA. These instruments allow adjustment and measurement of the performance of each module built. A good selection of test equipment can be affordable. The author's lab is shown in **Fig 14.19**.

OTHER CIRCUITS

Here are some of the sources used for deciding on the circuits for the other modules in the HBR-2000 design. The low-distortion audio module is from the "R1 High Performance Direct Conversion Receiver" by Rick Campbell, KK7B, in August 1993 *QST*. The VFO design is from June *QST* ("Build a

Fig 14.20 — The 100-W amplifier board.

Fig 14.21 — The 100-W amplifier, 10 low-pass filters and the power supplies are located in a separate enclosure.

Universal VFO” by Doug DeMaw, W1FB).

The first mixer, post-mixer amplifier and crystal heterodyne oscillator design was taken from “A Progressive Communication Receiver” design by Wes Hayward and John Lawson, K5IRK, which appeared in November 1981 *QST* and was featured in *The ARRL Handbook* for many years. This is a classic radio article with many good circuit ideas.

Table 14.2
HBR-2000 Test Measurements

Spacing:	20 kHz	5 kHz	2 kHz
Two-tone blocking dynamic range:	>126 dB	124 dB	122 dB
Third-order IMD dynamic range:	103.5 dB	102.5 dB	93.0 dB
Third-order intercept:	25.5 dBm	24.0 dBm	14.5 dBm
Image rejection all bands:	>135 dBm		
Receive to transmit time:	8 ms (incl 2 ms click filter)		
CW, full QSK transmit to receive time:	17 ms (30 WPM = 20 ms dot)		

Fig 14.22 — VE7CA’s partly home brew Amateur Radio station.

The receiver input RF band-pass filter and diplexer designs along with the noise blanker and 100 W amplifier circuits were taken from the three-part series beginning in the May/June 2000 issue of *QEX* titled The “ATR-2000: A Homemade, High-Performance HF Transceiver” by John Stephenson, KD6OZH. The power amplifier and output circuit filters are in a shielded sub-enclosure as shown in **Fig 14.20** and **Fig 14.21**.

The BFO and power supply circuits were lifted right out of the *ARRL Handbook*. The transmitter portion of the transceiver consists of combinations of various circuits found in *Experimental Method in RF Design*.

RECEIVER SPECIFICATIONS

Some readers may question whether an amateur can build a competitive grade contest class transceiver from scratch. For the skeptics, the actual measured performance of the HBR-2000, as confirmed in the ARRL Lab is shown in **Table 14.2**.

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

The receiver specifications were made

following ARRL procedures as outlined in the ARRL "Lab Test Procedures Manual" at **www.arrl.org/product-review**. Making accurate receiver measurements is not a trivial matter and should be approached with the understanding of the limitations of the test equipment being used and thorough knowledge of the subject.

You may notice that the author made no attempt to miniaturize the HBR-2000. With large knobs and large labeling, he is able to operate the transceiver without the need for reading glasses. When you build your own equipment, you get to decide the front panel layout, what size knobs to use and where they should be located. That is a real bonus! See **Fig 14.22**.

Why not plan to build your dream station? If you haven't built any Amateur Radio equipment, begin with a small project. As you gain experience you will eventually have the confidence to build more complex equipment. Then someday you too can say with a smile, "my rig here is homebrew."

14.6 References

[1] R. Bitzer, WB2ZKW, "Modifying the Collins KWM-2 for Serious CW Operation," *QST*, Jan 2008, pp 30-34.

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[3] R. Lindquist, N1RL, "ICOM IC-756 ProIII HF and 6 Meter Transceiver," Product Review, *QST*, Mar 2005, pp 56-59.

[4] R. Lindquist, WW3DE, "ICOM IC-7700 HF and 6 Meter Transceiver," Product Review, *QST*, Oct 2008, pp 41-47.

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[6] R. Arland, K7SZ, *ARRL's Low Power Communication — The Art and Science of QRP* bundled with an MFJ Cub transceiver kit available from your ARRL dealer or the ARRL Bookstore, ARRL order no. 102YK. Telephone 860-594-0355 or foll-free in the US 888-277-5289, **www.arrl.org/publications-online-store**; **pubsales@arrl.org**.

[7] **www.arrl.org/QST-in-depth.** Look in the 2008 section for file **QS0508Veatch.zip**.