HF Circuits for a Homebrew Transceiver

Work the world with these front-end circuits for a high-performance radio.

By Mark Mandelkern, K5AM

HF is the backbone of ham radio. Even at a station designed primarily for 6-meter DX work and VHF contesting, an HF radio can provide countless hours of fun while DXing, contesting and rag-chewing. Circuits for the IF stages in a high-performance homebrew transceiver have been described in previous articles.[1, 2, 3] The main transceiver panel operates at the first IF, tuning 40-39 MHz. Three front-end sections effect the conversions to HF, 50 MHz and 144 MHz. The present article will describe the HF section, shown in Fig 1.

General Plan

The circuitry in the HF section includes mixers, amplifiers, and filters for converting the transceiver range of 40-39 MHz to the HF amateur bands. A 200-W tetrode amplifier is included. Use of a tube at this point provides low-distortion performance rarely achieved with solid-state amplifiers at this power level. For receiving, an RF amplifier, a mixer, and a post-mixer amplifier are employed. For protection against out-of-band signals, a high-Q front-end preselector is used. The front panel, which allows control of all essential parameters, is shown in Fig 2.

The main transceiver panel tunes the 39-40 MHz range in reverse, enabling high-side injection in the front-end sections. To cover the ham bands between 1 and 30 MHz, LO injection is required on 10 frequencies in the 41 to 69-MHz range. To avoid instability caused by a crystal switch, ten separate crystal oscillators are used, with diode switching of the oscillator outputs.

For transmitting, a mixer and a seven-stage solid-state amplifier drive a conduction-cooled tetrode power amplifier (PA). ALC is used for limiting of output power, reverse power due to high SWR, screen current, and grid current. External ALC input is also accepted from a kilowatt-level amplifier. Three of the driver stages are used primarily as buffers to ensure smooth ALC functioning without distortion.

The PA uses an 8072 tetrode; it is electrically identical to the more familiar air-cooled 8122. The 8072 has no cooling fins; its anode is clamped to a heat sink. Alternatively, an 8122 may be directly substituted, if forced-air cooling is provided. Similarly, the

[1] Notes appear on page 41.

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popular 4CX250B may be used. The control and protection circuits shown here may also be used for other small tetrode amplifiers at any frequency.

Receiver Circuits

Fig 3 is the circuit diagram of the receiving section. Signals arrive from the antenna relay in the PA section and proceed to a switched attenuator, a high-pass filter to reject broadcast-band signals, a low-pass filter to reject images at VHF and signals at the 40 MHz IF, a preselector and an RF amplifier. Included at the input to the receiver circuits is a reed relay, serving to ground any stray RF energy from the transmitter or from the auxiliary receive antenna.

No AGC is applied to the front-end section. AGC is applied only to the IF strip in the main transceiver panel 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. This was discussed in more detail in Part 1, page 18 (see Note 3). The main transceiver panel has an IF-gain control; it can be used for AGC-threshold operation. This provides maximum readability for very weak signals, while at the same time keeping the AGC circuits active when ear-shattering strong signals come on the same frequency—a very common occurrence in DX operation. AGC threshold operation is more effective and much safer than the all-too-common practice of operating with the AGC off. This receiving method is discussed more fully in Part 1, pages 21-22.

Auxiliary Receiving Antenna

For DX operation on the 160-meter band, panel control of an auxiliary receive antenna is mandatory. In this radio, there is also provision for control of the **RX IN** jack by a switch on the operating bench or a foot switch. This external control operates not merely in parallel with the panel switch, but serves to reverse the selection on the panel. This is required because the usual set-up on 160 meters is to receive on the auxiliary antenna, with some arrangement for occasionally trying the transmitting antenna. Thus the panel switch can select the auxiliary antenna and the foot switch will then momentarily select the transmitting antenna. With a simple parallel switch, the operator would need to keep a foot on the foot switch all night. There is also an RX OUT jack; together with the RX IN jack, it can be used for an external filter or for a second receiver.

Receiver Front-End Attenuator

The front-end attenuator is necessary for optimum performance on the lower bands, since no attempt has been made to adjust the band-by-band front-end gain to fit typical ambient-noise and signal-level conditions. One advantage of this method is that high gain and good noise figure are available for use with Beverage, loop or other low-output receiving antennas. The attenuator has positions for 0, 20, 40 or 60 dB of attenuation. Smaller steps were considered unnecessary. On 40 and 80 meters, 20 or 40 dB attenuation is commonly used. The reason for the 60-dB position is simple: There was one more position on the switch I happened to find in the junk box. Unexpectedly, the last position did turn out to be useful. On the higher bands, the 60-dB attenuator is nearly equivalent to a dummy load; it provides a very convenient way to compare antenna noise with internal receiver noise. This is not only easier, but also better than removing the antenna, because a proper comparison requires a 50-Ω load at the antenna terminal.

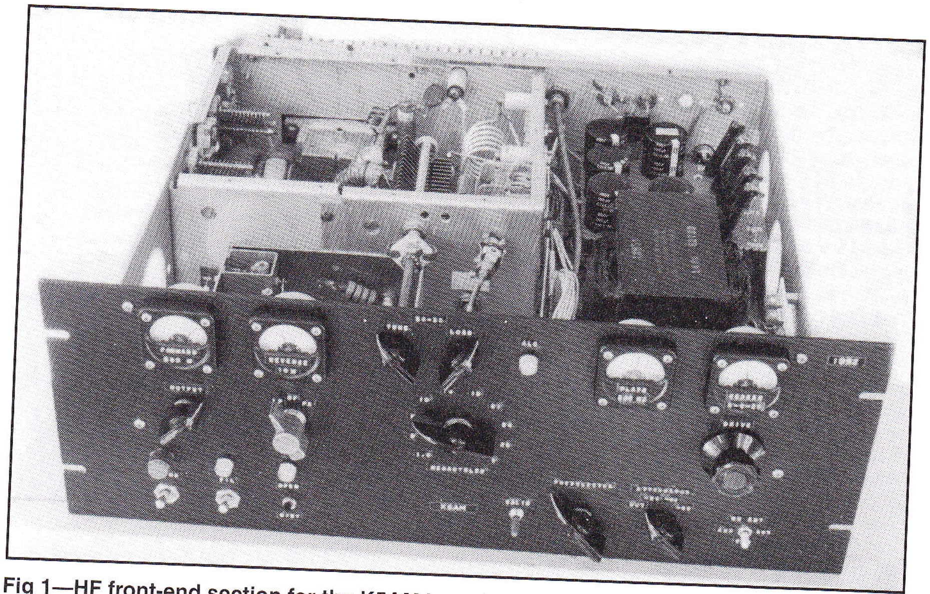


Fig 1—HF front-end section for the K5AM homebrew transceiver. The PA tank compartment is at the left rear, with its shield cover and exhaust fan removed. The 8072 conduction-cooled tetrode is clamped inside the large block. The 160 and 80-meter toroids are at the left of the PA compartment. The long "bread-slicer" capacitor is for tuning the 24-30 MHz range. (Photos by Lisa Mandelkern)

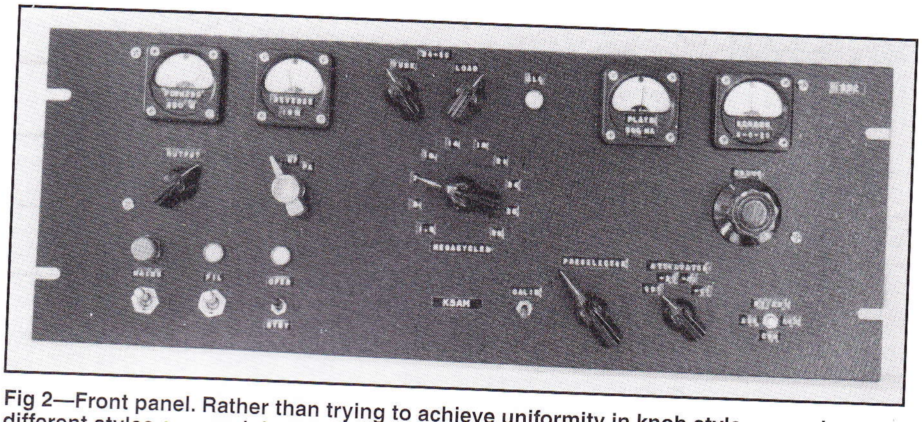


Fig 2—Front panel. Rather than trying to achieve uniformity in knob style, several different styles are used deliberately; this helps the operator find the correct knob very quickly. For consistency and additional convenience, the same style choices are also used on the other front-end sections for corresponding controls.

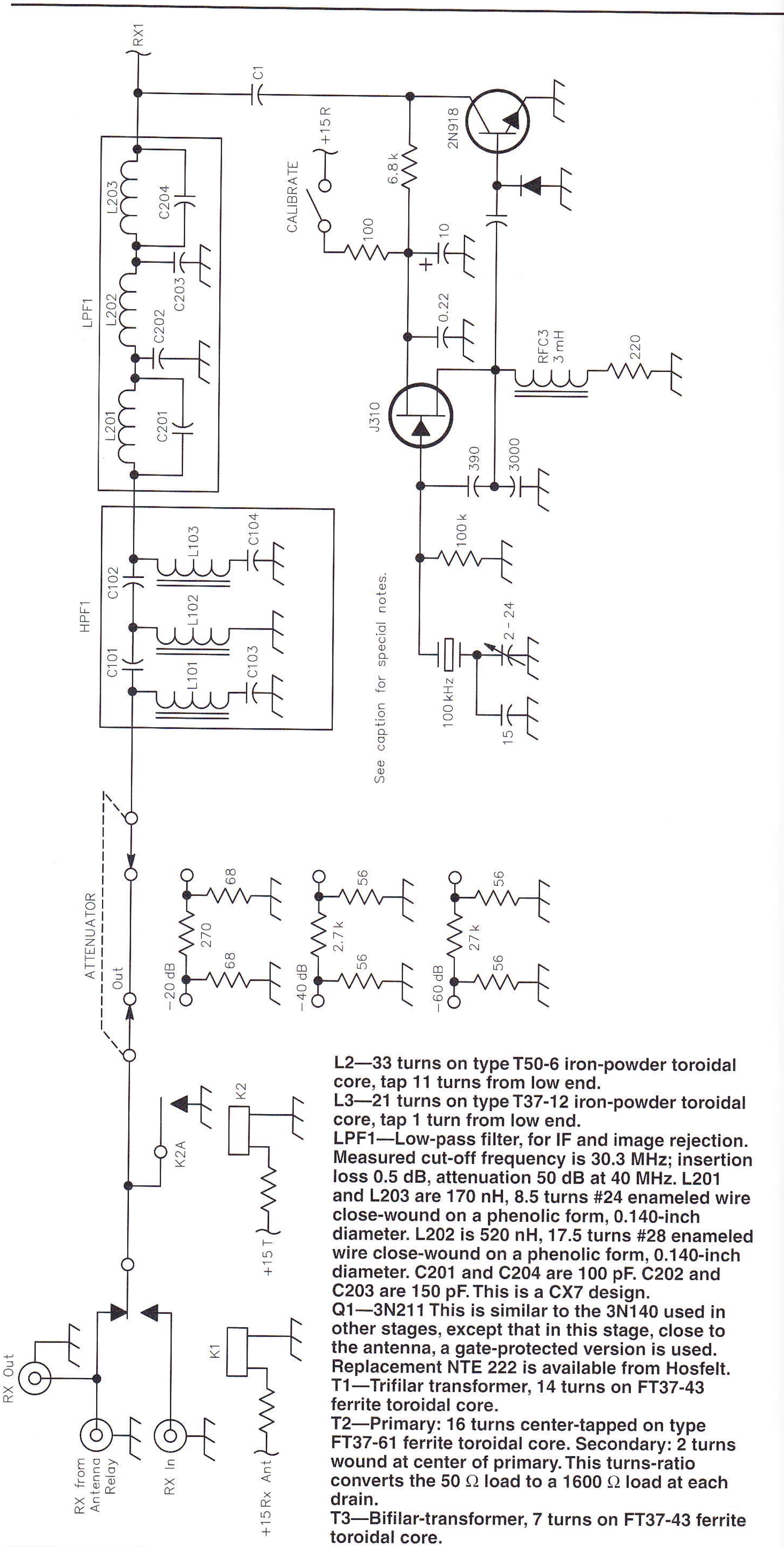


Fig 3—Receiver circuits. Except where otherwise indicated, the schematics in this article use the following conventions. Each resistor is a $^1/_4$ W carbon-film type. All trimpots are one-turn miniature units, such as Bourns 3386F; DK#3386F-nnn, MO#652-3386F-1-nnn. Stock numbers for Digi-Key and Mouser are given as DK# and MO#. Suppliers' contact information appears in Table 4. All unmarked coupling and bypass capacitors are 10-nF, 100-V, disc-ceramic units. Those marked 0.1 or 0.22 are monolithic ceramic types. Each control and power terminal has a bypass capacitor or feedthrough capacitor, as appropriate, often not shown. Also not shown are the bypass capacitors across each rectifier and switching diode and each switching transistor base-emitter junction. Electrolytic capacitors have 25 V ratings, with values given in µF; those less than 100 µF are tantalum types. Capacitors labeled "s.m." are silver-mica units, with values given in pF. Feed-through capacitors are 1 nF, 1 kV, ceramic components. Values of RF chokes (RFC) are given in µH. The MOSFETs are small-signal dual-gate VHF units. Type 3N140 is used here, but any similar type may be substituted. Replacement NTE 221 is available from Hosfelt. The JFETs are J310s. The diodes are small-signal silicon, such as 1N4148. The bipolar transistors are 2N4401 (NPN) and 2N4403 (PNP), or similar. The op amps are all sections of quad LM324N. Each op amp is powered by the +15 V and −15 V rails. Not shown is the bypassing at each op-amp power terminal, a 100-nF monolithic ceramic capacitor. The toroidal coils are wound with #26 enameled wire; the cores are available from Amidon. The various control lines are provided by the control board. Potentiometers labeled in all capital letters are front panel controls; others are circuit-board trimpots for internal adjustment. Also not shown are the usual diodes and bypass capacitors across each relay coil. The unmarked resistors at certain relay coils are selected to accommodate the particular relay installed. In the receiver circuits, the capacitors in the preselector and the filters are silver-mica types.

BPF1-BPF2—Band-pass filter, center frequency 39.5 MHz, bandwidth 3 MHz. The inductors are 480 nH, 11 turns on T37-10 iron-powder toroidal cores. The end coupling capacitors are 12 pF. The resonating capacitors are 22 pF. The top coupling capacitor is 2 pF.

C1—Gimmick capacitor; see text.

HPF1—High-pass filter, for rejecting AM broadcast signals. Measured cut-off frequency is 2 MHz; insertion loss over the HF range is less than 0.5 dB and 5 dB at 1.8 MHz. Attenuation is 20 dB at 1.4 MHz and 50 dB or better below 1 MHz. L101 and L103 are 10 µH, L102 is 2.2 µH; these are small molded inductors. C101 and C102 are 1000 pF, C103 and C104 are 3000 pF. This is a CX7 design.

K1—Auxiliary receive-antenna relay. High-frequency, low-loss, high-isolation relay, SPDT, 12 V dc, 25 mA coil. Omron #G5Y-1-DC12, DK#Z724.

K2-K14—Miniature reed relay, SPST normally open, 12 V dc coil, 1450 Ω, 8 mA. Gordos #0490-1478DZ, or similar relay. Hosfelt #45-191.

L1—53 turns on type T68-2 iron-powder toroidal core, tap 2 turns from low end.

L2—33 turns on type T50-6 iron-powder toroidal core, tap 11 turns from low end.

L3—21 turns on type T37-12 iron-powder toroidal core, tap 1 turn from low end.

