A High-Performance Homebrew Transceiver: Part 5

A full-featured radio has many circuits associated with operator controls. This logic board uses a simple, direct method to execute those controls. This segment also covers the PTOs, frequency counter, power supply and some construction details.

By Mark Mandelkern, K5AM

Part 1 gave a general description of this transceiver, built for serious DX work and contest operating. Parts 2 through 4 covered the main signal boards. This article gives circuit details for the logic board, PTOs, frequency counter and power supply. It concludes the series describing the 40-MHz main panel. Subsequent articles will describe the three front-end panels for HF, 50 MHz and 144 MHz and will include performance measurements.

Logic Board

The K5AM homebrew transceiver was designed on a no-compromise basis with regard to performance and operating features. The result is that numerous circuits require operator adjustment and many of them interact. A general description of the logic board was given in Part 1. The board is shown here in Fig 1. The rather large circuit diagram need not be given in its entirety; it will suffice to specify all the logical relations and to give examples of the methods used.

Requirements

Here are some transceiver features that require control by the logic board:

1. Instant, one-button PTO switching.
2. Six modes—a mode switch with only six leads.
3. Relay-switched crystal filters.
4. One-button second-PTO monitoring.
5. PTO B frequency spotting while listening to PTO A’s frequency.
6. CW offset panel control with an audio monitor to hear the amount of offset.
7. Full break-in (QSK) at 50 WPM.
8. TUNE switch; pulse tuning or steady carrier.
10. Secondary band selection.

In addition to the control circuitry for the features listed above, the logic board contains the T/R, R/T, PTT, key-line, standby, QSK, semi-QSK and automatic keyer circuits.

TTL Control: Is It Obsolete?

The motivation for using TTL to control this radio was discussed in Part 1 (pages 22-23). TTL stands for “transistor-transistor logic.” This refers to a series of low-cost logic ICs...
that became available in 1972. The TTL system allows very simple and
direct generation of the logic functions
required to control radio circuits. The
effectiveness of this system is shown by
its continued use over three decades.

Modern alternatives to TTL exist. The
currently very popular "PIC" system is a compact solution to control
problems. However, TTL and other
discrete-logic systems have not been
completely superseded by PIC or other
microprocessor systems—only supple-
mented. PICs operate with the same
voltage levels as TTL, so the systems
may be used in conjunction. PICs were
not available in 1990 when this logic
board was built. Even now, however,
PICs may not be the preferred method
for controlling a radio of this sort. Along
with their many advantages, PICs have
some disadvantages compared to TTL:
PICs are more difficult to use, take
longer to design, require facility in a
programming language and require
special equipment to physically install
the program. In addition, to use PICs
efficiently requires expertise in proper
software-design processes.

This discussion assumes a single
ham building a single radio. For mass
production and team-designed equip-
ment, or for a widely distributed
amateur project with circuit boards,
parts kits and preprogrammed devices,
the situation is very different.
The investment of time and money in
a PIC controller is justified by the
savings in production. In contrast, for
one ham working alone in a garage
workshop, using a PIC for a medium-
sized project may be too involved.

Along with the original 7400-series
TTL, there are also many high-speed
and low-power spin-offs. Thus for
high-frequency and battery-operated
devices, the 7400 series is indeed
obsolete. For control of a line-powered
radio in a home ham shack running
usual amateur power levels, however,
a few milliamperes won't matter, so
the plain 7400 series is a good choice.
The higher currents and lower impe-
dances of this original series result in
less susceptibility to RFI than some
faster and low-power systems.

In summary, TTL is still a reason-
able choice for controlling a homebrew
transceiver, especially for someone who
does not want to put down the soldering
iron long enough to take a compre-
hensive course in programming.

Using TTL

Information on TTL and Boolean
algebra can be found in various
places. However, no extended study
program is required. It is not necessary
to understand much of what is inside
the logic chips in order to use them,
just as one does not explore the innards
of a Pentium chip in order to send e-
mail. Only the function of each chip
need be known. Only four different
types of TTL gates are used here and
one type of data selector. If an inverter
may be thought of as a 1-input NAND
gate, then the four gate types used are
all NAND gates: 1-input, 2-input,
3-input and 4-input. They are the 7404,
7400, 7410 and 7420, respectively. The
data selector is discussed below. The
function and pin-outs for each of these
ICs is given in the data book.

Including some OR gates or other
types could simplify some parts of the
circuit. We must consider the trade-off,
though, between achieving circuit sim-
plicity and employing a small number
of different gate types. Too many
different gate types in a circuit design
may result in some TTL pack-ages
being 75% unused. This is especially
true for this board, since it is built in
eight small, self-contained sections.

It is necessary to acquire a working
knowledge of the logical connectives:
AND, OR and NOT; these are denoted in
the formulas used here by •, + and −
(overline read as “bar”). DeMorgan’s
Theorem is needed to manipulate the
expressions—it is just common sense.
For a discussion of logical rules,
notation and calculations see Chapter
7 of recent ARRL Handbooks (Note 6).

Input Lines

The behavior of logic circuits may be
contemplated in terms of inputs and
outputs. The inputs are the settings of
all the various panel controls, plus the
PTT and key lines. The outputs are the
circuit lines leading to all the circuits
in the radio. The inputs may be
whatever the operator chooses; the
outputs depend on the inputs. Thus,
the inputs may be thought of as inde-
pendent variables and the outputs as
dependent variables. This enables us
to think of the logic circuits as
functions—in this case, Boolean
functions. Boolean algebra is used to
calculate the outputs as functions of
the inputs. All the rules for Boolean
calculations are in the referent of Note
6. In this design, intermediate logic
lines are specified; interface circuits
convert these lines to output lines.

