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The Heart of a 160 to 2-Meter Homebrew Station

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A High-Performance Homebrew Transceiver: Part 1

Here is a general description of a transceiver built without regard to size or complexity—the only goal is optimum performance for DX and contests.

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Ham radio affords an opportunity for a variety of fascinating experiences. For many hams, foremost among these is operating with equipment built in a home workshop. Traditionally, hams have built equipment that outperforms factory gear. Today, modern methods allow the production of miniaturized, microprocessor-dependent units that are difficult for radio amateurs to duplicate. However, in regard to basic performance and operating features, the home workshop can often produce gear that outclasses factory equipment.

This article begins a description of a homebrew transceiver built for seri-

ous DX work and contest operating. It was designed without compromise regarding performance and basic operating features, but includes no modern computer-related features. The goal was to build a radio that would outperform any available factory-built radio, regardless of price.

In 1948, I began homebrewing my first station, W9ECV, in Wisconsin. By 1990, everything in the shack was homebrew except the transceiver. Work began on this high-performance homebrew transceiver—it was completed three years later. Two portions of the radio, perhaps the most innovative, have already been described in *QEX*: The high-performance AGC system and the non-crunching noise blanker.^{1, 2} A description of the completely home-

brew K5AM station recently appeared in *NCJ*.³

Basic attitudes toward homebrewing acquired in the 1940s have been retained. Homebrew means “built-from-scratch,” and often newly designed. I’ve tried to keep up with some of the latest devices and techniques, but this transceiver uses no microprocessor, no synthesizer and no phase-locked loops. No phase noise, no spurs, and no birdies! This, of course, involves limitations: No memories, no instant frequency jumps, no computer control, no DSP.

For ordinary DX work, nonetheless, these features are not missed. For contesting, however, here is the disclaimer: World-class contesters would not find this radio acceptable. They often want to operate two radios simultaneously, with computer control. They

¹Notes appear on [page 24](#).

want frequencies read from the radio and entered into the computer to create band maps, and for logging purposes. In other words, they want bells and whistles *ad infinitum*. So I must hedge on the contesting claim in the subtitle of this article; this radio is designed for the sort of contesting that I do. This includes single-operator DX contests, domestic HF contests and VHF contests on several bands with transverters. Results have been gratifying. A number of section and area awards have been won with this homebrew radio. I have operated the best of the current factory radios and—in many respects—find them lacking in comparison. The bottom line is that this homebrew transceiver has certain performance characteristics that surpass those of the best factory gear. This more than compensates for the lack of bells and whistles, at least for my style of operating. As for backing up the basic performance claim, I'll give data in a following article about alignment and measurements.

This radio was built for daily use in a station with a heavy operating schedule. It was not built as an experimental platform. Experimenting with each circuit, trying at each stage to obtain results surpassing all previously published circuits, would have meant that the project would run to decades, rather than years, and would likely never have been completed. Besides, this builder has no professional training and lacks the expertise for such a project; I merely put together circuits, already optimized by experts, to produce a complete operating unit. Individual circuits were chosen from the available literature at the time of construction.

This article describes only the general plan of the transceiver, with emphasis on design considerations and a discussion of features required for serious DX work and contesting. Subsequent articles will give circuit details.

Conversions: Fewer are Better

The craze for multiple conversions began in the 1950s. At that time, there were some good reasons. A single-conversion receiver with a 455 kHz IF had intolerable images on the 10-meter band. Thus, a first conversion to about 3 MHz was a great improvement. In addition, it was difficult to obtain very sharp selectivity at 455 kHz, so a third conversion to about 50 kHz was helpful. Eventually, we saw advertisements for quadruple-conversion radios.

The advantages of multiple conversions came at the cost of increased IMD. Mixers have noise figures equal

to their conversion loss, and this loss must be compensated by gain stages ahead of the mixer. The result is very high signal levels at the last mixer before the high-selectivity filter. It is this last mixer that mainly determines the close-in dynamic range of the receiver. The current hype about strong front-ends is misleading. The crunch is at the last mixer [for nearby signals—*Ed*]. Even more misleading is the hype about strong preamps for VHF and UHF. A preamp cannot improve the IMD performance of a receiver, it can only degrade it; the more gain in the preamp, the more trouble down the line.

The situation is different today than in the 1950s. Excellent crystal filters for both SSB and CW are available at about 9 MHz. With a first up-conversion and a second conversion down to 9 MHz, superb image rejection and selectivity are easily obtained.

This transceiver tunes the bands in 1-MHz segments, with a variable first IF tuning 40 to 39 MHz. The tuning is “reversed” because the injection is on the high side; eg, at 68 MHz for the 28 to 29 MHz band. The result is a very high-performance radio with only two conversions. The high-side injection method results in virtually no spurious responses; it is used on all bands. There is no difference between the 160 and 2-meter bands, as far as mixing scheme is concerned. The arithmetic is easy: Simply add 40. Injection is at 41.8 MHz for the 160-meter band and at 184 MHz for 2 meters. All the front-end oscillators use third or fifth-overtone crystals, well known for their low phase noise. For 2 meters, the 92-MHz oscillator is followed by a balanced doubler. (In this article, the author uses the term “front-end” to indicate both the receive front-end and the transmitting circuitry along with a control panel for a particular frequency range: HF, 6 meters or 2 meters.—*Ed*.)

I didn't invent this conversion scheme. It is taken from the Signal One CX7, a radio that appeared in 1969, and that had dozens of groundbreaking innovations. Few hams today know that the CX7 is the granddaddy of all present-day radios. I operated, repaired and modified my CX7 for 20 years before designing my homebrew transceiver. Did I learn anything from the CX7? Well, when it first arrived in my shack, all I could say was: What are those funny little things with three legs?