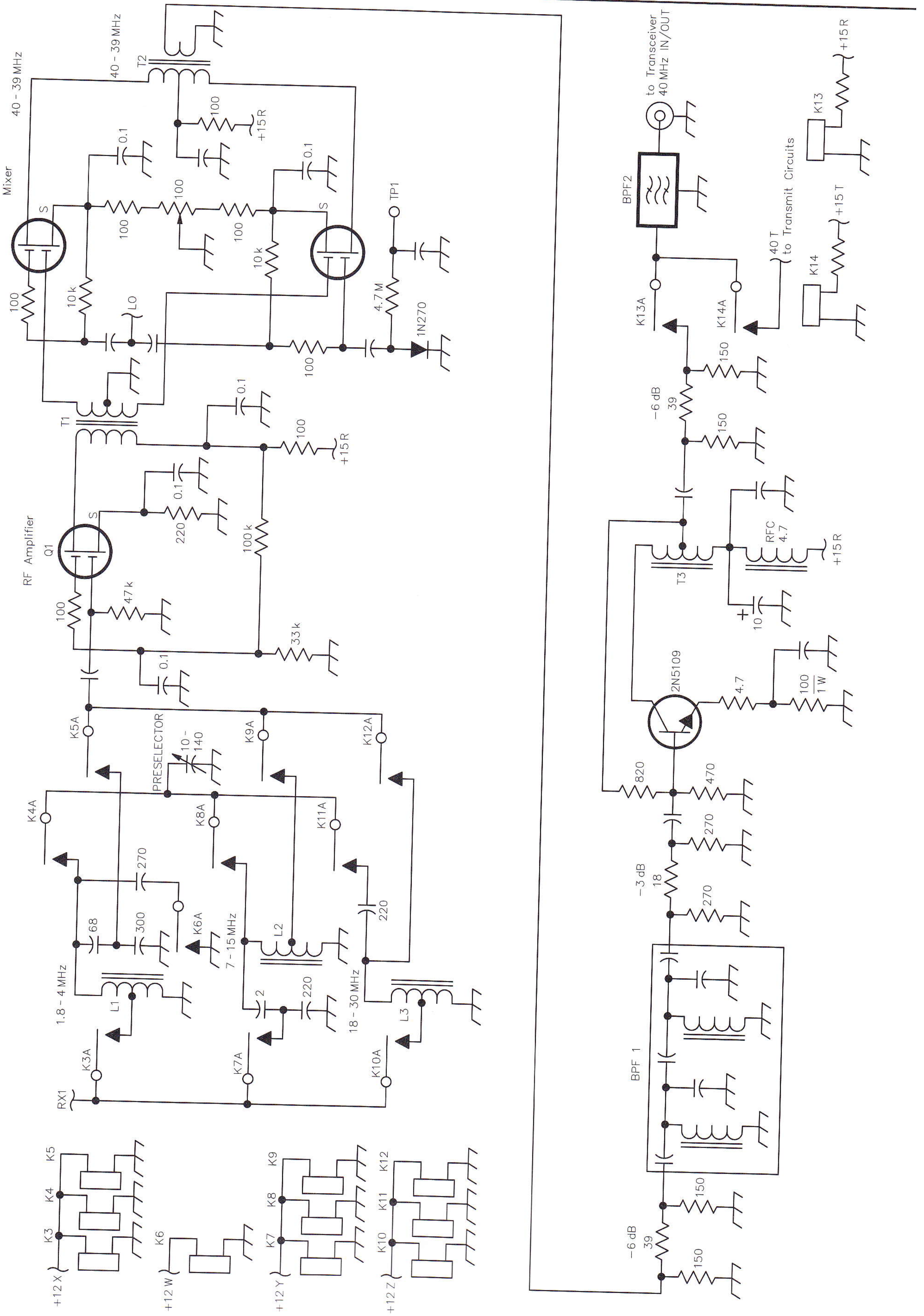
LPF1—Low-pass filter, for IF and image rejection. Measured cut-off frequency is 30.3 MHz; insertion loss 0.5 dB, attenuation 50 dB at 40 MHz. L201 and L203 are 170 nH, 8.5 turns #24 enameled wire close-wound on a phenolic form, 0.140-inch diameter. L202 is 520 nH, 17.5 turns #28 enameled wire close-wound on a phenolic form, 0.140-inch diameter. C201 and C204 are 100 pF. C202 and C203 are 150 pF. This is a CX7 design.

Q1—3N211 This is similar to the 3N140 used in other stages, except that in this stage, close to the antenna, a gate-protected version is used. Replacement NTE 222 is available from Hosfelt.

T1—Trifilar transformer, 14 turns on FT37-43 ferrite toroidal core.

T2—Primary: 16 turns center-tapped on type FT37-61 ferrite toroidal core. Secondary: 2 turns wound at center of primary. This turns-ratio converts the 50 Ω load to a 1600 Ω load at each drain.

T3—Bifilar-transformer, 7 turns on FT37-43 ferrite toroidal core.


Mixer
40 - 39 MHz
40 - 39 MHz
T2
100
+15 R
0.1
0.1
S
S
100
100
100
10 k
10 k
100
LO
TP1
4.7 M
1N270
100
T1
0.1
100
+15 R
RF Amplifier
Q1
S
0.1
220
100 k
100
47 k
33 k
0.1
K5A
K9A
K12A
PRESELECTOR
10 - 140
K4A
K8A
K11A
270
68
300
K6A
7 - 15 MHz
L2
220
1.8 - 4 MHz
L1
2
220
18 - 30 MHz
L3
K3A
K7A
K10A
RX1
K5
K4
K3
+12 X
K6
+12 W
K9
K8
K7
+12 Y
K12
K11
K10
+12 Z
to Transceiver
40 MHz IN/OUT
BPF2
K13
+15 R
40 T
to Transmit Circuits
K14
+15 T
K13A
K14A
150
-6 dB
39
150
RFC
4.7
+15 R
T3
10
2N5109
4.7
100
1 W
820
470
270
-3 dB
18
270
BPF 1
150
-6 dB
39
150

Preselector

Rejection of out-of-band signals has become one of the most prominent measures of performance for modern receivers. Most other performance factors, some even more important, have reached levels in excess of practical requirements. Modern factory-built radios have attacked the problem of out-of-band signals with a variety of front-end filter arrangements, with varying success.

Older radios from the 1940s and earlier have one or more RF amplifiers tuned along with the local oscillator by a multisection, air-variable capacitor; they often achieved front-end selectivity better than many current factory-built radios.

In the 1950s, radios appeared having tunable IF strips, requiring separately tuned RF preselectors. The Collins 75A-4 uses slug-tuned circuits at both the input and output of an RF amplifier. These are mechanically linked to the tuning dial, resulting in continuous resonating of the two front-end circuits to the signal frequency without operator intervention. The Collins 51S-1 design is perhaps the ultimate example of this method; it has a *double-tuned* circuit ahead of the RF amplifier and another single-tuned circuit ahead of the first mixer. In effect, there are 30 separate triple-tuned, turret-selected RF circuits. The front-end circuits in the Drake 2B are capacitor-tuned and require peaking by the operator with a separate panel control. The Collins KWM-2 also requires operator tuning of the receiver front-end circuits, which are shared by the transmitter circuits, by means of a separate panel control labeled EXCITER TUNING.

The Signal/One CX7 also has a separate operator-tuned preselector, with only a single tuned circuit. The preselector in my homebrew radio is derived from the CX7 design, using a three-band, high-Q tuned circuit ahead of the RF amplifier. One difference here is the use of relays to switch the three circuits; this avoids the need for more band-switch sections. The relays are driven by a diode matrix driven by the same 12-V dc bandswitch wafer that selects the local oscillator. The three bands are switched by 10 relays–three relays for each of the three tuned circuits and one extra relay to tie in a "padder" for the 160-meter band. Coils and relays for these three bands are built on three separate plug-in boards. This greatly facilitates circuit adjustment, since some tweaking of the coils and capacitors may be needed to cover the specified ranges.

The circuits shown here may be easily adapted to an outboard preselector/preamplifier for any receiver, whenever additional gain and front-end selectivity is needed. Surprisingly, the idea of an operator-tuned preselector, while thought to be already archaic and obsolete when built into the homebrew radio nine years ago, has just recently been revived as a selectable feature in a top-end radio, the Yaesu FT-1000MP-Mark-V.

RF Amplifier

This amplifier is comparable to the stage called a preamplifier in many radios, except that it cannot be switched out. The RF amplifier is needed for proper functioning of the high-impedance preselector circuits; the front-end attenuator is used when reduced gain is appropriate. Using a 3N211, dual-gate VHF MOSFET, the amplifier is fed directly from the preselector circuits. The preselector networks provide voltage-step-up impedance matching for the MOSFET, which is essential for achieving the full-gain possibilities of the transistor. The MOSFET provides higher gain than a JFET (which was also tried) and thus better system noise figure.

The MOSFET has received little press lately; this is partly due to some difficulty in locating devices with wire leads for experimenters. Nevertheless, it is still widely used (in surface-mount form) in factory-built radios. With all the talk of strong JFET front-end circuits, owners of new radios may be surprised to find a number of MOSFETs inside the box. For example, the Yaesu FT-1000MP uses a dual-gate MOSFET preamplifier for the upper bands, a MOSFET second mixer, and about 20 more small MOSFETs in other RF circuits.

Receiver Mixer

The mixer uses push-pull, dual-gate MOSFETs. Currently, JFETs are more commonly used. This 1992 decision was influenced by a *QST* article by Ulrich Rohde, KA2WEU.[4] He wrote, "... a push-pull arrangement with N-junction FETs or dual-gate MOSFETs. Both give similar performance. The dual-gate MOSFETs have slightly more conversion gain, higher intercept points and higher isolation..." The generous use of attenuator pads helps to provide proper terminations for the mixer, filters and post-amplifier.

Frequency Calibrator

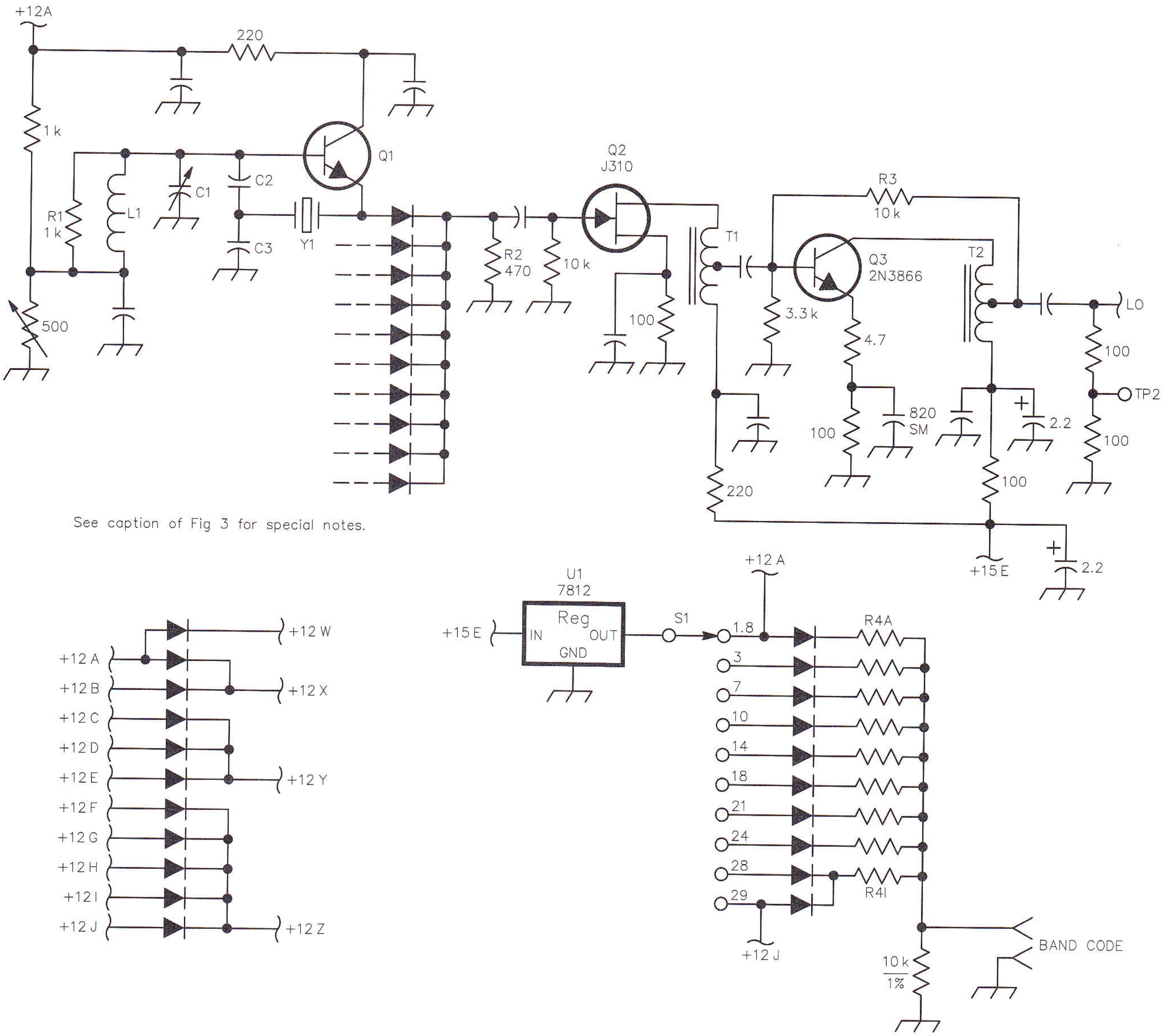
The 100-kHz marking oscillator, while not strictly required, is quite useful for simple checks of the preselector, crystal filters and passband settings. The JFET oscillator is followed by a squaring amplifier to produce harmonics. Output coupling is very light, simply by means of a wire placed close to the receiver input. This capacitive coupling favors the higher frequencies and helps to produce a signal level more uniform through the bands.

Local Oscillator

Fig 4 shows the local oscillator and injection-amplifier circuits. The oscillators use series-resonant, third-overtone crystals in a common-collector circuit. The often-seen inductor shunting of the crystal is not employed; frequency adjustment is readily possible without it.

Ten separate oscillators ensure freedom from instabilities induced by mechanical switches. The oscillator section of the bandswitch carries only +12 V from a secondary regulator powered off the regulated +15-V line. The selected oscillator is powered by +12 V from the switch. The diode at the output of the selected oscillator circuit is switched on by the transistor emitter current. Both the diode and the base-emitter junction serve to isolate the oscillator when it is not selected. A single resistor, R2, serves as a common-emitter resistor for each of the 10 oscillators; it draws current only from the oscillator in use. The same oscillator bandswitch wafer is used to generate a level-sensitive control voltage that may be used to select external amplifiers and antennas. Two stages are used in the local-oscillator injection amplifier.

The crystals chosen are of the highest grade obtainable; the ICM part numbers are given in the parts list. Each crystal frequency is 40 MHz above the low edge of the corresponding 1-MHz-wide band. Rather than a 41-MHz crystal for the 160-meter band, 41.8 MHz is used. There are two reasons for this. One is merely operator convenience: The band is tuned from 000 to 200 on the counter and this saves cranking the knob over 30 turns when going from the low end of the dial to the portion that would otherwise be used for 160. The second reason is more serious. A local oscillator at 41 MHz would allow considerable LO energy to enter the 40-MHz IF circuits; shifting to 41.8 MHz reduces this problem. The counter readings for 160 meters cause no trouble; DX work is done at the low end, so the readings are 000 to 040, and



See caption of Fig 3 for special notes.

Fig 4—Local oscillator and injection amplifier. For general notes on the schematics, refer to the caption of Fig 3. Only one of the 10 separate oscillator circuits is shown. Certain component values for the 10 circuits are given in a sequence corresponding to the oscillator frequencies from 41.8 to 69 MHz.