Some notational conventions are
used here to make the formulas easier
to read. Capital Latin letters are used
for TTL lines. The letters are chosen
as mnemonics. For clarity, a letter
alone indicates a high logic state, or an
enabled function. The panel switches,
however, are grounded-to-operate
(that is, active low). For example,
dual-receive is enabled by a switch
that grounds a TTL line. Thus the line
to the panel is labeled D, so that dual
receive is enabled when line D is low.
An inverter on the logic board gener-
ates line D, which is high when dual
receive is enabled. All TTL inputs are
listed, in enabled form, in Table 1. In

Fig 1—Top view of the logic board in the K5AM homebrew transceiver. The DIP test
switch is at the top toward the left. At top center are the pulse-tuning adjustments
for on/off timing. Toward the right, under the protective edging, is the QSK-delay
adjustment. It keeps the transceiver in the transmit mode during the decay (break)
portion of each CW element. This adjustment ensures that the CW element will not
be chopped and that this delay is not excessive, so the receive circuits may recover
quickly. This transceiver “hears” breaking stations while transmitting at 50 WPM.
Table 1
Logic-board output lines: This table lists TTL lines actuated by front-panel controls. The lines are denoted in enabled form (see text). There is no designation for the center position A/B of the PTO switch for split operation. No contact is made here—the split-operation command is deduced by the logic board. Thus, only two wires are sufficient for selecting three PTO modes.

<table>
<thead>
<tr>
<th>Letter</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>PTO A; transceive</td>
</tr>
<tr>
<td>B</td>
<td>PTO B; transceive</td>
</tr>
<tr>
<td>D</td>
<td>Dual receive</td>
</tr>
<tr>
<td>M</td>
<td>Monitor frequency B</td>
</tr>
<tr>
<td>N</td>
<td>Noise blanker</td>
</tr>
<tr>
<td>S</td>
<td>Spot PTO B</td>
</tr>
<tr>
<td>PT</td>
<td>From PTT line</td>
</tr>
<tr>
<td>CWW</td>
<td>CW; 2-kHz bandwidth</td>
</tr>
<tr>
<td>CWN</td>
<td>CW; 200-Hz bandwidth</td>
</tr>
<tr>
<td>USB</td>
<td>Upper Sideband</td>
</tr>
<tr>
<td>LSB</td>
<td>Lower Sideband</td>
</tr>
<tr>
<td>AM</td>
<td>Carrier with two sidebands</td>
</tr>
<tr>
<td>FM</td>
<td>NBFM</td>
</tr>
<tr>
<td>SO</td>
<td>Spot CW offset</td>
</tr>
<tr>
<td>TD</td>
<td>Tune, pulse</td>
</tr>
<tr>
<td>TK</td>
<td>Tune, steady carrier</td>
</tr>
</tbody>
</table>

Table 2
Logic-board output lines: These lines lead to all parts of the radio, controlling all the circuits. Table 1 in Part 2 lists the Greek-letter prefixes that indicate the functionality of each type of line. For example, a m line enables a circuit when at ground level and disables it when at −15 V. This table indicates the circuits controlled by each line.

<table>
<thead>
<tr>
<th>Letter</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>βR</td>
<td>Counter (readout)</td>
</tr>
<tr>
<td>βN</td>
<td>Noise blanker</td>
</tr>
<tr>
<td>βM</td>
<td>AM/FM relay and circuits</td>
</tr>
<tr>
<td>βX</td>
<td>Transmit relays and circuits</td>
</tr>
<tr>
<td>μPD</td>
<td>Product detector gate</td>
</tr>
<tr>
<td>βAM</td>
<td>AM detector gate</td>
</tr>
<tr>
<td>βFM</td>
<td>FM detector gate</td>
</tr>
<tr>
<td>βCR</td>
<td>Carrier gate for CW and Tune</td>
</tr>
<tr>
<td>βSB</td>
<td>Sideband selection, LSB/USB</td>
</tr>
<tr>
<td>βST</td>
<td>Sidetone oscillator</td>
</tr>
<tr>
<td>βSSB</td>
<td>Transmit SSB circuits</td>
</tr>
<tr>
<td>μA</td>
<td>PTO A</td>
</tr>
<tr>
<td>μB</td>
<td>PTO B</td>
</tr>
<tr>
<td>μD</td>
<td>Dual receive</td>
</tr>
<tr>
<td>μMO</td>
<td>Master oscillator</td>
</tr>
<tr>
<td>μOO</td>
<td>Offset oscillator</td>
</tr>
<tr>
<td>μSO</td>
<td>Spot CW offset</td>
</tr>
<tr>
<td>μIA</td>
<td>LO injection buffer for PTO A</td>
</tr>
<tr>
<td>μIB</td>
<td>LO injection buffer for PTO B</td>
</tr>
<tr>
<td>T/R</td>
<td>−15 V receive; 0 transmit</td>
</tr>
<tr>
<td>R/T</td>
<td>0 receive; −15 V transmit</td>
</tr>
<tr>
<td>XMIT</td>
<td>Transmit order to front-end panel</td>
</tr>
</tbody>
</table>

Table 3
Intermediate TTL lines: These lines operate in the logical realm between the input and output lines. They are formed as Boolean functions of the inputs and applied to the interface circuits to generate the outputs.

<table>
<thead>
<tr>
<th>Letter</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>P</td>
<td>PTO A</td>
</tr>
<tr>
<td>Q</td>
<td>PTO B</td>
</tr>
<tr>
<td>R</td>
<td>Counter readout; PTO B</td>
</tr>
<tr>
<td>J</td>
<td>Receiver-mixer LO injection; PTO A only</td>
</tr>
<tr>
<td>K</td>
<td>Receiver-mixer LO injection; PTO B only</td>
</tr>
<tr>
<td>L</td>
<td>Receiver-mixer LO injection; dual receive</td>
</tr>
<tr>
<td>X</td>
<td>Transmit</td>
</tr>
<tr>
<td>T</td>
<td>Tune, pulse or steady</td>
</tr>
<tr>
<td>OP</td>
<td>Operate</td>
</tr>
<tr>
<td>KL</td>
<td>Key-line control</td>
</tr>
<tr>
<td>CW</td>
<td>CW, either bandwidth</td>
</tr>
<tr>
<td>PD</td>
<td>Product detector</td>
</tr>
<tr>
<td>CR</td>
<td>Carrier</td>
</tr>
<tr>
<td>ST</td>
<td>Sidetone</td>
</tr>
<tr>
<td>NB</td>
<td>Noise blanker</td>
</tr>
<tr>
<td>MO</td>
<td>Master oscillator</td>
</tr>
<tr>
<td>OO</td>
<td>Offset oscillator</td>
</tr>
<tr>
<td>SSB</td>
<td>LSB/USB, transmit</td>
</tr>
</tbody>
</table>

Table 4
Boolean Functions: These determine the operation of all circuits in the radio.