Basis for Design

Many ideas were taken from the CX7

besides the frequency-mixing scheme. Notably the RF speech clipping, the transmitter driver circuits and the PA bias and ALC circuit. In addition, some surplus parts were used from basket-case CX7 radios found at flea markets. The crystal filters, precision-machined mechanical parts (bearings, etc) for the PTOs, the panel escutcheon for the frequency counter, the conduction-cooled 8072 PA tube, the anode clamp and heat sink, and a few other miscellaneous small parts were salvaged from various dismantled assemblies.

The goal in building my own radio was to obtain improvements in performance, operating convenience and new features. The features I had used for 20 years and liked, I retained. Even the panel layout bears some resemblance to the CX7. This led one friend to ask: “Is your radio a CX7 clone?” Definitely not! Is every radio with a 455 kHz IF a clone of the first one? Although the frequency-mixing scheme in this radio is the same as in the CX7, virtually every circuit is newly designed. At the same time, my debt to the CX7 designers is enormous. It was essential to keep the same IFs for two reasons: First, I planned to use surplus 9-MHz CX7 crystal filters, which are excellent, if selected from a batch. Second, transverters that fed directly into the CX7 40 MHz first IF had already been built.

Here are some features of the K5AM homebrew transceiver:

- Balanced JFET and balanced MOSFET mixers
- Careful gain distribution
- High dynamic range
- Non-crunching noise blanker (see [Note 2](#))
- High-performance, no-pop, no-click hang AGC circuit (see [Note 1](#))
- Super-sensitive integrating squelch for SSB and CW (mainly for 6-meter DX)^{1,4}
- Complete TTL logic control. Eg, the mode switch has seven leads, not dozens.
- Quick, one-button PTO switching
- Relay-switched crystal filters
- A sharp CW filter at the IF output (in addition to one at the input)
- Electronic attenuators for all audio level controls. This reduces hum problems.
- 60-Hz filter in receiver audio
- High-pass filter in transmitter audio to eliminate externally induced hum.
- Pulse tuning circuit for safe, easy external amplifier tuning; set for 33% duty cycle⁵
- Sharp CW shaping. No dit delay after key closure.

- RIT—separate knobs for each PTO
- One-button second-PTO monitoring
- Automatic (optional) transverter switching tied to PTO switching. This is mainly for instant 6 to 2-meter switching during VHF contests. It is also useful for instant switching between 144.200 MHz and 3.818 MHz (75-meter liaison) during meteor showers.
- Clear, sharp audio—the audio output module uses a class-A, push-pull circuit

Tuning the First IF

This radio differs from nearly all current designs—the first IF circuits are tunable. One advantage applies to VHF DX operators. The basic 40 to 39 MHz tunable transceiver forms an excellent foundation for the attachment of VHF transverters. For the 6-meter band, the LO injection is at 90, 91, 92 or 93 MHz, from four separate crystal oscillators. This high-side injection yields no detectable spurious responses. The overall conversion total is merely two. This is in sharp contrast with common practice, where 50 MHz is converted to 28 MHz; LO injection at

22 MHz allows the possibility of unwanted spurs. In such an arrangement, the overall conversion total can be as high as five, with the resulting high possibility of spurious responses, spurious emissions and IMD.

Tuning the first IF means that the circuits following the first mixer have a bandwidth of 1 MHz and thus the second mixer must be strong enough to handle any signals within this range. This is in contrast with current production radios that use a fixed-frequency first IF and crystal filter at about 70 MHz, to limit the spectrum of signals within the first IF strip. These filters are usually about 20 kHz wide, with poor shape factors and ultimate-rejection characteristics, compared to filters at 9 MHz. During lab tests using two-tone spacing of 20 kHz, such receivers may demonstrate excellent dynamic range. Nevertheless—with today's crowded band conditions—one cannot hope to find a clear 20-kHz-wide segment in which to operate. Published reviews do not address this problem.

This radio, on the other hand, while not employing a first IF filter, does have good dynamic range performance

with respect to adjacent-channel signals, as well as more distant signals. This performance relates more closely to real operating conditions.

Another problem arises in some current production receivers. These develop AGC in the first IF, ahead of the sharp crystal filters, and apply AGC voltage to the first IF strip and front-end. This may prevent IMD in the first IF strip, but gain is reduced and weak signals may be lost. Receiver sensitivity is reduced in the presence of nearby strong signals that lie outside the second-IF passband. Hence, front-end AGC and gain reduction may be unacceptable for some weak-signal work.

In this radio, AGC is applied only to the IF strip at 9 MHz, after the crystal filters. This arrangement allows the IF gain to be controlled with no loss of sensitivity in the front-end. The mixers are built to handle strong signals, and the sharp 9-MHz crystal filter following the second mixer effectively keeps off-channel signals out of the AGC circuits. The front-end runs wide open at full sensitivity, the best arrangement for weak signals. On the lower HF bands, it is sometimes pru-