C1—12 pF ceramic piston trimmer capacitor.
C2—Silver mica or NP0 ceramic: 39, 39, 33, 33, 33, 27, 10, 10, 10, 10 pF.
C3. Silver mica or NP0 ceramic: 150, 150, 120, 120, 120, 100, 39, 39, 39, 39 pF.
L1—Oscillator coil, 11 turns #24 enameled wire wound on R1, 0.225 inch ID, 10 required. Adjust or alter to 10 turns as required.
Q1—High-frequency bipolar transistor, f_τ rating of 600 MHz or higher, 10 required. MPS918, 2N918, 2N5179, BFY90 or similar.
R1—1 kΩ, 1 W, carbon composition, 10 required.
R4A-R4I. Nine resistors to generate the band-code output, 1% metal-film with the following values (in kΩ): 104, 47, 28, 18.5, 12.8, 9, 6.3, 4.3, 2.7. This results in band-code outputs of 1 to 9 V, for the nine ham bands.
S1—Bandswitch, 11 position phenolic wafer, 10 positions used. This wafer is mounted to the front panel, and ganged to the PA bandswitch. Ten lines, +12A to +12J, lead to the oscillators and to the diode matrix for the preselector; only two of these lines are shown.
T1—9:1 transformer, 8 trifilar turns on FT37-61 ferrite toroidal core.
T2—4:1 transformer, 4 bifilar turns on FT37-61 ferrite toroidal core.
U1—This IC voltage regulator requires bypass capacitors that are not shown; see Part 5, page 36, note 18. (Also see Note 3, here.)
Y1—Third overtone AT-cut crystal, ICM grade HA-5, ICM #471570 or #476570 above 65 MHz. The 10 crystals are cut for 41.8, 43, 47, 50, 54, 58, 61, 64, 68 and 69 MHz. For more convenient tuning, optional crystals cut for 43.5 and/or 64.5 MHz may be substituted; see text. Some savings in cost may be obtained by using grade CS-1 crystals, perhaps with nearly the same performance; ICM #471370 or #476370 above 65 MHz.

no operator confusion results. Similarly, to reduce VFO knob-cranking, a builder may choose to use crystals for 80 meters and 12 meters at 43.5 MHz and 64.5 MHz, although this will result in somewhat awkward counter readings.

Oscillator Adjustment

The procedure is the same for any oscillator using a third-overtone crystal. During adjustment, both the frequency and the oscillator's output level must be monitored. The frequency is measured at the LO amplifier output. Test point TP2 in Fig 4 provides a reduced level sufficient for a counter, without danger of overload. The counter probe is not allowed to encroach on the oscillator itself, where it may disturb the circuit, lowering the output and shifting the frequency. The bias trimpots in the oscillator circuits are individually adjusted to minimize collector current consistent with good starting and to obtain equal oscillator output levels on each band. The injection level at the receiver mixer is measured at test point TP1 in Fig 3, using the built-in RF probe. The nominal injection level is 1 V of RF. This is measured at test point TP1 as –1.0 V with a 10-MΩ dc meter, or –1.4 V measured with a 100-MΩ meter. If necessary, R3 may be altered somewhat to change the bias on Q3 and obtain the desired output.

Using the built-in RF probe is preferable to measuring injection level with a scope. Even a 10:1, low-capacity probe and a 100-MHz scope can cause a 3-dB

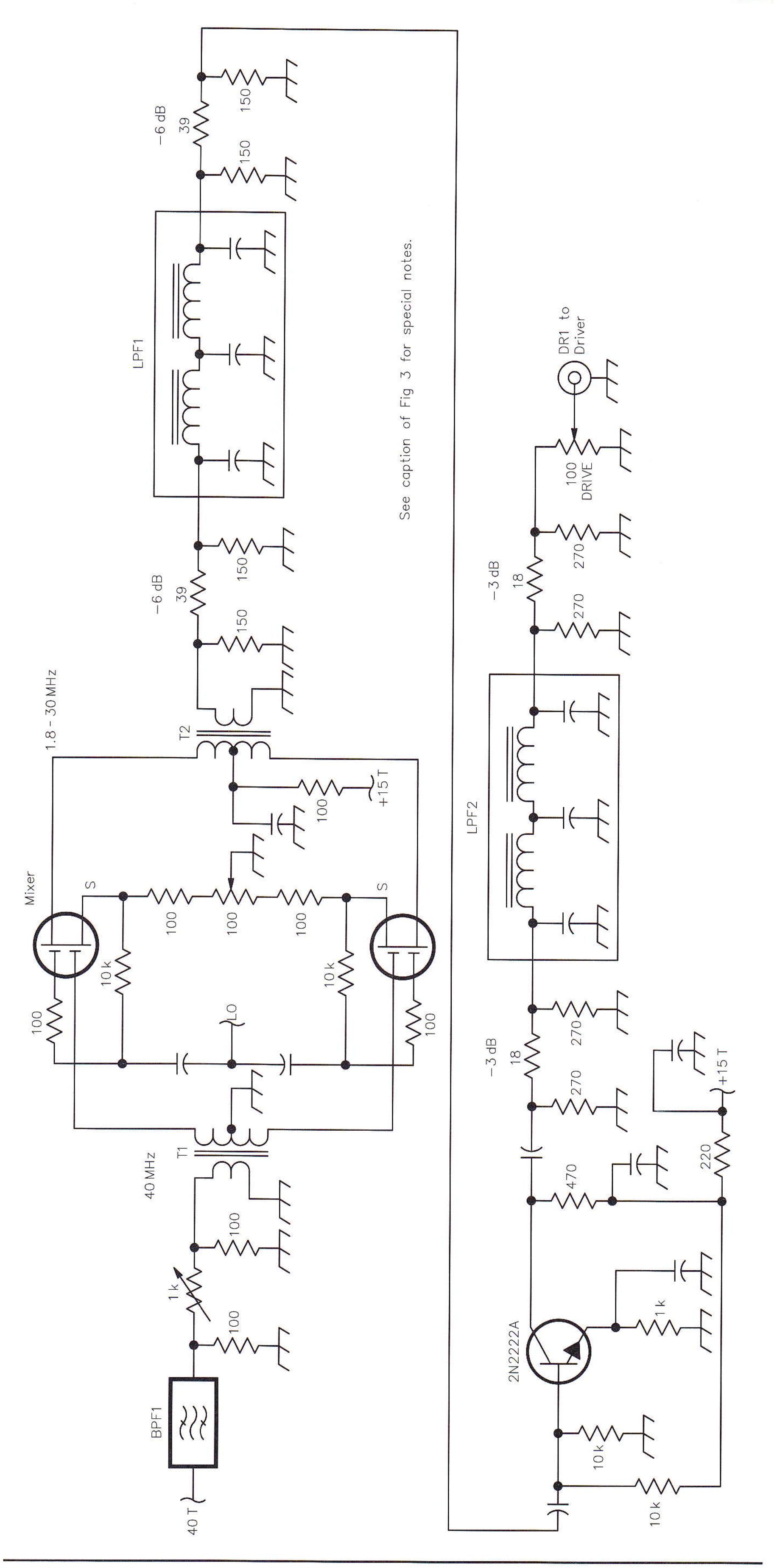


Fig 5—Transmitter circuits. For general notes on the schematics, refer to the caption of Fig 3.
BPF1—Same as BPF1 in Fig 3.
LPF1—Low-pass filter, 5-pole Butterworth, cut-off frequency 32 MHz. Each inductor is 400 nH, 15 turns on T37-12 iron-powder toroidal core. The outer capacitors are 62 pF silver mica; the central capacitor is 200 pF.
LPF2—Low-pass filter, 5-pole Chebyshev, cut-off frequency 30 MHz, ripple 0.5 dB. Each inductor is 326 nH, 11 turns on T25-10 iron-powder toroidal core. The outer capacitors are 180 pF silver mica; the central capacitor is 270 pF.
T1—Secondary: 12 turns on FT37-61 ferrite toroidal core, center-tapped. Primary: 2 turns over center of secondary. The turns-ratio is chosen not to match impedance or maximize gain, but to obtain the desired signal level at each mixer gate.
T2—Primary: 20 turns on FT37-43 ferrite toroidal core, center-tapped. Secondary: 3 turns wound over center of primary. This turns-ratio converts the 50 Ω load to 1100 Ω for each drain; this is a heavy load that contributes to good linearity.

loss in injection level when applied to gate two of a MOSFET. Any temptation to occasionally touch up the oscillator frequencies with only a counter should be resisted; the injection level at the mixers must also be watched. The built-in RF probe makes this easy. A slight change in trimmer capacity often results in a drastic change in the oscillator output level. An injection level much less than specified will degrade mixer performance. A moderately higher level is tolerable, though. The usual specification given for MOSFETs is 5 V(pk-pk); this is only needed for absolute-maximum conversion gain, which is not usually required. The level specified here is about 3 V(pk-pk); this is a compromise producing nearly maximum conversion gain, with less LO feed-through.

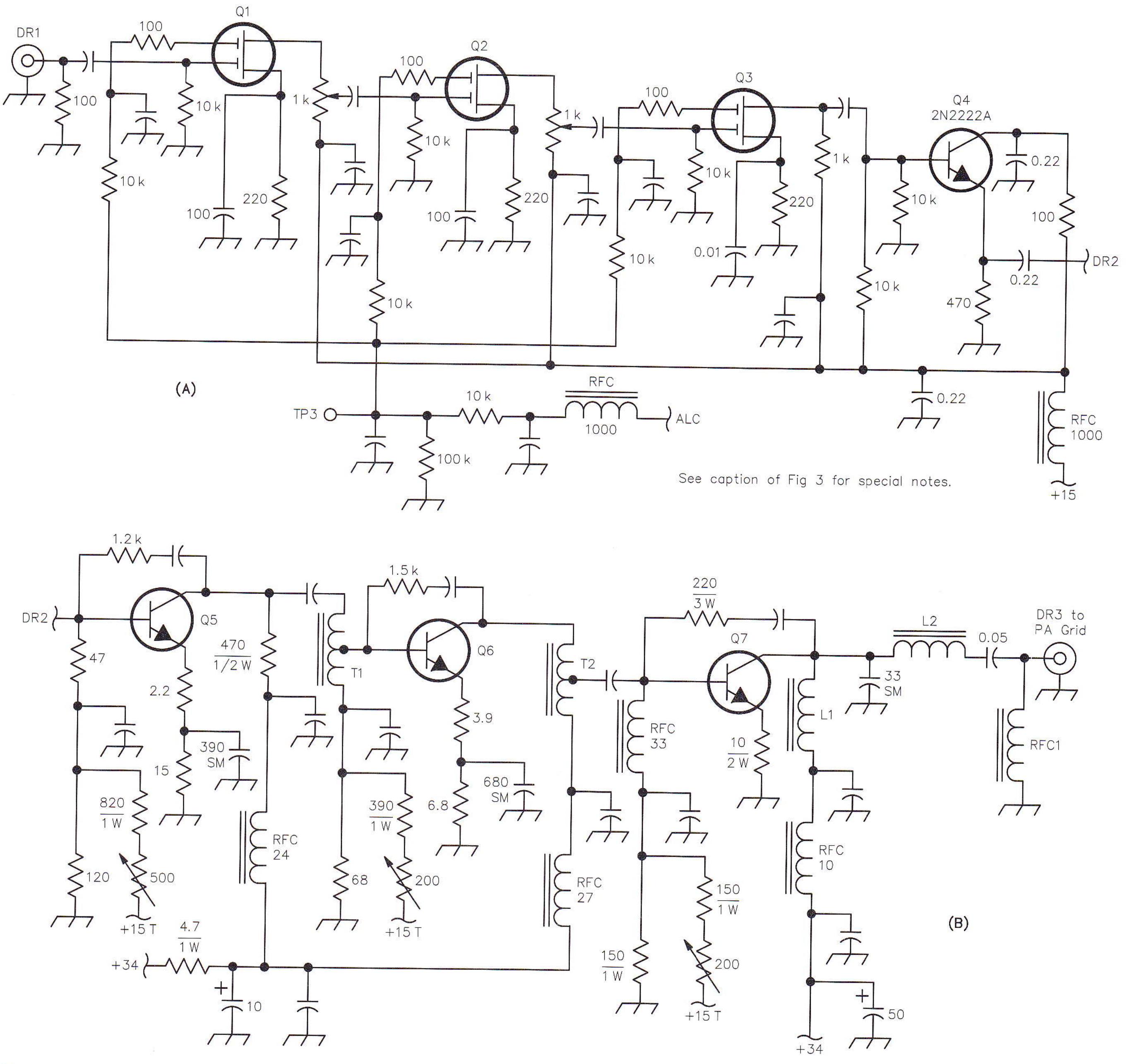


Fig 6—Driver circuit. For general notes on the schematics, refer to the caption of Fig 3. The bypass capacitors at all ALC lines are 1 nF. To ensure stability, the driver is built in two separate shielded compartments; the circuits are shown at (A) and (B). The limited bypassing of the source terminals in the first two MOSFET stages, with 100-pF disc ceramic capacitors, helps equalize the gain over the HF range. Complete bypassing of the third stage is necessary to provide adequate drive for Q4. The trimpots in the drain circuits of the first two stages are used to adjust for individual transistor gain variations and to distribute the gain equally between these two stages. The bias trimpots should be set initially to maximum resistance.

L1—100 µH, 43 turns #28 enameled wire on FT37-61 ferrite toroidal core.
L2—900 nH, 15 turns #24 enameled wire on T50-6 iron powder toroidal core.
Q5—2N3866; install a small snap-on top-hat style heatsink.
Q6-Q7—Motorola 2N5641, or similar stud-mounted, bipolar VHF transistor, dissipation rating of 15 W. (Available at Richardson)
RFC1—Output choke for protection, 82 µH, 14 turns on FT37-43 ferrite toroidal core.
T1-T2—4:1 transformer, 18 bifilar turns #28 enameled wire on FT37-43 ferrite toroidal core.

While adjusting the oscillator trimmer capacitor, the frequency will vary and the oscillator output level will have a peak. The oscillator should be set at the peak or on the *low-frequency side* of the peak—with the trimmer capacitor set to a greater capacity than at the peak. Settings on the low-capacity side of the peak may result in instabilities. A good crystal will usually have a frequency at peak output that is above the marked frequency, so adjustment at precisely the marked frequency is easily obtained. An adjustment within 100 Hz is sufficient. Although the resulting frequency-readout accuracy does not approach that of modern frequency-synthesized radios with TCXOs, experienced operators know that for serious DX work the ear is more important than the dial.

The coils should be Q-doped for stability. (Q-dope, a polystyrene coating specially formulated for RF circuits, is available from GC Electronics, #10-3702; see Table 4.) In the event that oscillation does not occur, the resonant frequency of the tuned circuit should be checked with a grid-dipper. Oscillation results when the feedback is of the proper phase. This occurs when the resonant tank frequency is *slightly above the crystal frequency*; individual coils may need to be trimmed accordingly. The bias trim-pots allow operation at the lowest feasible crystal current, dependent on individual crystal activity. This helps achieve high stability; very little frequency drift has been observed over nine years of all-day, every-day operation. Specifying crystals of the highest quality from a first-rate manufacturer has no doubt helped to produce this happy result.

Transmitter Circuits

The transmitter's mixer circuit is shown in Fig 5. After the singly balanced MOSFET mixer is a bipolar stage that delivers the HF signal to the DRIVE control on the front panel. The generous use of attenuator pads helps provide proper terminations for the mixer and the filters. From the panel DRIVE control, the signal is fed to the seven-stage driver. The resistive DRIVE control is crucial to keeping all stages operating well within their linear regions, without relying on excessive ALC voltage and without utilizing PIN diodes, which may degrade IMD performance. The low-pass filters serve mainly to reject the 40-MHz IF and the LO. Harmonics will also be generated in the PA and must be rejected there.