CR = (CW • T) • X
CW = CWW + CWN
J = P • ⊕
K = P • ⊕
KL = TK + (X • CW • TD)
L = X • D • M • B
MO = (CW + T) + X
NB = N • X
OO = MO + (SO • X)
P = (A • M) + (A • X) + (X • B • M • X)
PD = (AM + FM + SO)
Q = P + (X • (S + D))
R = P + (X • S)
SSB = (LSB + USB) • X • ⊕
ST = CW • ⊕
T = TD + TK
X = (PT + T) • OP

For example, the function NB = N • X (NB equals N and not X) enables (high state) the noise blanker when the blanker control knob is pulled out, sending input line N high, but only when receiving. This limitation is necessary because the tunable noise-channel LO could cause a spurious output if allowed to run while transmitting. An interface circuit converts line NB to the output line βN.

As another example, pulling the dual-receive knob out sends input line D high. This turns on both PTOs—but not while transmitting! Thus the trans-

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The discussion, we will refer only to the lines representing enabled functions, without reference to the panel lines and the inverters. Using two hex-inverter TTL packages avoids having to work with all the input lines in reversed logic. The PTT and key lines are external inputs, labeled αPT and αKL, respectively. The Greek-letter prefix conventions, also used in previous series segments, are listed in Table 1 of Part 2. The logic board output lines also use Greek-letter prefixes. They are listed in Table 2 here.

Intermediate Logic Lines

Generation of these signals is the central function of the logic board. Various inputs, corresponding to operator controls, are combined to form logic lines that represent command signals for the circuits. At the intermediate point, they are still TTL-level signals; additional interfacing circuits produce the actual output lines. The TTL designations of the intermediate logic lines are given in Table 3. The circuit decisions involve Boolean functions; these are listed in Table 4.

For example, the function NB = N • X (NB equals N and not X) enables (high state) the noise blanker when the blanker control knob is pulled out, sending input line N high, but only when receiving. This limitation is necessary because the tunable noise-channel LO could cause a spurious output if allowed to run while transmitting. An interface circuit converts line NB to the output line βN.

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emit line X must be combined with D. When transmitting, the PTO switch position must also be considered. When receiving, pressing the MON button must momentarily terminate the dual-receive function, enabling only PTO B. During split-frequency operation, the SPOT B switch turns on PTO B while receiving with PTO A; PTO B reads on the counter. The result is that the intermediate line Q, enabling PTO B, depends ultimately on six input lines.

Generating Boolean Functions

Only a few examples will be shown here. These may suggest ideas for using TTL on any small control problem that might arise. In Fig 2, the simple intermediate TTL lines CW and SSB are obtained with only a few gates. Somewhat more complicated are the intermediate lines CR, MO, and OO. Their circuit is shown in Fig 3. For Boolean functions with even more variables, data selectors are used. These are discussed below.

Output Lines

The intermediate logic lines must be converted to control signals that can be used by the circuits in the radio. Some of the circuits simply require a supply voltage to be turned on or off at the right times. Some circuits use dual-gate VHF MOSFETs, which require a positive voltage at the control gate to activate them, or a negative voltage to turn them off. There are also relays to control. The logical relation between an intermediate line and an output signal is simple and direct. For example, intermediate TTL line Q is high when PTO B is enabled and low otherwise. Output control line βB, derived from Q, is accordingly either 0 or –15 V. PTO B will run with 0 V on the control line, while –15 V applies cutoff bias to the oscillator and buffers. Op amps are used to convert intermediate TTL lines to control signals. Two basic types are used here: ordinary op amps and comparators (which is, strictly speaking, not really an op amp). A regular op amp, such as LM324N, will generate a β-type control line, switching from about +15 V to –15 V. In practice, with ±15 V dc rails, only about ±13 to ±14 V is obtained. This is taken into account in the design of the circuits controlled and of the diode switches, although the full voltages are used in the discussions. A comparator, such as the LM339N

Fig 2—Intermediate TTL lines. This circuit generates the lines, CW and SSB, that control the transmit CW and SSB circuits. When using the TUNE function in SSB mode, the transmit SSB circuits are disabled. This avoids noise on the carrier while tuning. The calculations given here show how DeMorgan’s Theorem and the other logic laws are used to design the circuits. The labels shown on the MODE switch are panel labels, not TTL designations. Not shown are the 2.2-kΩ pull-up resistors from the +5 V dc rail to each panel input line.

Fig 4—Interface circuits for obtaining control lines. In (A), the TTL line SSB is interfaced to obtain control line βSSB, used for controlling transmit SSB circuits. The circuit in (B) derives the control line βX from the TTL line X. Because line βX drives a number of circuits, the required current drain exceeds the capacity of the op amp, which has a maximum output of about 20 mA. With the buffer transistors added to the circuit as shown, we can draw well over 200 mA from line βX.