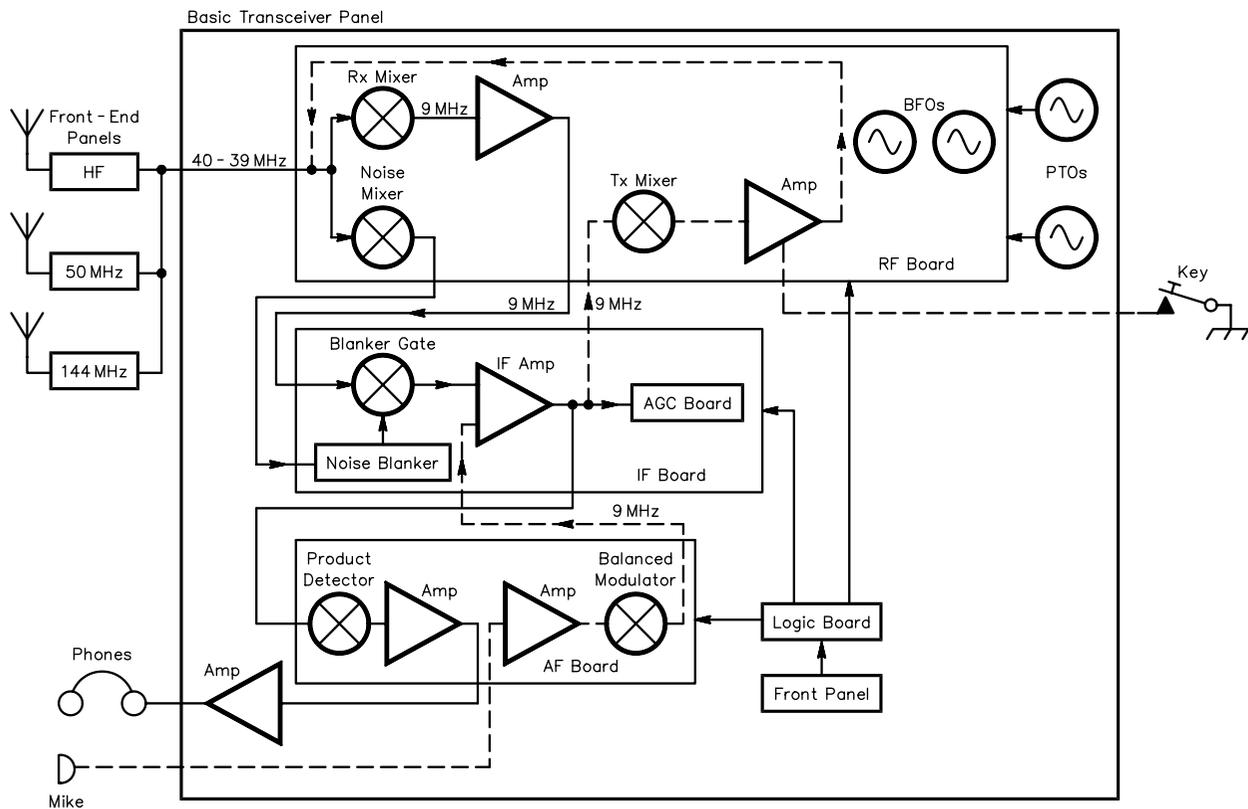


Fig 1—K5AM homebrew transceiver simplified block diagram. This diagram includes the basic transceiver panel, tuning 40 to 39 MHz, and the three front-end sections, for HF, 6 meters and 2 meters. Additional front-end sections, for other VHF or UHF bands, can be easily added. The dashed lines indicate transmit signal paths.

dent, although not always necessary, to use the front-end attenuator.

Block Diagram

Fig 1 shows the main sections of the transceiver. Its most unusual feature is that it is built on separate panels; one for the basic 40 to 39 MHz transceiver, and one for the 200 W HF front-end. These two items were completed, after three years work, in 1992 and together form an HF transceiver in the usual sense.

However, the transceiver covers all ham bands from 160 meters to 2 meters, so we need a brief description of how the transceiver fits into the complete station. The 6 and 2-meter front-end sections were built a few years earlier. These are often called transverters, but in this case they have 40 to 39 MHz outputs; they do not translate the VHF bands to any amateur band. They are integral parts of the transceiver, functioning exactly like the HF front-end. Now there are 11 ham bands from 160 through 2 meters. It takes four panels, and we have only 2 W on 6 and 2 meters, not a very acceptable power level for an 11-band transceiver. So, we now add 100 to 200 W 6 and 2-meter amplifiers. One 6-meter amplifier was built in 1951, when I was still in high school. So, I finally have a complete 160 to 2-meter homebrew transceiver at about 200 W, on only six panels, which took only about 40 years to build! There are

also homebrew 1.5-kW amplifiers covering all bands.^{5,6,7} A block diagram of the entire station is shown in the *NCJ* article (see Note 3).

Compactness and miniaturization have obviously not been prime goals for this project. On the other hand, this style provides a good deal of flexibility. For example, many homebrewers concentrate on VHF/UHF SSB/CW DX operating. Building the basic transceiver separately allows one to add whatever VHF/UHF front-end sections are desired. The 40-MHz IF, with high-side injection, works very well on the 6 and 2-meter bands, and should work well on higher frequency bands.

Receiver Gain Distribution

Receiver gain distribution is a crucial factor in obtaining high dynamic range. In this radio, the IF strip—after the sharp filters—was designed with the highest practical gain. This allows the signals at the mixer to remain at a low level. Gain before the sharp filters increases signal levels at the last mixer, and so reduces dynamic range. Gain after the filters has no detrimental effect on receiver performance, just as turning up the audio gain in a large room does no harm. This is one reason why a receiver with minimal conversions, and thus less need for front-end gain, has the best potential for superior performance. The most serious limitation on putting most of the gain after

the filters is the possibility of BFO signal leakage into the 9-MHz IF strip. The IF strip in this radio has the unusually high gain of 107 dB, and operates at the unusually low signal-input level of -119 dBm—or -128 dBm with the 200 Hz CW filter. This requires exceptional filtering and shielding of the IF strip, the BFO circuits and the power supply leads. The construction methods are briefly described below.

Frequency Mixing Scheme and IF Shift

Fig 2 shows the premixing scheme. The 3 to 4-MHz VFO is converted to 31 to 30 MHz LO injection power at the mixer, and thus 40 to 39-MHz signals are converted to 9 MHz. Most significant is the way the BFO frequency is subtracted, resulting in an IF shift, an essential operating feature. In this way, the BFO frequency does not affect the receive frequency.