Driver Circuit

Fig 6 shows the driver circuit. The design of most of this section is derived from the CX7.^{5} Three MOSFET stages provide moderate gain, but are used mainly for ALC. The 100-kΩ resistor on the ALC line performs no essential function; however, it is important during the construction phase. It is usual to construct a circuit such as the driver board as a separate module, and bench-test it before installation. During this time, the MOSFETs—with their unprotected gates—would be subject to damage if no return path to ground was provided for the gain-control gates. Even when the driver is installed, it is questionable what return path might be provided by the ALC circuit on the control board when the radio is powered off. The last three bipolar stages raise the level to about 500 mW to drive the grid of the PA tube. Thus, the 8072 tetrode stage has a gain of about 26 dB. The last three bipolar stages operate in class A at 34 V dc; this ensures good linearity.

For driving VHF transverters at HF, a take-off tap may easily be added at the output of Q5. ALC from the VHF units may then be applied to the HF section. Some factory-built radios do not provide an ALC function when used with transverters; this is one cause of splatter on the VHF bands. The driver must always be protected against high RF output voltages; this is done automatically by the grid ALC circuit and the PA-heater warm-up delay circuit. When the heater is off, though, the +15T line cannot be enabled. When driving a transverter at HF, provision should be made to enable only the portion of the driver that is used.

When an 8072 tetrode does fail, it is likely to do so in a rather unfriendly way. A short from screen to grid may apply a transient pulse from the +300 V line through the blocking capacitor to the driver. So, one may sadly find that in addition to the loss of the tube, there are several shorted transistors in the driver circuit. The RFC to ground at the driver output prevents damage from this transient. Two blocking capacitors are then required; one here in the driver and another at the PA grid.

The last three driver stages are biased for collector currents of about 30, 130, and 340 mA, respectively. Bias adjustments are made with the individual trimpots while measuring the emitter voltages: 0.45, 0.9 and 3.4 V. The bias-adjustment circuits include extra resistors in series with the trimpots. These extra resistors limit

Fig 7—Power amplifier circuit. For general notes on the schematics, refer to the caption of Fig 3. Only one of the seven separate fixed-tuned plate tank circuits is shown in the diagram. The bypass capacitor at the screen ring is connected as described in the text. There are no bypass capacitors connected to the screen pins on the tube base; the 560-Ω resistor serves to decouple the screen. The trimmer capacitors in the SWR bridge may be small ceramic types, but air trimmers are more likely to survive the occasional severe mismatch or atmospheric static discharge. Most of the PA components were salvaged from old CX7 radios.

C1—Tank tuning capacitors for the seven fixed-tuned ranges. 160 meters: fixed 100 pF, 7.5 kV transmitting, with 4-24 pF air trimmer in parallel. 80 through 15 meters: 4-24 pF air trimmer.

C2—Tank loading capacitors for the seven fixed-tuned ranges, 30-200 pF. Elmenco #304M mica trimmer, modified with four plates and double mica insulators.

C3—Tank tuning capacitor for the panel-tuned 24, 28 and 29 MHz ranges: 100-pF transmitting air variable, 3 kV, spacing 0.070 inch.

C4—Tank loading capacitor for the panel-tuned 12 and 10-meter ranges: Receiving air variable, 700 pF.

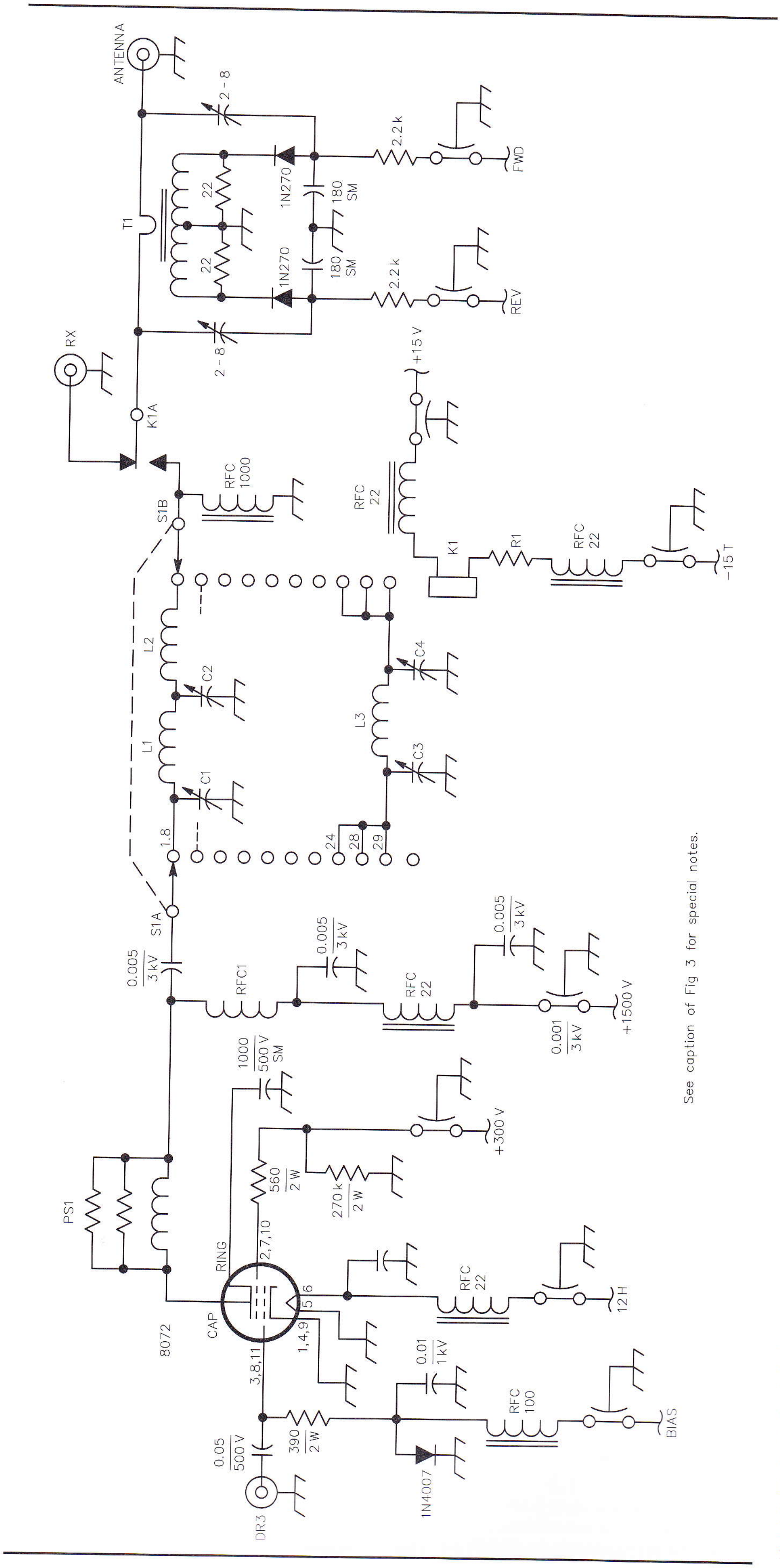
K1—Antenna TR relay. Kilovac type HC-1, 3.6 kV breakdown, 18 A current capacity, 6 ms operating time, 26.5 V dc, 80 mA coil. Jennings type RJ1A is identical; both are available from Surplus Sales of Nebraska. The reed relay from a CX7 may also be used with good results, but less reliability. The reed relay requires a higher coil voltage. The circuit allows easy modification for various coil voltages, by applying different voltages to the terminal labeled +15 in the diagram.

L1—Tank coils for the seven fixed-tuned ranges. Amidon T200A-2 iron-powder toroidal cores are used for 160 and 80 meters; fragments of type T200-2 are used for the next four bands (see text). The coils are wound with #16 enameled wire for the four lower bands, and with #14 for the other three bands. The ferrite cores are insulated with Teflon tape before the winding is applied. The 160 and 80-meter tank circuits are π-L networks; the other tank circuits are π-networks. 160 meters: 47 turns. 80 meters: 38 turns. 40 meters: 18 turns on ½ core. 30 meters: 16 turns on ½ core. 20 meters: 11 turns on ⅓ core. 17 meters: 10 turns on ¼ core. 15 meters: 12 turns air-wound, 1.125 inch ID, 1.5 inch long. Depending on individual component characteristics, the coils may need adjustment or trimming to obtain resonance and proper loading.

L2—L-network coils for 160 and 80 meters. T200-2 iron-powder toroidal cores are used. 160 meters: 29 turns. 80 meters: 17 turns. L2 is omitted for the other bands.

L3—Tank coil for the panel-tuned 12 and 10 meter ranges: 6 turns #8 bare wire, 1.25 inch ID, 1.5 inch long. Silver plating is optional, but not likely to improve performance significantly.

PS1—Parasitic suppressor: 4 turns #14 bare copper wire, 0.25 inch ID, 0.875 inch long. Two resistors, each 68 Ω, 3-W metal-oxide, are connected to the coil with minimal lead lengths. It is best not to wind a parasitic suppressor coil over a resistor,



See caption of Fig 3 for special notes.

as the RF field induced in the resistor may cause unwanted effects.
R1—Select according to the coil requirements of the antenna relay installed. For a 12 or 48-V coil, instead of the +15 V connection, use ground or the +34-V line.
RFC1—Plate choke: 140 μH, 500 mA. The CX7 choke works very well, even on the new bands. Other chokes must be checked for series resonances.
S1—PA bandswitch, 2 ceramic wafers, 11 position, nonshorting. Only 10 positions are used. This switch must handle reasonably high RF voltages. The more common size, with 1.25-inch spacing between mounting studs, is inadequate. The surplus flea-market switch used here has 1.5-inch spacing. The "nonshorting" specification refers to the narrow width of the moving contact; this lessens the chance for arcing between contacts. The 12-position switch, which has very close spacing at the lug for the moving contact, should be avoided. The switch is driven by a shaft connected to the rear of the local-oscillator bandswitch on the front panel.
T1—FT37-61 toroidal core. Secondary: 10 bifilar turns. Primary: a single #14 wire, with Teflon sleeving, through the toroid.

the range of control and prevent inadvertent application of maximum bias voltage to a stage, with probable attendant destruction of the transistor. The resistors also permit the use of smaller-value trimpots and reduced dissipation. The last stage operates at about 10 W collector dissipation—a very sturdy class-A stage for delivering only ½ W to the PA. This helps maintain good linearity, since the PA's driving impedance changes when grid current begins to flow, and there are no tuned circuits at this point to provide a flywheel effect.

Output Power Level Control

The main transceiver panel provides a fixed transmitter output level of −7 dBm. Power-level control and ALC operation are effected separately at each of the three front-end sections. The panel adjustments at the front-end sections eliminate the need for any operator adjustments at the main transceiver panel when switching front ends. This is particularly convenient for instant switching between the VHF bands during a contest—a necessary operating feature for a top score. In this HF section, the transmit signal from the mixer circuit is fed to the panel DRIVE control at a level of about 50-200 mV (pk-pk) (depending on frequency), and then to the driver section at about 0-50 mV (pk-pk) (depending on the desired output power and the amount of ALC compression in use). For precise control of operating parameters, both a DRIVE control and an OUTPUT control are required. Each control affects the output power and the ALC functioning, but in very different ways. The OUTPUT control varies a voltage threshold in the ALC circuit, setting the level at which the ALC circuit begins to limit the transmitter output power. The power output may be varied from nearly 0 up to 200 W. On the other hand, the DRIVE control directly varies the actual RF signal level applied to the driver. The transmitter RF from 1.8 to 29.7 MHz is routed directly through the carbon DRIVE potentiometer. As the DRIVE control is advanced, the drive level first reaches the point at which the power output attains the level preset by the OUTPUT control; the ALC voltage begins to rise at this point. Further advancement of the DRIVE control does not increase the power output; the ALC circuits keep the output at the preset level.

This arrangement avoids a common problem that occurs when only an OUTPUT control is provided. In that situation, an excessively high ALC voltage is required to achieve low output power levels; this may be more than the ALC-controlled stage may be able to handle without distortion. This problem can arise in QRP operation, when driving a low-drive tetrode kilowatt amplifier, or when driving a VHF transverter. The OUTPUT control in this HF section is used for QRP operation, low-power contest operation at 100 W, when conditions allow reduced power or with a linear amplifier lacking an ALC provision. Normal operation is very simple: The OUTPUT control is left at maximum, and the DRIVE control is used to set the proper ALC compression level.

Automatic Level Control

The **DRIVE** control on the panel of the HF front-end section is adjusted for the correct amount of ALC compression, usually because of limiting of the 8072 grid current or for proper drive level to a kilowatt amplifier. An ALC control line runs from each kilowatt amplifier back to the corresponding front-end section, with ALC metering at the transceiver. The ALC control voltage is applied to dual-gate MOSFETs, as is common. An IMD problem can occur if excessive ALC voltage is applied to a MOSFET to obtain a large gain reduction. An extreme case occurs when an ALC line is improperly used to drastically reduce the power output of a radio to drive a low-input-level transverter. A proper drive-level adjustment will result in ALC compression of 2 to 3 dB—a moderate amount. A single MOSFET may be able to handle a 3-dB gain reduction without producing IMD, but to ensure the cleanest signal possible, the ALC voltage is applied to three cascaded MOSFET stages, so that each is required to operate with a gain reduction of only 1 dB.

Proper output and drive-level adjustment by the operator is easy. The OUTPUT control is set at the desired level. Then, while keying or speaking, the DRIVE control is adjusted for the optimum ALC meter reading of about –2 V (40%) on the main transceiver panel. The ALC meter reads signal level while receiving and is calibrated from 0 to 100 dB. When transmitting, the same meter indicates the ALC voltage from 0 to –5 V; the scale readings may be interpreted as percentages. The proper DRIVE control setting is not critical; any reading between 20% and 80% will produce a clean signal at full power.

PA Circuit

The PA's output tank circuit is adapted from the CX7 design. The CX7 provides a set of manual PA tuning and loading controls and an optional "broadband PA tuning" feature. This feature involves banks of preset internal tune and load-trimmer capacitors—merely a fixed-tuned arrangement. It worked well enough on the lower bands, but the poor L/C ratio on 10 meters made coverage of an entire 1-MHz segment difficult. In addition, coil-turn shorting and toroid-core losses resulted in reduced output on 15 meters.

The K5AM homebrew radio uses a variation of that scheme. There is no operating choice between manual or fixed tuning; the choice is built-in. There are 10 1-MHz bands to be covered. For the lower seven bands, seven separate fixed-tuned π- or π-L networks are used, with no provision for manual control. For the three upper bands (24, 28, 29 MHz), there is one manually tuned π network with front-panel controls, with no provision for fixed-tuned operation. Air-wound coils are used for 15 meters and up. This arrangement improves performance by avoiding the use of shorted turns on a single tank coil, by utilizing components that are more appropriate and by providing better L/C ratios on the upper bands. For contesting, the panel controls are tuned for 28 MHz; the result is equivalent to fixed-tuned, no-hands operation on all bands.

The PA circuit is shown in Fig 7. The design shown here may be easily adapted to an external amplifier for any low-power homebrew transceiver. The use of completely separate tank circuits simplifies the construction. The bandswitch requires only two wafers in the PA compartment and a single wafer at the panel to switch +12 V to the selected local oscillator and the diode matrix for the preselector. The 270-kΩ resistor installed close to the tube's screen terminal provides an important protective function. In the event of loss of screen voltage and an open, unloaded screen circuit, induced current from the plate could produce a high voltage at the screen terminal, damaging the tube and/or the screen bypass capacitor. The resistor drains off this induced current.