The schematics in this article use the following conventions: Except as noted, the op amps are LM324Ns, powered from the ±15 V dc rails. The transistors are small-signal types, such as 2N4401 (NPN) or 2N4403 (PNP); the diodes are small-signal silicon switching types such as 1N4148. Resistors are 1/4-W, carbon-film units. Trimmer potentiometers are one-turn miniature parts, such as Bourns 3386 (Digi-Key #3386F-nnn, see Note 22). Capacitors labeled “s.m.” are silver micas, with values given in pF. Values of RF chokes (RFC) are given in μH. The 100-nF monolithic ceramic bypass capacitors at the power terminals of each TTL and op-amp package and 10-nF disc ceramic bypass capacitors at each board terminal are not shown. Unmarked coupling and bypass capacitors are 10-nF disc ceramics. Potentiometers labeled in all capital letters are front-panel controls; others are circuit-board trimmers for internal adjustments.
used here, has an open-collector output. With ±15 V dc rails, it provides either a −15 V output or an open circuit. This is useful for generating a μ-type control line. In later designs, however, only a regular op amp is used. This simplifies things, as a μ-type line can be generated from a β-type line merely with the addition of a diode. Thus, only the generation of β-type lines will be shown here. One valuable characteristic of an op amp is its ability to supply moderate output current while drawing virtually no current from the inputs. Fig 4 shows the way TTL lines are converted to β-type control lines. Although we use 0 and 1 as logic symbols, the TTL circuits do not use 0 and 1 V for FALSE and TRUE, they use roughly 0 and 5 V. These voltages are only nominal; typical values might be 0.5 and 3.5 V. The exact range of permitted values is given in TTL reference books. A good intermediate value is 1.4 V. A voltage divider establishes this with only two resistors, and the reference voltage thus obtained is used throughout the logic board. We apply 1.4 V to the inverting input of the op amp and the TTL line to the noninverting input. When the TTL line shifts from about 0 V to about 4 V, the op-amp output shifts (nominally) from −15 V to +15 V. For example, if we apply the TTL line X (transmit), we obtain the output control line βX, which shifts from −15 V in receive to +15 V in transmit. One use of this βX line is to control MOSFETs in the transmitter section of the radio, with a voltage divider in the MOSFET circuit to obtain ±4 V for the control gate.

PTT and T/R Circuits

The STBY/OPER function is incorporated into the PTT circuit. Several output lines are provided for the transmit/receive function: T/R, R/T, XMIT and βX. This extra bit of circuitry simplifies design of other circuits throughout the radio. A PTT circuit is shown in Fig 5.9

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**Fig 5**—PTT and standby circuit schematic (see Note 9). In this circuit, the external PTT line, usually operated by a foot switch, is transformed into the TTL line X, for transmit. The STBY/OPER switch on the front panel enables the circuit. The output line XMIT conveys a transmit order to the selected front-end panel.

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**Fig 6**—CW break-in (QSK) circuit (see Note 9). The timing adjustment is set for a PTT hold-in delay of about 4 ms after the end of each code element. This prevents any chopping of the decaying CW waveform. Other methods that introduce delay into the keying circuit may distort the CW waveform and cause excessive delay that degrades the QSK performance. This radio can hear breaking stations while sending at 50 WPM.
Key Line and Break-in Circuits

The interface of an external input line with internal circuits becomes critical for the keying line, since timing is important. We must have circuit isolation, otherwise capacity on the key line or from an external keyer might alter the timing and distort the keying waveform. A keying circuit is shown in Fig 6 (see Note 9). The keying waveform is developed at the 40-MHz buffers on the RF board, as shown in Fig 9 of Part 3. A Curtis 8044 keyer IC is included. It is valuable in case the external memory keyer fails.

There are two CW break-in modes. Full break-in (QSK) requires full receiver recovery between CW elements. This radio can hear breaking stations while sending at 50 WPM. Semi-break-in (SQSK) is a misnomer: It only implies an automatic PTT function. Stations cannot actually break in. SQSK is useful with an amplifier that will inhibit quick receiver recovery and limit the ability of the radio to check for key clicks. Too much delay will inhibit quick receiver recovery and limit the ability of the radio to hear breaking stations between dits.

The keying section of the logic board includes the pulse-tuning circuit. The advantages of pulse tuning and of the circuit details were described in a previous article. To reiterate: The chief advantage is greatly reduced anode dissipation in the kilowatt-amplifier tubes. The circuit has on/off timing adjustments, so the pulse width and duty cycle may be adjusted. Settings for 13-ms on and 27-ms off provide a 33% duty cycle with a pulse rate corresponding to shortened CW dits at 60 WPM.

PTO Control

For the utmost in operating flexibility, PTO control is of special importance. This radio has two PTOs and dual-receive capability. In addition, it provides instant, one-button monitoring of the second frequency for split-frequency DX operations. This feature is useful because dual receive is not feasible with extremely weak, barely readable DX signals. There is also provision for spotting the transmit frequency while receiving, as for 40-meter DX SSB work. In any given situation, the logic board must make several decisions. Which PTOs should run? Which PTO should determine the receiver's mixer injection? Which PTO should be displayed?

Data Selectors

Simple gates are used for most of the intermediate TTL functions. For the more-complicated functions, such as PTO control, 74151 data selectors are used as Boolean function generators. Complicated Boolean functions would require a large number of simple gates; a single data selector can often do the same job. The term data selector refers to the primary use of the device: to choose among several data inputs as determined by the address inputs. Here we employ its secondary use: as a Boolean-function generator. We may think of the selected data as the desired result, based on the operator's orders as applied to the address inputs. Three 74151 data selectors are used here to control PTO A, PTO B and counter display selection. Each 74151 is a 16-pin DIP device with three address inputs and eight data inputs.

The Boolean functions for the PTOs must have inputs involving manual PTO selection, dual receive, monitoring of the second PTO, spotting a frequency on the second PTO and the transmit/receive condition. As an example, the circuit for TTL line P, which determines power to PTO A, is shown in Fig 7. We have four variables, A, B, M and X, corresponding to the panel switches for PTO A, PTO B, MON and the transmit condition, respectively. Since the data selector has only three address inputs, a fourth input is effected by using the data inputs. These four variables together result in $2^4 = 16$ logic states. The desired output for each of these states is selected by configuring the appropriate data-input pin.