With this premixing method, the receiver frequency is the suppressed-carrier frequency for SSB and the zero-beat frequency for CW. If a 14.010 MHz CW signal is tuned for a 500-Hz audio tone, the receiver will read 009.5. An advantage of this method is that if tuned to zero-beat, the receiver reads the actual signal frequency. A more important advantage appears in VHF DX work, where operators frequently shift between SSB and CW—without changing

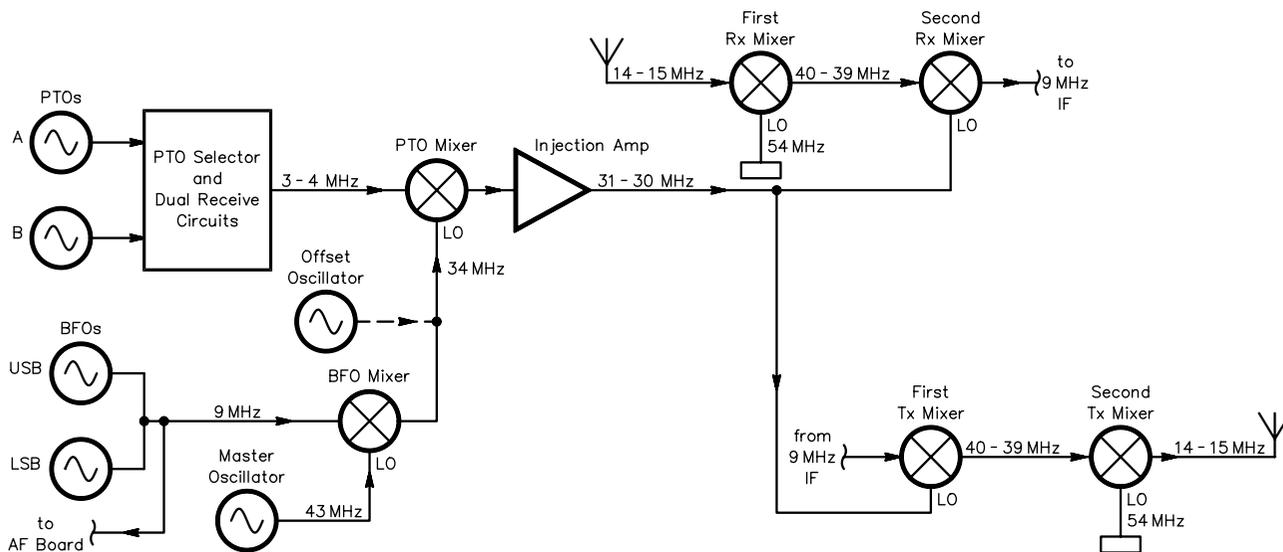


Fig 2—Simplified frequency-mixing scheme. Premixing the low-frequency VFO up to the injection frequencies required by the mixer would be simple enough. The main feature here, however, is the mixing of the BFO frequency to obtain IF-shift operation, a necessity for any radio designed for serious DX or contest work. The result is that the BFOs can be tuned without changing the receive frequency. Credit for this mixing scheme is due to the CX7 designers. Rather than actual frequencies, round numbers are used in this diagram; this allows the basic idea of the mixing scheme to be shown without lots of ugly decimals. See text for details.

frequency—during a single contact. With some “modern” radios, a frequency shift occurs when changing modes, or changing CW filters, often resulting in a lost contact. With the system used here, the CW signal is transmitted within the SSB channel.

For transmitting CW, the master oscillator is disabled, and the offset oscillator is used for injection at the PTO mixer. The BFO still provides the signal for the CW carrier gate on the AF board. Thus the offset oscillator can be used to vary the transmit frequency. Using the round numbers from Fig 2, setting the offset oscillator to 33.9995 MHz (via the front panel **CW OFFSET** knob) will result in a 500-Hz offset. The operator will hear a 500-Hz tone when the offset monitor button is pressed.

This frequency mixing method is exactly as in the CX7, although in Fig 2, round numbers have been used in order to show the basic idea without lots of ugly decimals. The actual VFO frequency range is 3.1 to 4.1 MHz, eliminating an obvious spur on the entire 80-meter band. To accommodate this shift, the master oscillator runs at 43.1 MHz. The actual crystal filter center frequency is 8815 kHz, and the actual BFO frequencies are 8816.5 kHz and 8813.5 kHz. Any crystal filters in the 9 MHz range with corresponding BFO crystals may be used, with no circuit change. The actual frequencies in Fig 2 are now easily calculated; in USB and CW modes the BFO is at 8.8165 MHz, the BFO mixer has output at 34.2835 MHz, and the PTO mixer output, for LO injection, has the range 31.1835 to 30.1835 MHz.

The functioning of the IF shift feature can be seen in Fig 2. When receiving USB signals, for example, the BFO frequency is above the crystal filter passband, because of the high-side injection and the resulting inversion in the front-end. If the BFO frequency is decreased somewhat using the **IF SHIFT** control on the front panel, it will be closer to the crystal filter passband, resulting in a lower-frequency audio passband. At the same time, the output frequency of the BFO mixer will increase, causing the PTO mixer output frequency (the injection frequency) to also increase, in the same amount. This causes the frequency of the signal in the IF strip to decrease, so it mixes with the BFO to produce the same audio tones as before. Thus, the receiver is still precisely tuned to the station. One can work out the simple formula for the frequency of the receiver audio output, using the signal frequency, the transmitted tone frequency and all the oscil-

lator frequencies. The BFO frequency appears twice, with opposite signs, and cancels out.

Front-Panel Controls

While not having the bells and whistles that a microprocessor-controlled radio might have, this radio does have some features that, as least for this operator, beat current factory radios in operating convenience. I do have a few late-model radios up at my Horse Mountain VHF contest station (at 7900 feet) and do know that memories and other features are useful and fun, and that one can become accustomed to menu-driven controls. Nevertheless, I find that the traditional panel controls on my homebrew radio at home allow quicker and easier operation in the heat of battle, such as during a rare one-minute DX opening on 160 meters, or during a contest.

The front panel is shown in Fig 3. The template in Fig 4 shows the controls and labels clearly. Some of the control features are discussed below.