There are eight separate PA tank circuits; coils for the lower six fixed-tuned ranges use iron-powder toroidal coils or coils wound on portions of a toroidal core. The 15-meter, fixed-tuned range and the panel-tuned range for 12 and 10 meters use air-wound coils. Portions of a core were used because it was found that when only a few turns were wound on one side of a large toroid, nearly the same inductance could be obtained using only a piece of ferrite material slightly larger than the winding; this method also saves space. Alternatively, smaller-sized cores could be used. (The idea for using a fragment of a large core was provoked by an unscheduled event: accidentally dropping a toroid on the concrete floor of the garage shack.)

The use of an air-wound coil for 15 meters followed a few experiments. The CX7, while reaching 200 W or more on the lower bands, was notorious for dropping to about 130 W on 10 meters, and surprisingly, even lower on 15 meters, to little more than 100 W. It was usually thought that shorting turns on the large toroid with the bandswitch was the main reason. The method used here avoids that problem. Another cause of power loss was also found. When a ferrite core was tried for 15 meters, only 170 W was obtained, the same as on 17 meters, while the rig reached over 200 W from 160 to 20 meters. Further, the ferrite core became extremely hot, burning the insulating fabric. With the air-wound coil, the power on 15 meters increased to 190 W. The conclusion might be that type-2 iron-powder material (Micro-metals red) is unsuitable at this power level on 15 meters, and is not optimal on 17 meters. Type-6 (Micro-metals yellow) could be tried for these bands.

The panel-tuned circuit yields 180 W on the 12 and 10-meter bands.

SWR-Bridge Adjustment

The usual procedure is followed. First, the transmitter is set up to deliver about 100 W to a good dummy load on 10 meters. Then the trimmer capacitor associated with the reverse detector (closest to the tube) is adjusted for minimum voltage at the REV terminal. The input/output RF connections and REV/FVD connections to the bridge are then reversed by reversing the entire bridge subassembly; the adjustment is then repeated. The bridge may be left in this final position. This completes adjustment of the bridge itself; further circuit adjustments on the control board are indicated below.

PA Protection Circuits

The 8072 is one tough bottle! I use a total of eight of these tetrodes. They were all obtained on the used/surplus market at very little cost; most are 25 to 30 years old. With proper protection circuits, failures almost never occur.

Screen Current Limiting

The crucially delicate part of the 8072 is the screen; screen protection is mandatory. Unfortunately, the Signal/One CX7 had no effective screen-protection circuit. Thus, the failure rate of the 8072 in the CX7 was quite high, earning the 8072 an undeserved notoriety. The protection circuit used here monitors the screen current and uses the ALC system to limit the drive level to the PA, holding the screen current to a safe level. At 300 V, a preset limit of 20 mA keeps the screen dissipation under 6 W, well below the manufacturer's absolute-maximum rating of 8 W. High screen current occurs under improperly light loading conditions. When the loading is set too lightly with the manual controls or when a faulty antenna provides an improper load, the ALC voltage rises and the transmitter output will be reduced, but the screen current will be held at the safe limit.

Grid Current Limiting

Grid current is limited by the ALC circuit. This is not so much to protect the 8072 tube, which is also rated for class-C service and can take 50 mA of grid current, but to ensure linearity. Lack of ALC in amplifiers is a major cause of splatter on the ham bands. The 8072 requires grid current of about 2-3 mA for full linear output. This means that the tube operates slightly into the class-AB_2 region. The CX7 grid-ALC circuit provides limiting at about 4 mA of grid current and is very simple and reliable. It is used here with only slight modification and with components selected for a grid current of about 2 mA. The circuit does require initial adjustment and further re-adjustment if the tube or bias setting is changed. This grid-ALC circuit should be easily adaptable to other tetrodes and other bias voltages.

The grid-ALC circuit is shown in Fig 8; it is installed on the control board. Using only a single transistor, the circuit includes provision for bias-voltage regulation and adjustment. The transistor operates as an emitter-follower voltage regulator. The *Idle* trimpot establishes a preset voltage at the base, and thus also at the emitter. This voltage, usually about –20 V dc, is the operating bias for the PA grid. After the idle adjustment is made for 100-mA plate current, the *Balance* trimpot is adjusted to obtain 0 V at the collector, test point TP4. When the grid draws current under peak RF drive conditions, nearly all this current appears at the transistor collector. This current increases the voltage drop in R1 and drives the collector negative. For example, a grid current of about 2.2 mA will cause an increase of 7.2 V in the voltage drop across R1. The collector is thus driven from 0 to –7.2 V. The Zener diode and the three diodes in the remainder of the ALC circuits have a total drop of about 6.2 V. The resulting –1.0 V on the main ALC line will begin to reduce the gain of the driver and to indicate on the ALC meter. The grid-current threshold at which ALC action begins can be changed by changing the Zener diode. When not transmitting, or between code elements, the **KEY1** line is open, and the full –60 V from the bias supply is applied to the grid as cut-off bias.

Heater Warm-Up Delay

The 8072 heater requires a 60-second warm-up period before plate current may be safely drawn. The classic glass vacuum time-delay tube is still available at rather inflated prices and is only infrequently found at flea markets at bargain prices. The easiest solution, as for most timing problems, is an op-amp timer. The warm-up circuit is on the control board. Transmitting is inhibited until about a minute after the 8072 heater is switched on.

Heat-Sink Fan Timer

The 8072 PA heat sink does not require a fan; but in the interest of long service life, it is best to keep equipment as cool as possible. In high-duty-cycle contest operation, or on AM or RTTY, the heat sink can become quite hot if a fan is not used. A small, inaudible 120-V ac "muffin" fan keeps the heat sink fairly cool. A timer turns on the fan at the start of each transmission, and keeps it running for several minutes after the end of the transmission. The result is that during a contest, the fan runs continuously. The fan timer circuit is on the control board. Another muffin fan, also inaudible, is installed directly above the tube; it runs continuously whenever the heater is lit. In receive mode, this exhaust fan re-

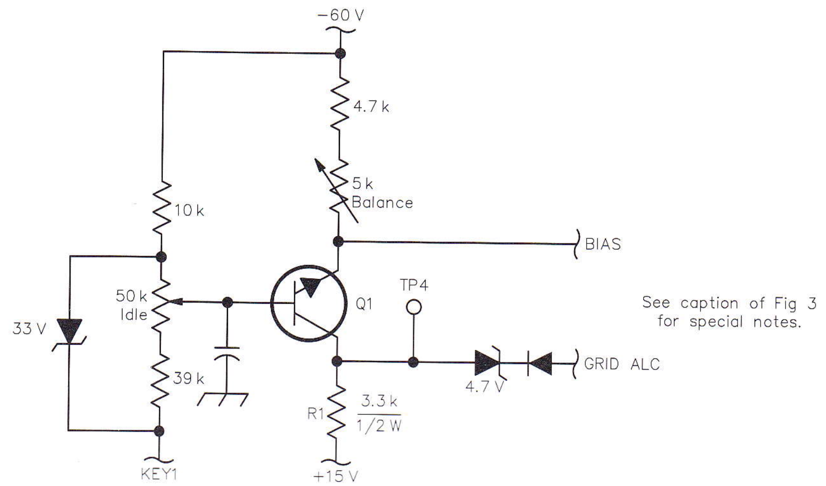
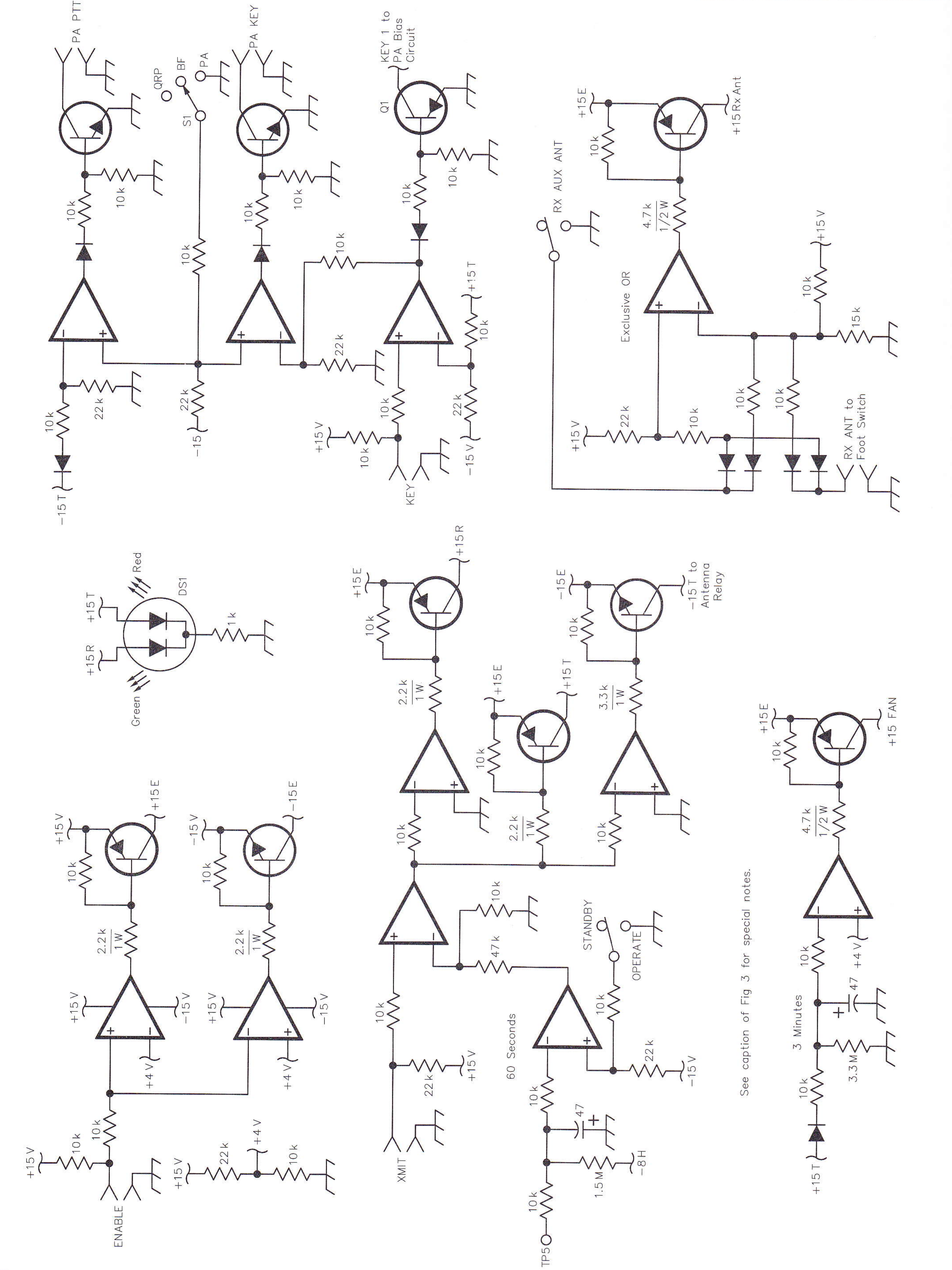


Fig 8—Grid-ALC circuit. For general notes on the schematics, refer to the caption of Fig 3. This circuit allows a certain amount of grid current to flow before developing ALC voltage to limit the drive level; see text. The circuit may be adapted to any small tetrode. Q1—MPS-A42, or similar small NPN transistor with a voltage rating of at least 150 V.



See caption of Fig 3 for special notes.

Fig 9—Control circuits. For general notes on the schematics, refer to the caption of Fig 3. Except for the two op amps in the *Enable* circuit, the op amps on this board are all powered from the +15E and −15E lines.
DS1—Two-color LED, 3 leads.
S1—Rotary switch; 2 pole, 3 position. The other section, for QRP operation, is shown in Fig 11.
Q1—MPS-A92, or similar small PNP transistor with a voltage rating of at least 150 V.

moves heat generated by the tube heater. In transmit, it helps cool the anode.

Control Circuits

Many functions are carried out by the control board. One is special to the arrangement of this homebrew station, with a 40-MHz transceiver and three front-end sections. The front ends must be capable of quick change, with just one button on the operating bench and no cable changes. This is managed by the front-end relay box described in Part 5 (see Note 3). Aside from the coax relays involved, the key to the system is the *enabling* feature built into each front-end. The single control line for this purpose is termed the ENABLE line. When grounded, it enables the selected front-end to function; otherwise all circuits are disabled. When the HF section is enabled, the LED above the STBY/OPER switch lights up green. Then, when transmitting, the same LED turns red.

Other control lines from the front-end switch box are for XMIT and KEY to control the front-end section, and for ALC metering on the main transceiver panel. Although keying and timing of the keying waveform are done at 40 MHz on the main transceiver panel, the 8072 tetrode in the HF section is also keyed. The HF section serves also to control the kilowatt amplifier. The panel switch labeled QRP/BF/PA, selects QRP operation, barefoot operation at up to 200 W from the HF section or kilowatt operation using the external amplifier. In each of these modes of operation, the OUTPUT control on the panel sets the desired power output level. The control circuits are shown in Fig 9.

Enabling and TR circuits

In addition to enabling by the front-end relay box, the HF section has an OPERATE switch that enables the transmit circuits. The STANDBY position of this switch is very useful for testing memory keyers and computer CW or voice features, without transmitting QRM. The STANDBY mode allows the main transceiver panel to remain in *Operate*, so the computer interface, voice levels, clipping, sidetone and so forth, can all be checked out and adjusted without transmitting a signal.

When the HF section is enabled, the +15E, −15E, and +15R lines are energized. If the OPERATE switch is engaged, and the XMIT line is closed by circuits on the main transceiver panel, then the +15R line drops out, and the +15T line is energized. The control signals between the various units are all carried by two shielded cables: one from the front-end relay box to the HF section (or, alternatively, directly from the main transceiver panel), and one from the HF section to the kilowatt amplifier. In addition, phono jacks permit separate connection to each control line; these phono jacks are normally used only during tests on the workbench.

Auxiliary Receiving Antenna Control

To enable the reverse-selection, foot-switch function described above, an *exclusive-or* circuit is used, with diodes and an op amp. The auxiliary receive antenna is connected whenever one, but only one, of the two switches, panel switch or foot-switch, is closed.

Control of External Kilowatt Amplifiers

Although the kilowatt amplifiers in my shack have the usual STANDBY /OPERATE switches, each front-end section includes a switch to select either barefoot or amplifier operation. This is easily accomplished because control of each amplifier is provided by its associated front-end section, rather than by the main transceiver panel. If the QRP/BF/PA switch on the HF panel is set to PA then the external PA PTT and PA KEY lines are closed whenever the XMIT and KEY control signals are received from the main transceiver panel. The control board in each front-end section includes circuits connecting to the PTT, KEY and ALC circuits in the HF amplifier. The external kilowatt amplifiers are keyed along with the transceiver; thus, plate current is reduced to zero between CW code elements. This reduces average plate dissipation considerably.[6]

The main transceiver panel provides an XMIT control signal only for the selected front end. This means that selection of the appropriate amplifier is automatic. In more typical situations, this arrangement would mean that the radio controls the transverter and the transverter controls its associated amplifier. One button on the operating bench instantaneously switches the entire station from HF to 50 or 144 MHz. Further, the main panel BAND switch option can be used so that merely switching PTOs will automatically switch front-end sections and amplifiers. A typical VHF contest set-up with the two PTOs is for 50 MHz and 144.200 MHz. While running stations on six meters, one light touch on the MON button above the main tuning knob is enough to check for propagation on two meters. During sunspot-maximum periods, PTO A can be used with the HF section for DX chasing, with PTO B set for 50.110 MHz. One touch on the MON button is enough to check for that elusive six-meter, F_2-layer propagation.