The three address inputs result in eight possible states, represented by numbers in binary form: 000₂ to 111₂, or 0₁₀ to 7₁₀. For each of these states, output signal Y at pin 5 is determined by the level of the corresponding data-input pin. The data input pins are labeled D0 through D7. To generate P, the address inputs are M, A and B; these correspond to the MON, PTO A and PTO B switches. Note that three different labeling systems are employed! The circuit lines are M, A and B; the

<table>
<thead>
<tr>
<th>Panel Switch</th>
<th>Input Lines</th>
<th>Input State</th>
<th>X</th>
<th>P</th>
<th>Data Input Line</th>
<th>Pin Number</th>
<th>Selected Connection</th>
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<tbody>
<tr>
<td>B/A/B</td>
<td></td>
<td></td>
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<td>1</td>
<td>X</td>
</tr>
<tr>
<td>1 0 0</td>
<td>100</td>
<td>Four</td>
<td>0</td>
<td>D4</td>
<td>15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 0 1</td>
<td>101</td>
<td>Five</td>
<td>0</td>
<td>14</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Fig 7—Data-selector logic diagram. The schematic at (A) shows the data selector used to generate the line P, which determines when PTO A runs. The 74151 data selector is used as a Boolean function generator. This method is simpler than using a large number of separate gates. The truth table for this Boolean function is shown at (B). The table is incomplete; there are no entries for the input states 110₂ and 111₂. These states occur when the operator throws the PTO switch in both directions at once!
The use of logic circuits for mode switching yields many advantages, as discussed in Part 1, pp 22-23. A portion of the mode-switching circuit is shown in Fig 8. This circuit enables the sharp (200-Hz) CW filter when requested by the mode switch. Most of the power-supply load is on the +15 V dc rail, so certain circuits are run from the -15 V dc rail in an effort to distribute the load more evenly. The special sharp CW-filter preamplifier and the CWN relays present good opportunities for this. The special -15CWN line is at once a control line and a power source. The buffer circuit used to obtain more current for the βX control line in Fig 4 drops the available op-amp output voltage by an additional V\text{be} and so is not appropriate here. The circuit used for -15CWN, shown in Fig 8, provides nearly the full -15 V.

Secondary Band Selection
This radio has a special band-switching feature. Although quite meager compared to the many memories and flexibility of a computer-controlled radio, it is very useful in many situations. The panel switch labeled BAND controls a line leading to the external front-end switch box, which has switches for choosing a primary and secondary band. The BAND switch on the main transceiver panel has the following functions: In the center position, no secondary band is selected; in the up position, whenever the radio switches to PTO B the secondary front-end panel is selected; in the down position, the secondary front-end is selected in all PTO modes. The BAND switch has many uses. For example, one can be busy working an HF contest and set the thing up so that one touch of the MON button checks the 50.110-MHz DX calling frequency. Or, you can be working 6-meter DX and set
up so that switching to PTO B immediately puts you on 28.885, the 6-meter DX liaison frequency. With some 6-meter DX openings lasting only 10 seconds, every second counts!

Rear-Panel Connections

Years of trouble with phono plugs and jacks led me to look for a better way to connect the radio to the rest of the station. Hams commonly use BNC connectors only for RF. Where reliability is important, however, it is common to use BNCs for control lines also. For contest work, I also want the highest level of reliability. Thus, I use BNCs for all rear-panel jacks that would normally use phono jacks. All control connections at the rear panel are filtered—mostly with pi-sections using a 1-nH RFC and two 10-nF disc ceramic capacitors.

To facilitate interconnections at the operating bench, a dual-connector system is employed. In addition to the BNC and key jacks, a seven-pin DIN connector connects the PTT line, key line, keyer dit/dah lines and transmit control line to the separate front-end panels with one quick push. It also connects the ALC-meter lines from the front-end panels back to the main transceiver panel. This cable leads to a station-hub switch box on the operating bench that selects the front-end panel: HF, 50 MHz or 144 MHz. Each of the three panels also connects to the station hub with a single control cable and a coaxial cable for 40 MHz. Pulling the radio for a quick trip to the workbench to add a new feature (between contests) is an easy task. There is also a DIN jack on the radio for connecting a front-end panel directly to the radio, so the radio can be used independently of the hub or tested with one front-end panel at the workbench.

Each front-end panel has a similar dual-connection arrangement. All this redundancy in connections required only a few extra hours of work, repaid many times since in convenience. The transceiver and front-end panels fit into the complete station layout as shown in Fig 9.

DIP Test Switch

Many test and alignment procedures require certain oscillators to be turned off. For example, sweep alignment of a filter following a mixer is impossible with the LO running and reacting with the sweep generator. For convenience, a four-gang DIP test switch is installed on the board. It can defeat MO, OO, PTO A or PTO B. The switch is positioned at the top of the board so it is easily reached with the logic board in place.

Logic Board Construction

The board itself is shown in Fig 1; its general method of construction was described in Part 1. Rather than copper circuit board, the logic board is constructed on perf board. Wiring on the board is done mostly with wire-wrap, with some point-to-point hand wiring. The board’s bottom surface is shown in Fig 10. A long copper strip along the edge with 59 terminals provides a common ground and a return for bypass capacitors on all the input and output lines.

Permeability-Tuned Oscillators

In a traditional homebrew radio, the VFOs may be the most difficult problem (leaving aside modern digital methods). The VFOs are most demanding of perfection. For the ham more comfortable with soldering irons and transistors than lathes or bearings, the mechanical demands may cause the most headaches; I sidestepped the mechanical obstacles. Although I built the circuit, filter and shielded box, these details are trivial compared to the powdered-iron tuning slug, coil, precision-rolled left-hand-drive screw, bearings, tuning rail, anti-backlash mechanism and the solid frame. All these mechanical parts were stolen from a junked Signal/One CX7. Even after this grand larceny, there is still much work to be done for mechanical overhaul and adjustment of these old PTOs. One shudders to think what it would cost to manufacture such a precision PTO mechanism today.