The dual PTOs have separate, large tuning knobs and separate, large RIT knobs. This feature is very desirable; in some factory radios, the RIT, once activated for one VFO, also affects the other VFO, where it is not wanted. The separate RIT circuits are turned on by simply pulling the knobs.

The PTO control switch (**A/B**) is a three-position, black Bakelite bat handle lever switch, directly beneath the digital frequency display. The right position selects PTO A, left selects PTO B. Center position selects split; receive on A, transmit on B. What about the opposite split? I never use it. It's best to acquire a fixed habit in this regard and stick to it; then there is less chance of

transmitting on the wrong frequency. If desired, the opposite split may be obtained using the monitor switch.

For monitoring the B channel (with counter read-out), there is a momentary push button directly beneath the digital frequency display, and a lever switch at the lower left. I thought that having the button in the middle would be most convenient, but toward dawn after a long night on the 160-meter band, the lower switch is used more often. All the lever switches on the front panel are old Switchcraft models with black Bakelite levers. They're still found on the surplus market. They are manufactured in either momentary or fixed styles, but the fixed version can be used either way: Lean gently on the lever for momentary action, push harder to make it hold. For example, the **KEY** switch can actually be used to send CW in an emergency, or pushed fully down to hold for a steady carrier.

When the lower B-channel monitoring switch is pushed up, it lets you set the PTO B frequency while listening to PTO A. A panel control sets the amount of **CW OFFSET**, and an audio-monitor momentary push button to hear the offset. The controls are arranged so that the button can be pushed—and the **CW OFFSET** knob turned—with one hand. Another knob sets the **OFFSET LEVEL** of the tone in the headphones. The transmit-side tone frequency is independent of the offset, and is set internally, with a level control on the front panel. The **DUAL RX** feature is turned on and off by simply pulling that knob; the knob adjusts the balance.

It is universally agreed that the best speech processing method is RF clip-



Fig 3—Front panel of the basic 40 to 39-MHz transceiver. Four of the operating features are enabled by means not apparent in the photo. The A RIT, B RIT, BLANKER, and DUAL RX knobs are all attached to potentiometers with ganged push-pull switches. Pulling the knob out actuates the function.

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ping. This requires a second SSB crystal filter, but the extra DX countries and contest points make it well worth the trouble. Separate **MIKE**-gain and **CLIPPING** controls are provided on the front panel. After changing mikes, one calibrates the radio for the new mike by simply turning the **CLIPPING** control fully ccw and adjusting the **MIKE** control for minute indications on the **CLIP** meter (at clipping threshold). Then the **CLIPPING** control is advanced to the desired level. Microphone calibration ensures the best gain distribution in the transmit audio circuits, the proper audio level at the balanced modulator, the best transmit-audio quality and optimal carrier suppression. The **CLIP** meter circuits are adjusted so that full-scale on the meter represents 20 dB of RF compression; one-quarter scale represents the normal level of 6 dB compression.

In addition to the front-panel **MIKE** jack (which I never use), there is a high-level speech input jack on the rear panel, which receives audio from the station audio-distribution system and digital voice recorder.⁸ There is no **KEY** jack on the front panel; I don't like a clutter of cables on the operating bench. There are **KEY**, **KEYER** and **FSK** jacks on the rear panel.

The radio has two analog meters on the panel. In receive, one meter reads **SIGNAL** level. When the squelch circuit

is in use, the other meter reads integrator voltage (**SQUELCH**); this allows quick and easy squelch-level adjustment. In transmit, one meter reads **ALC** voltage. In SSB mode, the other meter reads **RF-CLIP** level. Constant monitoring of these two meters ensures good signal quality.

Full break-in CW operation (**QSK**) is included for HF: no dit shortening no lag and break-in ability up to 50 WPM. Semi-break-in (**SQSK**) is available for all bands; the delay is set by a knob on the panel. A three-position panel switch chooses **QSK**, **SQSK** or neither. A Curtis keyer chip is included, with a **SPEED** control on the panel. The CW-waveform make and break times have separate internal adjustments.

The **TUNE** switch provides **PULSE** tuning (described earlier) if pushed up or a steady carrier if pushed down.

The **AF GAIN** (**AFG**) knob on the front panel also functions when using an external audio DSP filter. This is much more convenient than dealing with the AF-gain control on the external unit. For this purpose, audio jacks on the rear panel provide connections to the line-level input/output jacks on the DSP unit. Also included are special amplifier and attenuator circuits to set (and forget) the proper drive level to an external unit, and to equalize the DSP on/off audio levels in the radio.

In lieu of the RF gain (**RFG**) control

found on almost all receivers, this transceiver uses an **IF Gain** (**IFG**) control. This **IFG** control lowers the gain only of the IF strip, leaving all stages ahead of the sharp crystal filters running at full gain. This preserves full sensitivity for weak-signal work. The main use of this **IFG** control is for "AGC threshold" operation. For this reason, the circuit is arranged so that using the **IFG** control does not cause the S-meter to read upwards. AGC-threshold operation is very effective with extremely weak 160-meter DX signals and with EME (earth-moon-earth, moonbounce) signals. Even the best AGC system is not as good as a well-trained ear.