ALC Circuit

Fig 10 shows the main ALC circuit; it is installed on a portion of the control board. This ALC method could be adapted to a variety of amplifiers. The ALC-combining op amp U1 is driven by five ALC signals: the output-power limiting circuit, the reverse-power (SWR) limiting circuit, the screen-current protection circuit, the grid-ALC circuit and the external kilowatt amplifier. The 10-µF capacitor near the combining op amp holds the ALC voltage between syllables; the decay time constant is 200 ms. Each ALC input is derived from a low-impedance source, so the attack time is very short. After the five ALC signals are combined, the result is applied to the three ALC-controlled stages on the driver board.

Op amp U1 is a voltage follower whose output corresponds to the highest of the five applied inputs. Usually only one of the ALC inputs hits its limit first and assumes control of the drive level. For example, my tetrode kilowatt amplifier requires a drive power of only 30 W; thus, the amplifier ALC controls the HF section, and the other four ALC circuits never get near their limits. When running flat-out barefoot with a good antenna, grid ALC is the controlling factor.

Adjustment is easy. The *Bias* trimpot is first set to provide a no-drive level of +2 V at the MOSFET gain-control gates (G2), test point TP3, in the driver section of Fig 6. This puts the operating point for the MOSFETs at the knee of the gain curve; see Fig 10 in the AGC article (Note 2). The *ALC Adjust* trimpot is then set so that 10 dB of

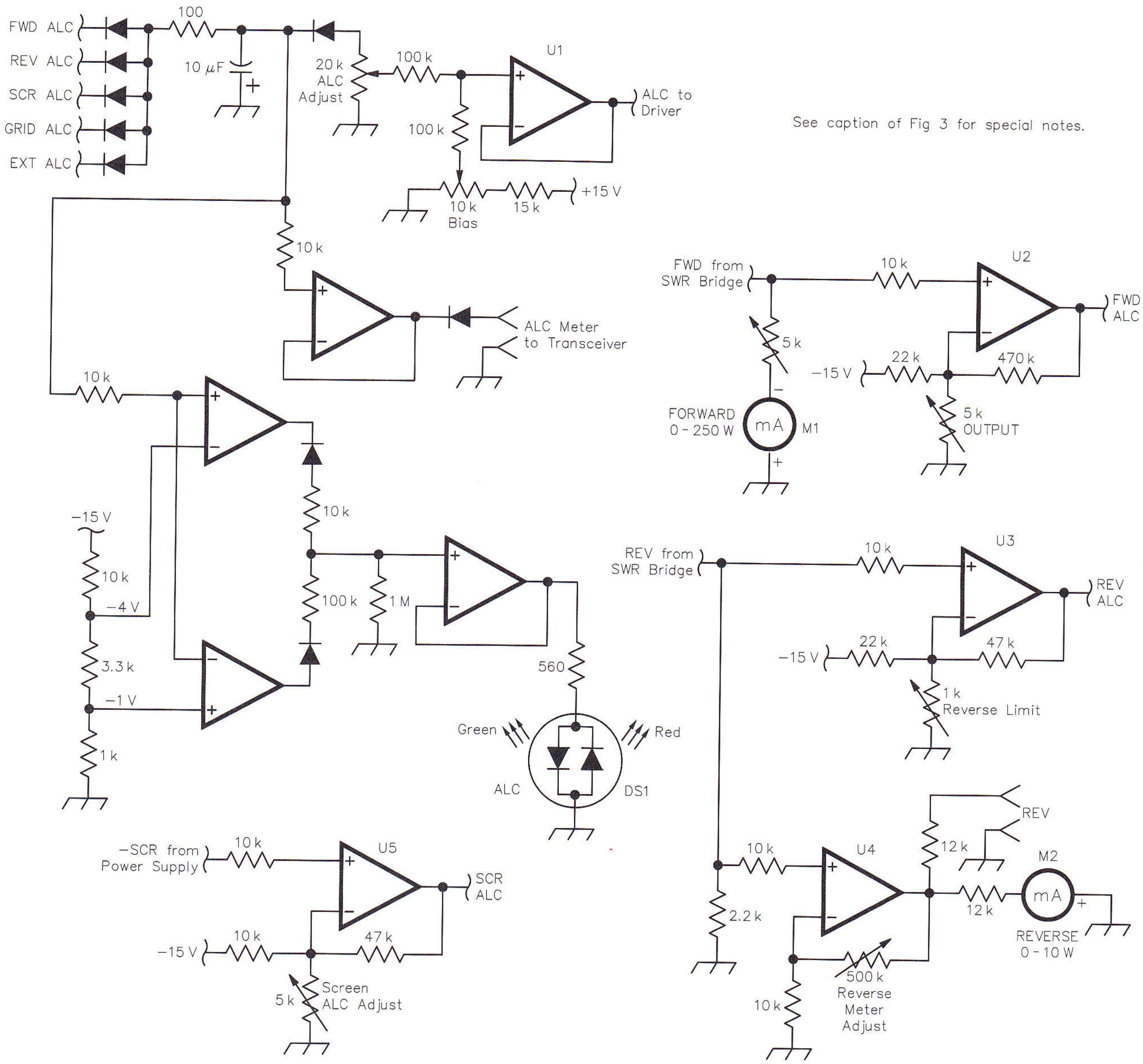
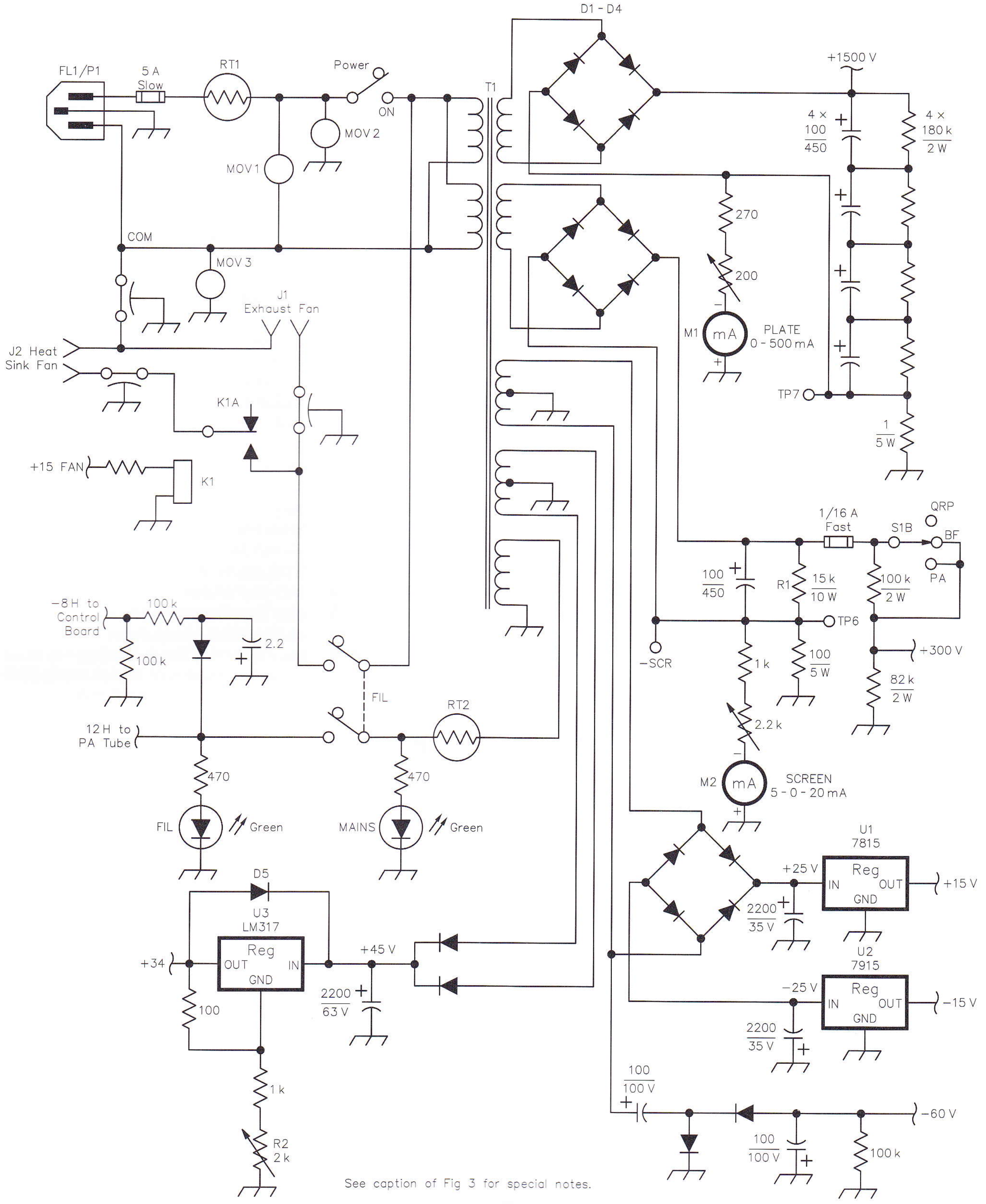


Fig 10—Main ALC circuit. For general notes on the schematics, refer to the caption of Fig 3.
DS1—Two-color LED, two leads; glows green or red, corresponding to a positive or a negative current.
M1-M2—Milliammeter, 1 mA, 100 Ω

Fig 11—(right) Power-supply circuit. For general notes on the schematics, refer to the caption of Fig 3. Diodes are type 1N4007, except as noted. The IC regulators are style T0-220, bolted to the rear panel as a heatsink.

D1-D4—1 A, 3 kV PIV
D5—This diode protects the IC regulator from damage by preventing the electrolytic capacitor on the driver board from discharging into the IC.
FL1/P1—Line filter with IEC ac chassis connector, 6 A.
J1, J2—Standard ac fan connector, with fan cord .
M1-M2—Milliammeter, 1 mA, 100 Ω.
MOV1-MOV3—Metal oxide varistor (MOV) transient protectors, GE type V130LA10A, MO#570-V130LA10A.
R1—This resistor draws more current than required for a bleeder; its purpose is to help stabilize the screen supply.
R2—Preset to minimum resistance to prevent damage to the driver transistors before adjustment.
RT1—In-rush limiter for ac line, Keystone Thermometrics CL-60, 10 Ω cold, 5-A operating current, MO#527-CL60.
RT2—In-rush limiter for PA heater, Keystone Thermometrics CL-180, 16 Ω cold, 1.7-A operating current, MO#527-CL180.
S1—Rotary switch; 2 pole, 3 position. The other section, for control of the external kilowatt amplifier, is shown in Fig 9.
T1—Power transformer; see text and Note 8.
U1-U3—These voltage regulators require bypass capacitors that are not shown; see Part 5, page 36, Note 18. (Also see Note 3, here.)



See caption of Fig 3 for special notes.

compression is obtained when the ALC meter reads –4 V (80%). One way to measure the compression is with a dual-trace scope at the input and output of the first section of the driver. There is a bit of interaction between the two trimpots; but it only takes a few minutes for the one-time adjustment of this circuit. The ALC begins to activate when the meter indicates –1 V and the ALC LED lights up green. At –2 V, the optimum operating point, the ALC compression is only 2 dB. A test can be run and an ALC-meter calibration chart drawn up; the exact correspondence between the ALC voltage and the compression level will depend on the individual MOSFET characteristics. For the ALC meter circuit in the transceiver, see Fig 9 in the AGC article (Note 2).

Power Output Control

The OUTPUT control on the panel sets the power output. When the set limit is reached, a control voltage is fed to the main ALC circuit. This ensures a definite, fixed output for QRP contest operation, or for driving a linear amplifier that does not provide ALC. Amplifiers without ALC are a major cause of splatter on the ham bands. The output level sampling is done by the directional coupler. From the same coupler, a sample of reverse power level is fed to the control board and used to cut back the drive when high SWR is sensed.

A jack labeled REV on the rear panel provides a reverse power sample for a remote meter; this is used for adjusting a remote antenna tuner. The radio is set for CW QRP operation at 5 W on a clear frequency, usually on a lower band in the daytime with little propagation. A shielded cable for the keying line and the REV line runs to the remote tuner at the base of the vertical antenna. The remote tuner includes a switch for the key line and a 1-mA meter for SWR indication. After initial tuning of a new vertical antenna at the center of each of the 160, 80 and 40-meter bands, a homebrew automatic tuner keeps the antenna tuned for 1:1 SWR throughout the band.[7]

The *Forward Power ALC* circuit uses op amp U2 in Fig 10. The OUTPUT panel control sets the threshold at the inverting input. When the voltage from the forward detector in the SWR bridge —as applied to the non-inverting input—reaches this level, the op amp's output begins to go negative. The feedback is chosen to provide enough gain to keep the transmitter's output within a few percent of the selected level. The *Forward Power* meter is driven directly from the detector in the SWR bridge; adjustment of the trimpot is done using an accurate external meter.

The *Reverse Power ALC* circuit uses op amp U3 in Fig 10. The circuit is similar to the one for forward power, except that the threshold is set internally by a trimpot on the control board. Op amp U4 is used to amplify the reverse detector's output to drive the meter to a full-scale reading of 10 W. To adjust the circuit, an external meter is used with a not-quite-perfect antenna to establish 10 W of reverse power, and the *Reverse Meter Adjust* trimpot is adjusted for a full-scale reading. Then the *Reverse Limit* trimpot is adjusted so that the ALC meter begins to indicate.

The reverse-meter circuit exemplifies the advantages of op-amp drive for meters. Not only can almost any meter be adapted to almost any requirement, but also op-amp drive can provide foolproof meter protection. In this circuit, the op amp's output is at most about –14 V. With the 12-kΩ meter resistor, the maximum meter current in any situation will be 1.16 mA; the meter can never be damaged (see Note 6).

The *Screen ALC* circuit utilizes the screen-current metering shunt in the power supply. A current of 25 mA through the 100-Ω shunt produces –2.5 V at test point TP6 in Fig 11 and results in a full-scale meter reading. The sense voltage from the shunt is also applied to op amp U5 in Fig 10. A –2.5-V threshold at the inverting input is set by the *Screen ALC Adjust* trimpot. Allowing for a 5-mA standing current on the +300-V line, this corresponds to a screen current limit of 20 mA. The *Grid ALC* circuit, shown in Fig 8, was discussed above.

The heater-warm-up-delay timer inhibits the PTT circuit until the tube is sufficiently warm, about 60 seconds after the heater is switched on. The fan timer circuit keeps the heatsink fan running about 3 minutes after each transmission. Both the fan timer and the warm-up delay timer use op amps, only a quarter of a quad package for each. Op amps as timers often result in more compact circuits than those using the ubiquitous 555, at least when there is no high-output-current requirement. Also, op-amp circuits tend to be simpler and more straightforward; the two inputs permit convenient setting of the reference voltages.

Metering

The motto of my shack is: "You can never have too many meters!" There are 37 meters on the homebrew gear at my contest operating bench, not including factory-built gadgets or the boat-anchor bench. This HF section has four meters: plate current, screen current, forward power, reverse power. With the two meters on the main transceiver panel, these two units together constitute an HF radio with only six meters.

No meter switch is used; this allows quick, confusion-free readings without reference to a switch position or multiple scales. The plate current reads 500 mA full-scale. The operating bias is adjusted to obtain 100 mA idling plate current; this usually requires about –20 V at the grid. In receive mode or between CW elements, the tube is cut off by the full –60 V from the bias supply. At full drive, the plate current runs somewhere between 200 and 300 mA, depending on the tuning and loading adjustments and the condition of the tube. The 8072 screen current at idle usually runs slightly negative. To allow measurement of this, the meter is configured with a total range of 25 mA, indicating from –5 mA to +20 mA. This is done simply with an 82-kΩ resistor on the +300 V screen-voltage line in the power supply. Together with the 270-kΩ resistor at the tube, these draw a total standing current of 5 mA. In standby or idle, the screen-current meter reads 20% of full-scale, indicating 0 mA.