PTO Circuit

The PTO schematic is shown in Fig 11. The circuit is very similar to that used in the Signal/One, except that the Signal/One included no RIT. The circuit may also be used for a variable-capacitor-tuned VFO. The capacitor’s reduction-gear tuning mechanism will be arranged by the individual builder. Because a frequency counter is used, the difficult problem of dial calibration is eliminated and linear tuning is not essential.

This PTO tunes about 25 kHz per revolution—no problem for old-timers, although faster than modern tastes would demand. There are several possible ways to reduce the tuning rate. One is to rewind the coil with a coarser pitch at the low end for the CW segments. Another is to rewind the coil to reduce the range to 500 kHz, adding extra 10-meter segments to the HF front-end panel as needed.

The Case for RIT

An RIT function is essential in most operating situations. Arguments against it—while logically perfect—apply only to a perfect world. If every operator tuned his radio perfectly, RIT would not be necessary. While RIT is the solution for the listening operator, ironically it is RIT itself that often causes any mistuning by the offending

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![Fig 10—Bottom view of the logic board. Wire-wrap construction is used for the TTL and op-amp circuits and point-to-point wiring for the circuits with discrete components. To minimize connector troubles, the board is hard-wired to the radio. A 12-inch-long bundle of wires allows the board to be easily lifted and serviced.](image-url)
transmitting operator. The problem is a general lack of awareness of the relation between the CQ-calling station and the replying station; that is, the requirement that the replying station tune with the RIT off. New operators might be advised simply: “Don’t use the RIT until you acquire experience.”

In any event, a contest operator must have RIT to hear the offenders. There are also other valid uses for RIT. During a CW QSO, one might wish to change the received pitch to improve readability in QRN or avoid QRM. RIT is especially useful for moon-bounce work. After acquiring an EME signal and making the first call, I pull out the RIT knob. This fixes my transmit frequency while allowing me to adjust tuning as desired at a slower rate. The RIT is also used to adjust for Doppler shift. As always, the rule is: Never change the transmit frequency after a QSO has begun, or even after a first call.

RIT Circuit

The RIT system uses a simple transistor switch. Let’s say the RIT is on. While receiving, the T/R line is at –15 V and keeps the transistor cut off, so the Xmit-Set trimmer has no effect; the varactor diode bias is varied by the RIT panel control. When transmitting, the T/R line is near ground; there is very little voltage at the RIT control, and it has no effect. Now, the transistor is turned on, so the Xmit-Set trimmer determines the varactor diode bias, setting the PTO frequency to the center of the RIT range. When the RIT is switched off, the transistor is always on, so the frequency is centered.

Fig 11—PTO schematic diagram. The 78L08 regulator that powers the oscillator is not shown.
C1—Temperature-stable monolithic ceramic capacitor, type C0G, 390 pF; Panasonic #ECU-S1H391JCA, Digi-Key #P4932 (see Note 22). From 0 to 60 °C, these capacitors have a tolerance range of 0.1%.
C2-C3—Temperature-stable monolithic ceramic capacitor, type C0G, 680 pF; Panasonic #ECU-S1H681JCB, Digi-Key #P4935 (see Note 22 and comment for C1).
D1—Hot-carrier diode, HP-2800. A small-signal germanium diode, such as type 1N270, may also be used.
L1—Permeability-tuned oscillator coil, salvaged from a Signal-One CX7.
RFC 1—RF choke, 100 mH. A 1-mH choke is often seen in this sort of oscillator circuit; that is larger than needed and may cause pick-up of AC hum.
VC1—Varactor diode, nominal 33 pF. Motorola type MV2109, NTE type 614 (see Note 21).
Except as indicated, decimal values of capacitance are in microfarads (µF); others are in picofarads (pF); resistances are in ohms; k = 1,000.
s.m. = Silver mica
~ = not

Connections
74143 pins  D2 - D4  LED Segment
15  1  c
16  13  b
14  10  c
9  8  d
11  7  e
10  2  f
13  11  g
RIT Adjustment

The Range-Set trimmer is adjusted to obtain a range of ±1 kHz, which is most convenient. Varactor diodes of the same type may vary greatly in characteristics. If the RIT control does not yield equal shift in both directions from center, resistors are selected and installed between the arm and either side of the control to center the curve. The range obtained may also vary, hence requiring adjustment of the 15-kΩ resistor. Thus, the RIT circuits are individually fine-tuned.

PTO Construction

The original Signal/One PTO cover design has several drawbacks. The cover is held by only two screws and does not fit tightly, which results in an RF-leaky enclosure. Connections to the PTO circuit are made through copper-clad circuit board. Feed-through bypass capacitors are used. All the usual CX7 capacitors, resulting in further leakage. For these reasons, new PTO enclosures were fabricated using copper-clad circuit board. Feed-through bypass capacitors are used. All the usual CX7 spurs caused by PTO leakage are eliminated. Building the HF front-end in a separate enclosure is also a major factor in this result.

Frequency Counter

The main transceiver panel covers 40-39 MHz, driving three front-end panels for HF, 50 MHz and 144 MHz. An external switch box with push buttons chooses one of these three. The HF panel (200 W) covers the ham bands up to 30 MHz in 10 1-MHz bands. The 50-54 MHz panel (2 W) has four 1-MHz bands. It was built during solar cycle 22, when ZLs and VKs still used the 51 and 52 MHz segments. The 144 MHz panel (2 W), used only for CW/SSB DX and for moonbounce, covers only 144-145 MHz. The frequency counter on the main panel counts only kilohertz. The operator must read the band from the switch box and the band switches on the front-end panels—an archaic method, although not a problem for experienced operators. The transceiver and front-end panels fit into the complete station layout as shown in Fig 9.