In this radio, the AGC threshold is about 10 dB above the MDS (minimum-discernible signal) level. Available gain is sufficient so that ambient antenna noise activates the AGC system. For AGC-threshold operation, the **IF Gain** is reduced so that weak signals and noise are a few decibels below the AGC threshold. In effect, the AGC threshold is raised; there is no decrease in sensitivity. The ear can now hear the weak signal in the noise. The AGC system is prevented from reducing the receiver gain at every little static crash. On the other hand, large static crashes and loud signals will activate the AGC system and protect the operator's ears. This is impor-

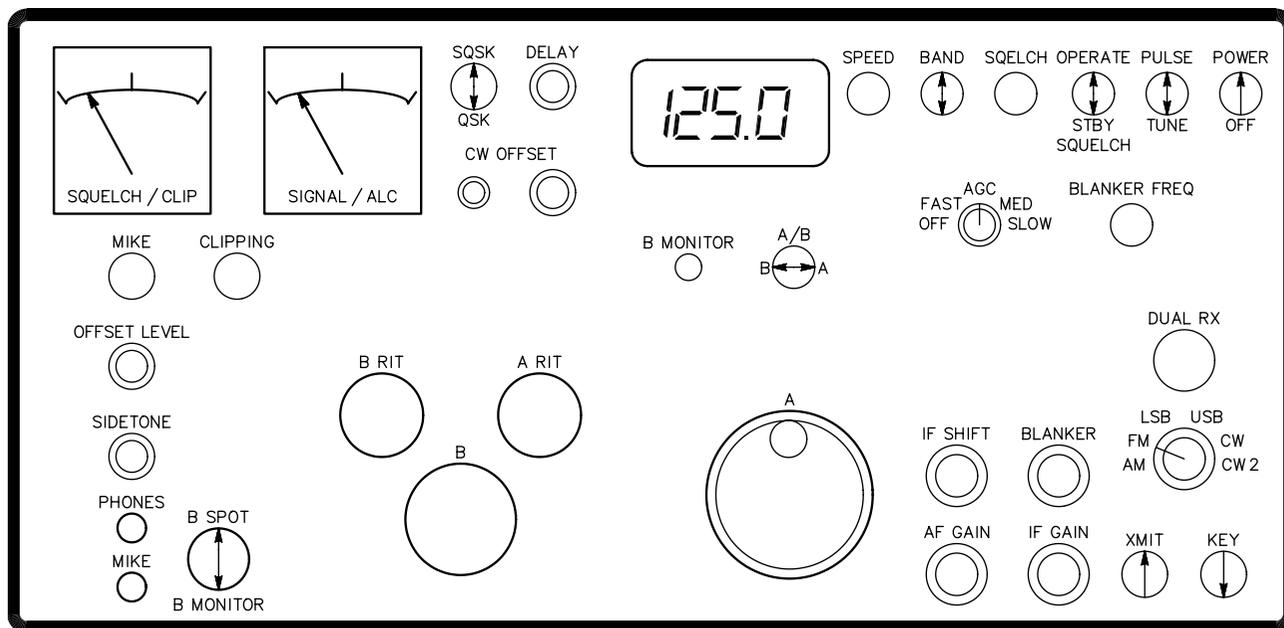


Fig 4—Front panel layout. This shows the transceiver controls and their labels. The digital readout counts the PTO outputs directly, and shows only the kilohertz part of the transceiver frequency. The megahertz band is indicated by band switches on the front-end panels. For details of the operating features, see text.

tant for hams who wish to work DX for many, many years. This operating method is safe, in contrast to the all-too-common practice of turning off the AGC.

Most radios suffer from two RFG control problems: Most RFG controls cause the S-meter to read upwards, making it very difficult to set the correct AGC-threshold operation level. Also, most RFG controls reduce the front-end gain; this reduces receiver sensitivity and causes signals to be lost. The IFG control in this radio raises the AGC threshold; the S-meter correctly indicates signal levels relative to the set threshold, and receiver sensitivity is not reduced.

The **STBY/OPERATE** switch is combined with the **SQUELCH** switch. **OPERATE** is up, **STBY** center, and **SQUELCH** down. Thus switching to **SQUELCH** automatically switches to **STBY**, and disables the transmitter. This is the simple one-touch procedure for leaving the radio on an HF DX operation frequency or a VHF DX calling frequency and going back to the workbench.

The **SQUELCH** level control is a separate knob, not linked to the **SQUELCH** switch, so it does not have to be reset each time the squelch is turned on or off.

There is one last, very important feature: There are no concentric dual knobs!

Construction and Layout

Fig 5 shows the basic transceiver, with four main circuit boards. Each board is hard-wired to the radio, with a 12-inch-long harness. This allows the boards to be lifted out for testing while in operation. Sub-boards are mounted on hinged spacers, for immediate access. The PTOs are mounted to the front panel, which can be removed in seconds, with no knobs or couplings to remove. The rear panel, which carries the power supply, receiver audio-output module and input/output jacks, can be removed in seconds.

All the gear in the shack is built on standard 19-inch black rack panels. The basic 40-MHz transceiver is built on a 8.75-inch-high panel. The 200 W HF front-end is on a 7-inch panel. The 2-W 6 and 2-meter front-ends are each built on a 3.5-inch panel.

The need for exceptional filtering and shielding was mentioned above in the section under “Receiver Gain Distribution.” To exemplify my techniques, the three signal boards can be used. Each measures about 7.5×15×2 inches and is constructed using double-sided circuit-board material. A floor is

soldered-in, forming a 1.5-inch-high living space for the circuits, and a 0.5-inch-deep space below for filtering. All power and control leads go through soldered-in feedthrough capacitors in the floor, and then through additional filters in the “basement.” Individual stages are separated by soldered-in walls. Signal leads pass through tiny windows in the walls. As required, some compartments are fitted with shielded ceilings.

Some of the surplus parts used in this design may not be readily available. If readers want to duplicate the radio, perhaps only in part, any of the currently available replacement crystal filters in the 9-MHz region could be used. Because of the unique premixing scheme, no circuit changes will be needed; only the two BFO crystals will need to be selected accordingly. The VFO problem will always present an interesting challenge.

The block diagram in Fig 1 reflects the physical layout into four main boards called LOGIC, RF, IF and AF. Smaller assemblies are mounted on the front and rear panels. The four boards, the panels and the HF front-end formed the six main phases of the project. A total of three years was scheduled, six months for each phase. I started with a rough overall plan, but not a complete plan for each phase; no schematics at first, only input/output specifications. Typically, the six

months work for each phase were divided into four months of designing and two month’s of building. General descriptions of each of the six main parts of the radio are given below, with emphasis on design criteria and operating features. Subsequent articles will deal with circuit details.