The forward-power meter is driven directly by the directional coupler; the reverse-power meter uses an op amp to read lower levels. Although the forward-power meter reads 250 W full-scale, the reverse-power meter reads only 10 W full-scale. This provides a very quick and convenient rough check of the SWR, a variation on the crossed-needle idea. When the two meters read the same—and the needles are observed to be parallel—the SWR is 1.5; this is usually considered a very good match. If the reverse indication is less than the forward, that's even better; if much higher, we may need to work on the antenna. This method does not give the exact SWR reading that a crossed-needle meter would give, but it does provide a quicker indication of satisfactory operation. The high sensitivity of the reverse-power meter is also useful for adjusting antenna tuners at an interference-minimizing level of 5 W.

ALC Indicator

A special feature, which might be considered a frill, is a panel ALC indicator using the two-color LED shown in Fig 10. The main transceiver panel has an ALC meter, always on line when transmitting, so an indicator on the HF panel is not strictly necessary; however, it is very useful! Its main use is for rapidly setting the proper drive level, especially when driving a kilowatt amplifier. For very rapid band changes, it is much easier to observe the LED than to read the meter. The LED glows either green or red. The circuit is arranged so that the LED lights up green when the ALC line reaches –1 V, and changes to red when it reaches –4 V. Anything between these levels is okay, so the interpretation of these colors will be obvious to any licensed driver. After the initial hurried drive-level setting, the meter can be used to set the optimum ALC level of –2 V; but by that time, you have probably already worked a new country!

The ALC LED is also useful when tuning the PA on the 12 and 10-meter bands. Tuning must be done with full drive, as for any linear amplifier. It happens sometimes that a linear amplifier is tuned for maximum output with low drive, and then the drive is brought up fully. The intention may be to reduce dissipation while tuning, to prevent damage to the tubes; but the result is not only reduced output, but also a severely inadequate loading adjustment—and splatter! An easy way to reduce dissipation at full drive is to tune up with CW dits at 50 wpm. Even better is pulse tuning at 33% duty cycle (see Note 6). With the ALC LED in a prominent position near the tuning controls and meters, it is easy to ensure that full drive is applied and maintained while tuning the PA for the higher bands.

Power Supply

Although the power supply section is routine, the number of various voltages required could present a problem in locating a suitable transformer. In addition to the usual +15 V and –15 V regulated lines, a +34 V regulated line is needed for the transmitter driver. In addition, the PA tube requires 12 V ac for the heater, –60 V for the bias/standby circuit, +300 V for the screen, and +1500 V for the plate. This problem was solved in the same way as the PA anode clamp and heat sink problem, with a used Signal/One CX7 power transformer. An exact replacement transformer is currently available.[8] The HF section circuits draw considerably less power than a complete CX7, so the transformer runs cool and should have a very long service life. The same transformer could be used to simplify power supply construction for any similar small tetrode amplifier.

The power supply circuit is shown in Fig 11. A 1500-V transformer secondary winding and a bridge rectifier provide +1500 V for the plate. A 300-V winding and a bridge rectifier provide +300 V for the screen. A 50-V center-tapped winding serves to simultaneously supply two rectifiers, for +25 Va and –25 V. Each of these rectifiers is a full-wave, center-tapped (FWCT) circuit using two diodes. The similarity in appearance to a bridge rectifier is deceptive; the clue is the grounded center-tap. These two lines supply the regulators for +15 V and –15 V. The bias supply, a voltage doubler providing about –60 V, is driven from one side of the 50-V winding. Finally, a FWCT rectifier supplies a +45-V line that powers the +34-V regulator for the transmitter driver. A separate switch controls the 12-V ac to the PA tube heater. This allows all-day-long receiver operation without keeping the tube warm, while waiting for the brave operators in the DXpedition boat to land on the island.

Plate and screen currents are measured with shunts in the negative leads. The meters may be safely calibrated with the radio power off. A small test power supply on the workbench is used to establish a current through a shunt: at test point TP6 or TP7 in Fig 11. The current is measured with an accurate, external meter. The trimpot is then adjusted for the correct reading. The safest method for working on the high-voltage supply is to connect an analog voltmeter, turn off the radio, unplug the line cord and watch the meter needle drop to zero.

The ac primary circuit has a full complement of protection features: an in-rush current limiter RT1 on the ac line, a slow-blow fuse and three metal-oxide varistor (MOV) line-surge protectors. In addition, in-rush current limiter RT2 on the 12-V ac line prevents thermal strain and tube damage during the heater warm-up period, even when the heater is switched on sometime after the main ac switch is turned on. Because of the way the panel lights are wired, the effect of RT2 is visually rather amusing. If the main ac switch has already been closed, then when the heater switch is closed, the ac line indi-

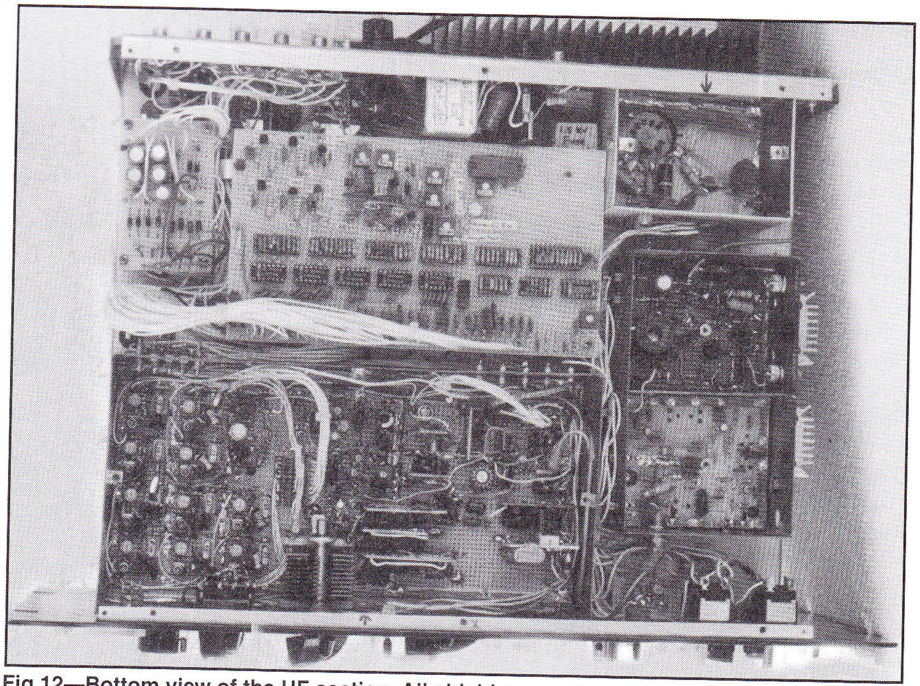


Fig 12—Bottom view of the HF section. All shield covers have been removed for the photo. The RX/TX board is at the left front. The 10 separate oscillator circuits are at the left side of this board. The variable capacitor at the front is for tuning the preselector; the three plug-in relay and coil boards are to the right. The two driver sections are at the right front; the stud-mounted transistors are bolted through the side wall into small heatsinks fastened to the outside of the wall. At the right rear is the PA grid compartment, completely shielded from the remainder of the circuit.

The control board is at the center rear; it is hinged at the left side for ease in servicing and modification. The part of this board using op amps is wire-wrapped. The part with discrete components is wired point-to-point. Each lead to the control board passes through two holes in the board, with its insulation, before connecting to its terminal; this provides strain relief and prevents broken wires.

cator light *goes out* for a few seconds! No need to worry. This is caused by the current drain of the heater and the voltage drop through the in-rush limiter before it warms up to operating temperature. This demonstrates the protection provided by the in-rush limiter. A similar effect is seen if the heater switch is already in the **ON** position when the main line switch is closed. When the PA-tube heater is switched on, a rectifier and filter on the heater line 12H produce the control line –8H to start the heater warm-up delay timer on the control board.

The schematic diagram for the screen supply includes the QRP section of the **QRP/BF/PA** panel switch described in connection with the control board. Tetrodes are real power hogs in idle condition. Even in normal operation, 150 W is a lot of idle power for a 200-W amplifier. For a QRP contest at 5 W output power, it would be bizarre to simply reduce the drive while running 150 W input power. The problem is solved by lowering the screen voltage for QRP operation. The idle current is reduced to zero, and 5 W output is obtained with less than 10 W of dc plate input power. This QRP switch is only for CW; linearity is destroyed without adequate idle current.

Construction

A major goal in construction is to ensure ease of access to all circuits. This will facilitate repairs, but it is mainly to allow convenient experimentation and modification. Fig 12 shows the bottom of the HF section. The main RX/TX board is built using a variation of dead-bug ugly construction. Two boards are used: Above is a pad-per-hole "perf" board, underneath is a solid-copper board forming a ground plane. The lower board is single-sided, copper-plated on only the lower side; the non-plated side insulates the ground plane from the upper board. The boards are bonded with copper foil grounds wrapped and soldered around the edge, wide copper foil ground strips running through the interior of the board, and wires through drilled holes. This provides a better ground plane than pad-per-hole boards with a perforated ground plane on the underside, and is more convenient than true dead-bug style. The pads provide very rigid mounting points and the resulting circuit is much more solid than with true dead-bug construction; this is important for stability in the oscillator section. Several portions of the circuit are built on small pieces of pad-per-hole board and soldered vertically onto the main board; this method conserves space, and is especially useful for added circuits and modifications.

The 8072 anode requires a solid brass clamp, a voltage-insulating, thermal-conducting beryllium block and a heatsink. These were all salvaged from an old CX7. The insulating block, which protrudes through the rear wall, is seen in Figs 1 and 13. The heat sink, mounted outside the enclosure, is seen also in Fig 14. The small cooling fan is mounted to the heatsink; a slight upward tilt works best. *Beryllium dust is dangerous; the block should not be drilled or machined in any way.* To avoid the need for locating the special conduction-cooling components, a type-8122 tetrode may be directly substituted; forced-air cooling must then be provided.

A tube socket is not used. Better air circulation and heat transfer by convection is achieved by using separate clip-on contacts for each required pin. While anode cooling is always taken seriously, adequate cooling for the seals at the base of a tube is sometimes neglected. The Eimac data sheet for the 8072 states: "Mounting should always be such that free movement of air past the base by convection is possible." The exhaust fan above the tube also helps to produce adequate air circulation for the base.

An equally valid reason for avoiding a chassis-mounted socket is that this prevents mechanical and thermal strain on the tube. This consideration is unique to a conduction-cooled tube, which has its anode rigidly clamped to a heatsink. The contacts are taken from a seven or nine-pin miniature tube socket. Heavy leads connect the contacts to pads cut into the edge of the opening in the copper circuit-board material. This allows shorter RF paths than a socket would allow. Only a single pin need be connected for tube elements provided with multiple pins. The screen is bypassed by a capacitor connected directly to the screen ring; this was not done in the CX7. One capacitor lead is simply soldered to the screen ring; the other lead is soldered to the ground plane. This solder-to-the-tube method may seem a bit less shocking when one considers that this top-quality tube may not need replacement for up to 20 years.

The transmitter driver is built in two separate copper compartments. The driver and the PA are located as far as possible from the local-oscillator section to minimize heat-related drift. The PA has separate compartments for the plate and grid circuits; this contributes greatly to stability. For the chassis, a surplus CX7 aluminum chassis was recycled. This may have been an economical choice, but it did not work out very well. It would be easier to construct a somewhat larger enclosure with LMB components, using the methods described for the main transceiver panel in Part 5 (see Note 3). A 7×17×14-inch enclosure with a seven-inch black rack

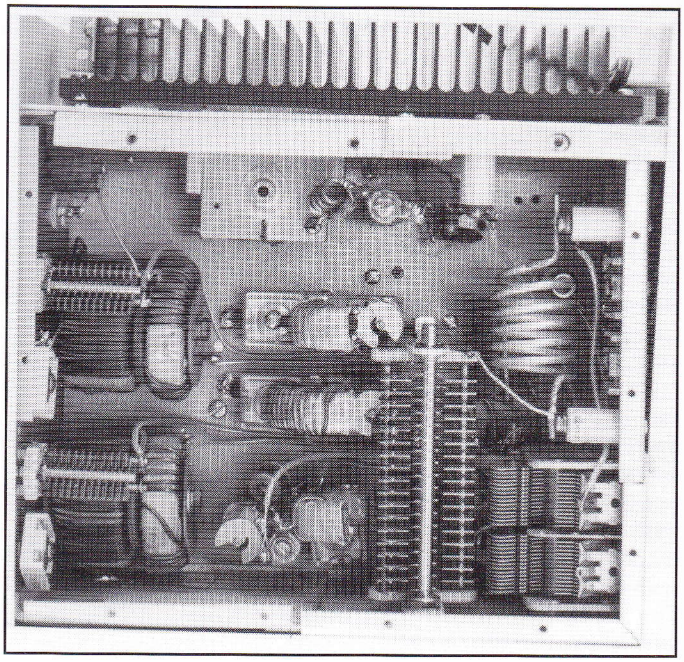


Fig 13—PA tank compartment. The large six-turn, silver-plated coil, the long, wide-spaced air variable tuning capacitor and the small two-section loading capacitor are used only on the 12 and 10-meter bands. The other seven bands utilize seven separate fixed-tuned tank circuits. The 160 and 80-meter toroidal coils are each mounted to the side wall with a single long brass threaded rod. A mounting bracket at the inside end (if not insulated) would create an effective *shorted-turn*, and seriously disrupt the functioning of the tank circuit.

panel should work well. All wiring is done with Teflon-insulated wire; RF is routed between sections with Teflon-insulated miniature coax, type RG-178B.

Alignment

It would be impractical to include complete step-by-step alignment details, especially since builders are likely to introduce modifications and improvements. Some special alignment notes have been included above; a few general remarks will be added here. At first, trimpots should be set to midrange or for minimum circuit current. To test the HF section on the bench without the transceiver, a shorted plug at the ENABLE jack is required. Another plug at the XMIT jack will allow the STBY/OPER switch to be conveniently used as a TR switch.

Most of the alignment, testing and adjustment can be done with the PA heater off. This avoids the bother of connecting a dummy load and allows the low-level transmitter sections to be tested and adjusted for hours on end without overheating the tube. Some precautions are still required, though. The heater-warm-up-delay circuit will prevent testing the transmitter sections. To defeat the warm-up feature when the heater is off, temporarily jumper test point TP5 in Fig 9 to –15 V. Now there is danger of damaging the output stage of the driver with excessively high RF voltage, since the grid-ALC circuit will not function when the tube is cold. To limit the driver output and test the grid-ALC circuit, temporarily connect a small diode from grid to cathode at the tube socket; this will simulate a warm tube.

For testing the transmit circuit only up to the second section of the driver without ALC, simply connect the base of Q5 to ground. To test the driver and grid-ALC circuit with the tube warm, but with no plate dissipation, output power or need for a dummy load, the screen fuse can be removed. For receiver tests, it is safer for the signal generator to use the auxiliary receive antenna jack RX IN.

The toroidal coils in the various filters should be measured and adjusted for proper inductance, since the permeability of individual cores may vary somewhat from published data. Some of the coils are quite sensitive to small changes in the position of the windings; they should be Q-doped to hold

Table 1—Receiver Sensitivity Measurements

Test results for minimum discernible signal (MDS) are given in dBm. To put the results in perspective, two other radios were also tested. The homebrew radio was tested at a bandwidth of 200 Hz. The Yaesu FT-1000MP (#9K470018) was tested at a bandwidth of 250 Hz using INRAD filters in both the second and third IF amplifiers, an INRAD first IF amplifier and an IF gain setting of 12. Measurements for the Collins 75A-4 (#2484) were taken using an 800-Hz mechanical filter.