Counter Circuit

The counter is that section of the radio that is closest to a direct copy of an established circuit. With only slight changes, I combined circuits from several versions of Signal/One counters and from an independent supplier. The design is straightforward; its circuit is shown in Fig 12. The chief advantage of this circuit is the absence of multiplexing, which can cause noise problems. The counter reads a PTO frequency directly, displaying only the kilohertz digits. Since the PTO range is 3.1 to 4.1 MHz (as explained in Part 1, p 20), the counter is configured to start at 0900000\(_{10}\). The resulting count, over 100-ms intervals, is 4000000\(_{10}\) to 5000000\(_{10}\). Leading and trailing digits are not displayed. The PTO covers 1 MHz, with about 50 kHz over-range coverage at each end. The normally displayed readings are from 000.0 to 999.9. Beyond that, an overflow dot lights on the left of the display, warning the operator. With the

Fig 12—Frequency counter schematic diagram (opposite). Commonly available TTL ICs are used. The simple gates are all included in one 7404 hex-inverter package and one 7410 triple three-input NAND gate package. Type 74143 is a combined BCD counter, storage latch, decoder and seven-segment output driver. It does not have a “start at nine” feature; this complicates the circuit by requiring several other ICs to drive the first digit.

D1-D4—LED panel read-out, seven-segment, common anode; HP type 7661, or 7660 for left-hand decimal point at the first digit for the over-range indicator. Panasonic types LNP140A and LNP140GA (orange and green) are available at Digi-Key, #P327 and #P329 (also available in red and amber; see Note 22). The Panasonic LEDs are not available with left-hand decimal point. The over-range indicator may be placed to the right of the fourth digit.

Fig 14—Top view of the frequency counter. The socketed DIP ICs are wire-wrapped; discrete components are hand wired point-to-point. The LED readout sub-board is also wire-wrapped and is cemented at right angles into the cutout on the main counter board.
produces the various control lines. The 7493 is a divide-by-16 binary counter; strapping the C and D output lines to the reset pins reduces it to a divide-by-12 counter. A count of 12 has binary output 11002; i.e., C and D are high. The gate line, G, determines the total counting time of 100 ms. The remaining 20 ms of the total counter period are for the transfer (line T) and clear (line L) functions. A timing chart is shown in Fig 13.

The third portion of the counter, from the PTO input to the display digits, performs the actual counting. The more complicated circuit for the first digit implements the start-at-nine and over-range functions.

**Powering the Counter**

The LED drivers in the counter can become quite hot. The TTL ICs are specified for operation at 4.75 to 5.25 V. I found, however, that this counter would operate perfectly at voltages down to 3.5 V dc. An LM317 adjustable regulator, with input from the 7808 primary regulator, supplies the counter power. Tests were run over many months while work continued on other portions of the radio. A setting of 3.9 V has powered the counter adequately for 10 years, with greatly reduced IC temperatures and a much longer expected life. The LEDs also benefit from this technique, giving a softer, yet sharper display.

**Counter Construction**

The counter is seen in Fig 14. It is built on plain perfboard using wire-wrap construction. Four LED digits are used for the display: three in yellow for kilohertz and a green one for tenths of kilohertz. An escutcheon, seen in Fig 3 of Part 1, covers the ragged edges of the panel cutout; it was recycled from a CX7.

**Power Supply**

Design considerations and a general description of the power supply were given in Part 1, pp 23-24. The circuit uses standard IC regulators; the schematic need not be given here. Four small transformers are used. A heat sink, spaced away from the rear panel, holds the four primary regulators: two 7815s, a 7918 and a 7808—all have TO-3 cases. Each of the four main boards employs TO-220 secondary regulators as needed: 7815, 7915 or 7805. One adjustable LM317 is used for the counter, as mentioned above. This double regulation avoids all transient problems. In addition, the IF board has a second 7815 regulator that powers only the AGC detector. This keeps AGC noise out of other circuits. In some radios, what sounds like an AGC click from inadequate AGC attack response is only noise conducted by a common power supply.

**Cabinet Construction**

Packaging for a full-featured radio can be a problem. The many circuits require considerable space. Modern mass-production methods are not available. A homebrew radio is more like a prototype; simple methods are required. Space must be provided for innumerable circuit modifications in the eternal quest for perfection.

The method used to build the main boards was described in Part 1 and is shown in the photos accompanying previous segments. The four main boards are secured inside the cabinet using pins. There are no removable screws or nuts to deal with. Each board has two small holes on the bottom wall and sits on pins fashioned from nylon screws attached to the cabinet bottom.

The IF board is pinned firmly in place by captive thumbscrews secured to the cabinet sides, which enter holes in the sidewalls of the board. This makes board removal very quick and easy. The plan was the same for the three other main boards. Because wire-harness overload developed during construction, however, the other boards had to be shortened; they have sidepins only on the right. (I omit gruesome details, including the need to saw off the left end of the RF board after it was built and installed.) A removable top bracket with four nylon pins (not shown) secures the other boards using the IF board as an anchor. The four holes in the top walls may be seen in Fig 5 of Part 1.

**Table 5** lists materials needed to assemble the cabinet. The LMB Omni Chassis series provides numerous prepunched holes for fastening and results in an excellently shielded enclosure. The cabinet’s bottom plate is permanently attached—all work is done from the top of the radio. The cabinet itself has no front; this avoids the troublesome problem of drilling and mounting controls on a double wall. The front panel, for a standard 19-inch rack, has a plain, unpainted rear surface. This ensures good bonding and shielding. A ridge of square aluminum is permanently fastened to the rear of the panel, positioned to fit inside the cabinet. The bar is fastened to the panel with twelve permanent screws threaded into the bar from the front of the panel. These permanent front screws may be seen in Fig 3 of Part 1. Part of the bar may be seen here in Fig 14, and an outline of the bar is shown in Fig 15. The panel is released quickly and easily by removing hidden screws that thread into the bar from the sides, top and bottom of the cabinet. This method avoids the need to remove screws from the front of the panel and so prevents marring or scratching of the paint. All panel-mounted controls and assemblies swing down with the panel, there are no knobs to be removed or shafts to be disconnected. Similarly, the rear panel is easily lowered.

The best size for the main boards is 7.5×15×2 inches. Details were given in Part 1. The front panel is 8½ inches high. The next standard size, 10½ inches, would allow space for another row of knobs along the top of the panel—and still more special features!