Logic Board

No one who has replaced the mode switch in a traditional radio has fond memories of the experience. With up to six modes, including several CW filter choices and numerous circuits to control, there can be dozens of leads. After fighting mode switches for decades, I used modern logic ICs to put an end to this nightmare.

There are even better reasons for using logic control. One is crystal filter switching. Switching filters directly at the mode switch is problematic in that it requires the filters to be somewhat exposed. In contrast, logic control with miniature relays allows careful shielding and greatly improved ultimate rejection. That is, there is reduced “blow-by”—the signals that leak around the filter.

Logic-mode switching also offers mechanical advantages that are important for the experimenter. The mechanical linkages and couplings that connect a traditional mode switch to the front panel are eliminated. I



Fig 5—A view from above.

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used no such linkages in this radio. A further advantage is the ease with which one can make modifications to the various control functions, simply by adding a few TTL gates.

Controlling six modes, the mode switch used here has merely six TTL-level leads, and a ground. The logic board converts the TTL signals to whatever levels are required to control the various circuits. In addition to the mode-switch signals, some panel controls (**PULSE / TUNE**, **STBY**, **A / B**, **DUAL RX**, **B MONITOR** and **B SPOT**) are converted to TTL signals that are combined in the logic chips for control of various circuits. This makes it very easy to implement any desired function. For example, one touch of the **TUNE** button automatically shifts the radio into CW, silences the mike, closes the PTT and KEY lines, disables the sidetone and shifts the carrier into the clear channel you have found.

The PTOs are also controlled by the logic board. The single, three-position PTO lever switch has only two leads and a ground, instead of a 16-pole, three-push-button, 24-wire assembly, plus an 8-pole, 16-wire concentric rotary knob obstacle course, as in the CX7. PTO control for flexibility is of special concern. The radio has two PTOs and dual-receive capability. In addition, it provides instant one-button monitoring of the second channel, for split frequency DX operations. (Dual receive is not suitable for extremely weak, barely readable DX signals.) In addition, there is provision for spotting the transmit frequency (as for 40-meter DX SSB work) while receiving. The logic board must select which PTO to read on the frequency counter in any given situation. For all this PTO and counter control, it was expedient to go beyond the simple TTL gate chips and use the larger data selectors, the 74151, as logic-function generators. Each variable is assigned a symbol, the logic function that gives the desired result is written and the chip is wired accordingly.

RF Board

This board contains the balanced JFET receive mixer that converts the 40 to 39-MHz signals to 9 MHz, and the balanced MOSFET transmit mixer that does the reverse. It also contains the two 9-MHz BFOs, the premixing circuits that enable the IF-shift circuit, the dual-receive circuits and the front-end of the tunable noise blanker. Premixing does allow the possibility of spurious responses or birdies, so there is very extensive filtering and shielding.

This board includes the oscillator that enables the adjustable CW offset. Also included is the mixer that mixes the offset oscillator with the normal output of the BFO mixer, to produce the audio tone for headphone monitoring of the offset.

IF Board

The IF strip functions in both receive and transmit modes, using six MOSFET stages, and several additional switching and buffering stages. The board includes the crystal filters, the RF clipping (and clipping metering) circuits and the AGC circuits.

For SSB, there are matched 2.4-kHz filters at the input and at the output of the IF strip. The result is a 2.0-kHz passband. The second filter is essential, because the RF clipping takes place within the IF strip and produces distortion products. This is an unavoidable effect of RF clipping. Because of the greatly increased effectiveness of the SSB signal, it is well worth the effort and cost of the second filter. The gain of the IF strip is reduced greatly—to a fixed level—during SSB transmissions. Clipping occurs at a fixed level within the strip. The amount of clipping is adjusted by varying the gain of a transmit stage leading to the IF strip. The transmit drive level is set on the front panel of each front-end module. There is no transmit output level control on the transceiver's panel—it would have to be readjusted when switching between front-ends.

RF speech clipping requires careful monitoring. A meter provides more definite indications than does headphone feedback. The meter indicates the actual amount of clipping, and alerts the operator to changes caused by fatigue, over-enthusiasm or changes in mike position. The RF clipper itself is not expensive—two diodes at a total cost of 10 cents—but associated circuitry is required for convenient panel adjustment, reliable operation and accurate metering. **CLIP**-meter calibration is independent of mike-input levels or the setting of the **MIKE** control.

For CW, narrow IF filters can be switched in. There is a 200-Hz filter at the IF strip input, and a matched 250-Hz filter at the output. The second filter removes excess noise developed in the IF strip. Many radios exhibit a disturbing behavior when a sharp CW filter is switched in. Their gain drops noticeably. In this radio, an extra stage of amplification ahead of the sharp CW filter compensates for the loss. When the sharp filter is switched

in, the S-meter holds steady, and there is no change in the sound of the received CW signal, except that the interfering signals are gone, and the noise-level is reduced.

The AGC system has been fully described in a previous article (see [Note 1](#)). The AGC system can make or break an otherwise good radio. Poor attack performance—with clicks and thumps—can cause operator fatigue, a crucial factor in all-night DX operating or all-weekend contesting. Poor decay performance can cause excessive receiver recovery time after a strong signal ceases transmitting, preventing a weak signal from being heard. Even worse, poor decay characteristics can sometimes cause excessive receiver recovery delay after every transmission, preventing reception at precisely the most important time. To avoid these problems, hang AGC circuits with carefully controlled timing are required.