	Receiver		
Frequency (MHz)	*K5AM*	*FT-1000MP*	*75A-4*
1.82	–142	–138	–143
3.52	–140	–138	–142
7.02	–133	–137	–141
10.12	–136	–138	–
14.02	–138	–139	–141
18.1	–144	–139	–
21.02	–142	–140	–143
24.91	–142	–143	–
28.02	–142	–144	–143

Table 2—Receiver Third-Order Dynamic Range Measurements

These tests were made at 14 MHz. The table shows dynamic range, DR3, at two-tone spacings of both 20 kHz and 2 kHz. The third-order intercept point, IP3, is also shown for both spacings. To put the results in perspective, two other radios were also tested. Tests were conducted for the homebrew radio at a bandwidth of 200 Hz. Tests for the Yaesu FT-1000MP were conducted at a bandwidth of 500 Hz using the stock filter in the second IF amplifier and an INRAD filter in the third IF amplifier; tests were also run at a bandwidth of 250 Hz. Tests for the Collins 75A-4 were conducted with the 800-Hz filter.

The measurement for the Yaesu at a bandwidth of 500 Hz and a two-tone spacing of 20 kHz is close to that reported in the ARRL product review.[10] For a two-tone spacing of 2 kHz, the measurement corresponds closely to that shown by the graph in the ARRL lab expanded report, provided the graph is adjusted so that its level at wide two-tone spacing conforms to the direct measurement.[10, 11] The tests show that the dynamic range of the Yaesu drops considerably when the two-tone spacing is reduced from 20 kHz to 2 kHz. This is because the roofing filter rejects interfering signals only at the wider spacing.

The homebrew radio uses no roofing filter; the dynamic range does not degrade drastically in the presence of nearby signals. During crowded band conditions, significantly better third-order IMD performance is obtained with the K5AM homebrew radio.

	20-kHz Spacing		*2-kHz Spacing*	
Receiver	*DR3 (dB)*	*IP3 (dBm)*	*DR3 (dB)*	*IP3 (dBm)*
FT-1000MP, 250 Hz	95	+4	75	–26
FT-1000MP, 500 Hz	92	+1	74	–27
K5AM	91	–5	88	–9
Collins 75A-4	72	–33	65	–43

the settings and retested. The completed filters should be tested before installation. The *Balance* trimpot in the receiver mixer-source circuit is adjusted for minimum LO feedthrough at 41.8 MHz; a setting near midrange indicates that the MOSFET pair is reasonably well matched.

Transmitter Alignment

The input to the transmitter-mixer circuit from the transceiver at 40 MHz is at a fixed level of –7 dBm, or about 280 mV (pk-pk). The trimpot should be adjusted to obtain a level of 100 mV (pk-pk) at each mixer signal gate; too much drive will increase spurious outputs. Even a 10:1 low-capacity scope probe at the gate will severely load the circuit. The required correction factor can be found by watching the signal level at the driver when the scope probe is touched to the gate. My probe caused a 3-dB drop, so the correction factor is 1.4 and a scope reading at the gate of 70 mV (pk-pk) is appropriate. The input level is easier to measure at the input transformer primary. The transformer has a voltage step-up of three times to each gate, so about 35 mV (pk-pk) at the primary is suitable. The *Balance* trimpot in the mixer source circuit is adjusted for minimum LO feedthrough at 41.8 MHz. The trimpots in the first section of the driver compensate for individual MOSFET characteristics; they are set to keep the gain in each of the first two stages roughly equal.

PA Alignment

The same procedure is followed for presetting the fixed-tuned circuits as for the panel-tuned circuit while operating. The best indication of proper loading conditions in a tetrode amplifier is screen current. The tuning control is always adjusted for peak screen current. In a stable amplifier, this should correspond exactly to maximum output and minimum plate current. The degree of amplifier loading is indicated by the level of screen current at this peak.

Different samples of the 8072 will develop maximum power at different peak screen-current levels. For most tubes, this will be between +5 and +10 mA. A tuning peak at 0 mA indicates excessively heavy loading and reduced output. A peak at +15 mA indicates excessively light loading. This again results in reduced output; but in this case, also the likelihood of distortion and splatter. For best linearity, loading should be adjusted slightly on the heavy side of the setting for maximum output. For example: If maximum output occurs at +9 mA, a loading adjustment that results in a tuning peak at +7 mA is best.

Performance

Complete performance measurements for the main transceiver panel and the three front-end sections must be deferred to a later article. For now, we report only a few measurements that relate specifically to the receiver and to the HF section. To put the data in perspective, measurements for a few other receivers are included. One of these, the Yaesu FT-1000MP, is used at my vacation cabin on Horse Moun-

Table 3—Receiver Second-Order IMD Measurements

The test signals are at 6 MHz and 8 MHz; the receiver is tuned to 14 MHz. The table lists the second-order intercept point IP2. To put the results in perspective, measurements for several factory-built radios are also listed. A number of older radios are included; they utilize a variety of elaborate and expensive RF tuning mechanisms, and it was of interest to see how effective they are with respect to second-order IMD. The table includes production dates when available. Measurements were made for the homebrew radio, the FT-1000MP, and the "boat anchors." Other data were taken from *QST* product reviews.[10]

Receiver	*IP2 (dBm)*	*Year*
Yaesu FT-1000MP-Mark-V, VRF on	112	2000-
Collins 51S-1	98	1959-72
Yaesu FT-1000MP	89	1995-2000
K5AM	83	1992
Drake 2-B	81	1961-65
Collins 51J-4	78	1952-62
Hammarlund HQ-129-X	77	1946-53
Collins 75A-4	74	1955-58
National HRO-5TA1	73	1944-47
Yaesu FT-1000MP, at RX IN jack	72	1995-2000
Hammarlund SP-600	70	1950-72
Yaesu FT-1000MP-Mark-V	69	2000-
Collins KWM-2	66	1959-75
Icom IC-756PRO	63	
Kenwood TS-570S(G)	59	
Ten-Tec Omni-VI-Plus	58	
Icom IC-718	55	
Yaesu FT-100	53	
Ten-Tec Pegasus	44	
Icom IC-706MKIIG	39	
Yaesu FT-847	15	

Table 4—Parts Suppliers

Amidon Associates, 7714 Trent St, Orlando, FL 32807; tel 800-679-3184, fax 407-673-2083; **tracy@bytemark.com**, **www.bytemark.com/amidon**.

Digi-Key Corporation, 701 Brooks Ave S, PO Box 677, Thief River Falls, MN 56701-0677; tel 800-344-4539 (800-DIGI-KEY), fax 218-681-3880; **www.digikey.com**.

GC Electronics, GC/Waldom Inc, 1801 Morgan St, Rockford, IL 61102-2690, distributors nationwide; tel 800 435 2931, fax 800 527 3436; **www.gcwaldom.com.**

Hosfelt Electronics, 2700 Sunset Blvd, Steubenville, OH 43952-1158; tel 800-524-6464, fax 800-524-5414; **hosfelt@clover.net**; **http://www.hosfelt.com**.

International Crystal Manufacturing Company, Box 26330, Oklahoma City, OK 73126-0330; tel 800-426-9825, 405-236-3741, fax 800-322-9426, 405-235-1904; **www.icmfg.com/**.

International Radio, 13620 Tyee Rd, Umpqua, OR 97486; tel 541-459-5623, fax 541-459-5632; **INRAD@rosenet.net**, **www.qth.com/inrad**.

Mouser Electronics, 2401 Hwy 287 N, Mansfield, TX; tel 800-346-6873, fax 817-483-0931; **sales@mouser.com**; **www.mouser.com**.

Richardson Electronics, 40W267 Keslinger Rd, LaFox, IL, 60147-0393; tel 800-348-5580; **gloria@rell.com**; **www.gloria@rell.com**.

Surplus Sales of Nebraska, 1502 Jones St, Omaha, NE 68102; tel 402-346-4750, fax 402-346-2939; **www.surplusales.com**.

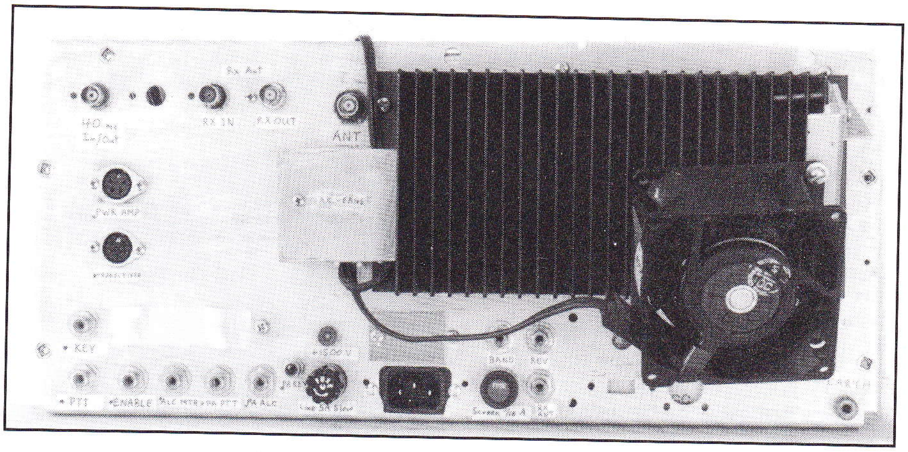


Fig 14—(right) Rear view of the HF section. The small copper box in the center covers feedthrough capacitors for the ac leads to the two small muffin fans. The two DIN connectors are for control cables to the main transceiver panel and to the kilowatt amplifier. This makes connections quick and easy. All control lines are also available at the phono jacks.

tain in New Mexico. Another, the Collins 75A-4, holds a pre-eminent position on the boat-anchor bench at home. Thanks to Emil Pocock, W3EP, for the suggestion to include the 75A-4, often declared by old-time operators to be the finest receiver ever built. This suggestion also led to the idea that I perform certain tests on several other old radios. The testing methods followed, as closely as possible, the procedures specified by the ARRL lab.[9] Results of the sensitivity tests for the various bands are given in Table 1.

Dynamic Range

Table 2 shows the results of third-order IMD dynamic range tests. The results for the Yaesu in the two-tone test at a spacing of 20 kHz demonstrate the effect of the roofing filter in the first-IF section. For the closer spacing of 2 kHz, the roofing filter provides no protection; the measurement then relates more directly to mixer performance and other factors such as diode switching. This problem was discussed in more detail in Part 1, page 18 (Note 3).

The K5AM homebrew radio uses a tunable first-IF section with no roofing filter. The dynamic range does not degrade drastically when the interfering signals are closer to the operating frequency. During crowded band conditions, this homebrew radio delivers significantly better third-order dynamic range performance.

Second-Order IMD

Second-order IMD test results are given in Table 3. There are wide differences between receiver designs that affect second-order IMD performance. For example, the Yaesu FT-1000MP uses eleven fifth-degree apolar Chebychev band-pass filters. A band-pass filter for the 12 to 15 MHz range is in use on the 20-meter band, where these measurements were made. In addition, the Yaesu uses three high-pass filters to reject signals in the f/2 region; these filters are included specifically to improve the second-order dynamic range. The results are excellent. The table also shows the results for the same radio using the RXIN jack. Unfortunately, this configuration bypasses the high-pass filters, and the performance is significantly degraded. Although measurements were not made on the 160-meter band, second-order IMD performance is also likely to be degraded there. This may be a serious consideration if a beverage antenna is used at the RXIN jack in areas with strong broadcast band signals.

The Yaesu FT-1000MP-Mark-V uses a selectable panel-tuned preselector called VRF; the results are exceptional, although there is a loss in sensitivity when the preselector is enabled. Another important design factor likely to affect second-order IMD performance is the use of diode switching in the front end of the factory-built radios. The high-pass filters in the Yaesu FT-1000MP are relay-switched and placed ahead of the diodes that switch the band-pass filters. No diode switching of signals is used in the K5AM homebrew radio.

My homebrew radio uses only a single, operator-tuned, high-Q LC circuit for preselection; the second-order IMD performance is adequate. High-pass filters could be easily added. Simple filters with only 20-dB rejection of signals in the f/2 region would raise the second-order intercept point by 40 dB.

Summary

The K5AM homebrew transceiver with the HF section has served faithfully for nine years, through many CW, RTTY and SSB contests and during countless hours of DXing. In a period of a little over a year, the radio worked over 100 countries on the 160-meter band (with help from an amplifier and a balloon). Thanks to the built-in protection circuits, there have been no breakdowns. The straightforward operating features, multiple meters and large knobs have contributed to highly enjoyable operating. The performance of the radio leaves little to be desired.

Readers are certain to notice points in the circuits where improvements are possible; please send in your ideas. This article completes the description of the homebrew transceiver up to 29.7 MHz. A subsequent article will describe the VHF sections.

Notes

[1] M. Mandelkern, K5AM, "Evasive Noise Blanking," *QEX*, Aug 1993, pp 3-6.

[2] M. Mandelkern, K5AM, "A High-Performance AGC System for Homebrew Transceivers," *QEX*, Oct 1995, pp 12-22. Corrections in *QEX*, Jul/Aug 2000, p 59.

[3] M. Mandelkern, K5AM, "A High-Performance Homebrew Transceiver." Part 1, *QEX*, Mar/Apr 1999, pp 16-24 (General plan). Part 2, *QEX*, Sept/Oct 1999, pp 3-8 (IF board). Part 3, *QEX*, Nov/Dec 1999, pp 41-51 (RF board). Part 4, *QEX*, Jan/Feb 2000, pp 47-56 (AF board). Part 5, *QEX*, Mar/Apr 2000, pp 23-37 (Logic board, etc). Corrections in *QEX*, Jul/Aug 2000, p 59, and *QEX*, Nov/Dec 2000, p 60.

[4] U. L. Rohde, KA2WEU, "Recent Advances in Shortwave Receiver Design," *QST*, Nov 1992, pp 45-55.

[5] The main differences are these: In lieu of an RCA type CA-3028A differential amplifier IC for (sometimes erratic) ALC control, three MOSFETs are used. The keyed stage is not used; keying is accomplished at 40 MHz on the main transceiver panel. In lieu of a low-pass filter here, a second filter is used in the mixer section on the RX/TX board. The bipolar emitter-follower stage using Q4 is added. Separate bias circuits are used for each of the last three bipolar amplifiers, and each stage has a trimpot for bias adjustment. TR switching is applied to each of the last three stages. The choke protection circuit at the output is added. Instead of heatsinking the last two stages to the chassis, these stud-mounted transistors are bolted through the wall of the driver compartment to small exterior heat sinks on the side of the enclosure. This helps keep heat away from the local oscillator. The control labeled OUTPUT on the CX7 is a *Drive* control in the sense used here; the CX7 has no *Output* control.

[6] This method is discussed further in M. Mandelkern, "A Luxury Linear," *QEX*, May, 1996, pp 3-12, and "Design Notes for 'A Luxury Linear' Amplifier," *QEX*, Nov 1996, pp 13-20.

[7] M. Mandelkern, K5AM, "An Automatic, Remote Antenna-Tuning Controller," *QST*, Sep 1995, pp 46-49.

[8] The transformer is available as model #CX7 from Peter W. Dahl Co, 5869 Waycross Ave, El Paso, TX 79924; tel 915-751-2300, fax 915-751-0768; **pwdco@pwdahl.com**; **www.pwdahl.com**.

[9] M. Tracy, KC1SX, and M. Gruber, W1MG, *ARRL Test Procedures Manual*, Revision F, June 2000. This document is available as **www.arrl.org/members-only/prodrev/testproc.pdf** on the ARRL members' Web site.

[10] Product reviews and expanded lab reports are available at **www.arrl.org/members-only/prodrev** on the ARRL members' Web site.

[11] For a discussion of dynamic range versus two-tone frequency spacing, see E. Hare, W1RFI, "Swept Receiver Dynamic Range Testing in the ARRL Laboratory," *QEX*, June 1996, pp 3-12, 29. ☐☐