AF Board

This board contains the product detector, balanced modulator, sidetone oscillator and low-level AF circuits. The need to isolate the BFO and the IF strip has been noted above. Hence, the BFO signal from the RF board is routed to the AF board at a low level, then amplified and fed to three BFO gates. Two of these feed the product detector and balanced modulator; the third is the carrier gate for CW.

The station microphone audio-distribution system includes a one-stage, high-pass filter, mainly to eliminate hum introduced by an external digital voice keyer (see [Note 8](#)). The AF board includes two stages of high-pass filtering, effectively eliminating any residual hum.

PTOs, Counter and Power Supply

The PTOs are straightforward, each with four stages of buffering. To avoid any possible spurious emissions during split operation, the PTOs are powered on and off at each TR transition. This permits full break-in operation with no chirp. The counter is simple, using 7400 series TTL chips. It reads to 100 Hz, which I find adequate.

The power supply may seem over-designed, but there is a reason. It results from years of experience with radios in which transient pulses travel between stages, and boards, by way of the power-supply circuits, or even a common power transformer. The elimination of these transients is crucial for proper AGC performance. The result is four separate regulated

supplies, with four separate small transformers. These power only the basic transceiver, with its 200- μ W exciter output. Locating the 200-W HF power amplifier on a separate panel keeps the rest of the transceiver cool and stable. The four separate small transformers, rather than being a problem, yield advantages in acquisition, mounting, space fitting and cost over a four-secondary transformer.

The four supplies include ± 18 V for the main boards and +8 V for the logic board and counter. The fourth supply is a separate +18 V supply for the receiver audio-output module, since this stage is often a serious offender in producing power-supply transients. Each of the four main boards and the counter then have individual on-board regulators for +15, -15 or +5 V, as needed. This double regulation avoids all transient problems.

HF Panel

The little-known 8072 external-anode tetrode—manufactured by RCA among others—is a gem. Only half the size of a 6146, it easily delivers a linear 200 W, even up on the 2-meter band, where I also use one. It is rated to 500 MHz. Being conduction-cooled, it needs no noisy forced-air cooling, but does require a special anode clamp and heat sink, salvaged from a junked CX7 found at a flea market. Although it is not necessary, a small inaudible muffin fan is attached to the heat sink. The fan comes on only when transmitting and has a timer to keep it going for one minute after each transmission. This means that it runs continuously during a contest. A new 8072 is expensive. I use a total of eight of these tubes on various frequencies, but they were all obtained as used surplus at very little cost. With adequate protection circuits, they seem to last forever.

The CX7 was the first ham transceiver produced with so-called “broad-band PA tuning”. In fact, the PA used a pi-L circuit on the seven 1-MHz bands, switching banks of internally adjustable tune and load trimmer capacitors. This is merely a fixed-tuning arrangement. It works well enough on the lower bands, but the poor L/C ratio on 10 meters makes coverage of an entire 1 MHz segment difficult. In addition, coil-turn shorting and toroid-core losses result in reduced

output on 15 meters. In addition, a set of manual controls was provided for use when desired.

This homebrew radio uses a variation on this theme. Ten 1-MHz bands were to be covered. The lower seven bands use seven separate fixed-tuned pi or pi-L networks, with no provision for manual control. For the three upper HF bands (24, 28 and 29 MHz) there is one manually tuned pi-network with front-panel controls and no provision for fixed-tuned operation. This arrangement suits my operating habits ideally. It improves performance by avoiding shorted turns on a single tank coil, and using more-appropriate components and better L/C ratios. For contesting, the panel controls are tuned for 28 MHz, and the result is equivalent to fixed-tuned operation on all bands.

A drive control on the panel of the HF front-end is adjusted for the correct amount of ALC compression—measured at the 8072 grid—or for proper drive level to an external 1.5-kW amplifier. ALC also runs from each driver and each kilowatt amplifier back to the corresponding front-end panel, with ALC metering at the transceiver. There has been much written about distortion caused by ALC circuits. It is true, but applies only to improperly designed and improperly adjusted ALC circuits. This radio applies ALC control voltage to dual-gate MOSFETs, as is common. An IMD problem can occur if too much gain reduction is attempted by varying the bias of a MOSFET. An extreme case occurs when ALC is improperly used to reduce the gain of a radio to drive a low-input-level transverter. At the K5AM station, the gain of each front-end panel is adjusted to obtain 3-dB ALC compression, a moderate amount. A single MOSFET may be able to handle a 3-dB gain reduction. To ensure the cleanest signal possible, however, ALC voltage is applied to three cascaded MOSFET stages, so that each reduces the gain by only 1 dB.

The drive control could be used to reduce the HF panel output to 5 W for QRP work, which presents refreshing challenges. Using the drive control, however, involves the usual touchy adjustment problem and band-change inconvenience. The HF front-end section has a separate QRP level knob, and a switch to enable it. The knob adjusts

an output detector that feeds the ALC circuits. The drive control is used to obtain the correct amount of ALC compression, read directly on the transceiver panel. It is not as critical on CW as on SSB, but too much ALC compression will distort the CW waveform.

The QRP switch is part of the AMP (amplifier) switch, with three positions: LP (low power), BF (barefoot, meaning transceiver only) and PA (external amplifier enabled). The 6 and 2-meter front-ends have similar switches. The entire station is controlled from the front-end panels conveniently located near the operator. On HF, the three positions instantly provide 5 W, 200 W or 1500 W output. The LP position can be used with the level set for 150 W for low-power contesting.

There is a panel switch for a second receive antenna, which is a necessity on 160 meters and useful on other bands, as well. The receiver circuits are fully protected—using reed relays—against RF energy picked-up by the auxiliary antenna while transmitting on the main antenna. A jack on the rear panel allows the auxiliary receive antenna relay to be controlled by a button on the desk, or by a foot switch.

Summary

This article gives a general description of a high-performance homebrew transceiver built with regard only to the best performance. It shows what can be accomplished without microprocessors, synthesizers and PLLs.

Notes

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