To avoid wire-harness overload, wiring between boards is best done with #24 stranded wire with thin (10-mil) insulation. Irradiated hook-up wire has insulation that will not melt from

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**Table 5**

<table>
<thead>
<tr>
<th>Material list for Cabinet Construction: The components used are intended for constructing a 4×17×17-inch chassis. Two sets of components are used, bolted together to form a cabinet 8×17×17-inches. LMB stock numbers are listed (see Note 23). The sides are 40-mil (1 mil = 0.001 inch) aluminum; the covers are 63-mil; the front panel is 125-mil. The cabinet is perfectly rigid when fully assembled. Because the bottom cover is permanently attached and all work is done from the top, the slight flexiblity with the top cover off causes no trouble.</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 S417 Chassis sides (pair); 4×17 inches</td>
</tr>
<tr>
<td>2 C1717 Top and bottom covers; 17×17 inches</td>
</tr>
<tr>
<td>1 875 Front panel; 8¾×19 inches (Specify black, texture finish)</td>
</tr>
</tbody>
</table>
the heat of a soldering iron. Alpha 7054-irradiated #24 hook-up wire is available as Mouser #602-7054-100-01. Coaxial-cable interconnections were discussed in Part 2, p 5.

There are several advantages to building the front-end sections on separate panels. First, the main transceiver panel—which boasts an output power of 200 mW—is made to generate a minimal amount of heat. This reduces drift problems to a negligible level. The CX7 powdered-iron sliding PTO cores used in this radio have a poor temperature characteristic, making compensation over the entire 1-MHz range impossible. Keeping the main transceiver cabinet cool circumvents this problem. Second, the cabinet needs no vent holes and is completely dust-proof.

Front-Panel Layout

This radio was designed and built with the firm belief that it would never be published. The inside photos show neglect for appearance, putting a whole new dimension on the term “ugly construction.” Eight years of modifications have not improved it!

A front panel is different: The operator will confront the panel for years to come and that is all most visitors to the shack will see. Every builder wants the front panel of his project to look special. Arrangement of controls is a serious matter, especially for contest work or all-night DXing. The goal is to promote convenient and efficient operating and, at the same time, a pleasing appearance.

An old Mac 512 computer with the MacDraw program was used to layout the panel, although any drawing program that produces full-size output could be used. Two panel versions, with and without center-lines, were kept on a floppy; this was easily managed by keeping the lines in an overlay file. A first-draft plain version was printed. Then all the knobs were set on top of the printout and the array studied for balance and general appearance. Changes were made, a new copy printed and the knobs again put in place. This process was repeated every evening for 30...
Results

The following statements concern-ing on-the-air tests are not given in lieu of precise measurements to be presented later, but only in reply to some inquires. During the eight years this home-brew radio has been in use, about 40 contest certificates have been received for events from 160 to 2 meters. Most of these are minor section awards; there is only one top-10 plaque on the wall. However, a contest is a radio to severe test, for a radio, not only for a big-gun, but also for a little-pistol.

DX work also subjects equipment to severe tests. With no Beverage antenna, the radio (with an amplifier) has worked 110 countries on top band (1.8 MHz). With only a single Yagi on the horizon for moon-rise/moon-set (and again an amplifier), seven countries have been worked on moonbance (144 MHz). All the ham frequencies in between have also been used extensively with excellent results.

Summary

This article concludes a series that describes the 40-MHz main panel of the K5AM homebrew transceiver. Although the radio was completed eight years ago and has been in constant use since, modifications and improvements are still in progress. Any suggestions are most welcome! Subsequent articles will describe the three front-end panels for HF, 50 MHz and 144 MHz.

Notes

5. Thanks to Bill Carver, W7AAZ, for help with this discussion of TTL and PIC methods.
6. R. Dean Straw, N6BV, Ed., The ARRL Handbook for Radio Amateurs (Newington: ARRL, 1999, Order #1832). ARRL publications are available from your local ARRL dealer or directly from the ARRL. Mail orders to Pub Sales Dept, ARRL, 225 Main St, Newington, CT 06111-1494. You can call us toll-free at tel 888-277-5289; fax your order to 860-594-0303; or send e-mail to pubsales@arrl.org. Check out the full ARRL publications line at http://www.arrl.org/catalog.

By some historical accident, this station uses negative external control lines for PTT and key lines. Former Signal/One owners will understand. The circuits shown in Figs 5 and 6 are modified and untested circuits that are suggested for use with the positive external lines more commonly used.

One of the most useful items of workbench test equipment is an old CX7, used as a receiver or a transmitter. With its bi-directional 40-MHz jack, it also serves as a front end for testing the basic transceiver or as an IF for testing a front-end panel. Added panel switches permit switching off the PA and the first LO as needed for various tests. All CX7 rear-panel connections are brought out to a test panel (on a shelf above the workbench) for quick connection to any device under test.

The four switches disable the oscillators by applying ~15 V to the lines µMO, µOO, µA, and µB.

These radios can indeed be repaired and used. I have six in perfect working condition, including two converted to 50 MHz for mountaintop testing. However, CX7s from early production runs lack some improvements in construction that are found in later runs, so they are found at flea markets it is best to consider them as “parts radios” (ie, for salvaging valuable components). Anyone who wishes to replace a CX7—an enjoyable and instructive “boat-anchor” project—is better off starting with a later version. The best are those with Florida labels and serial numbers in the 800s and 900s.

Thanks to Paul Kollar, W6CXS, for 25 years of advice on repairing CX7s and especially for detailed instructions for overhaul of the PTO mechanism.

Coil adjusting has been tried in a different context and found feasible. In one of the CX7s converted to cover 50-51 MHz, shifting only two turns gained 150 kHz at the upper end, enough to cover the 2L7 spaced at 0.25 inch. I have six CX7s, some are running. The best are those with Florida labels and serial numbers in the 800s and 900s.

Each regulator requires input and output bypassing. Minimum requirements vary with the type of regulator and even with the manufacturer. To avoid consulting the data books every time a regulator is needed, I keep a stock of inexpensive surplus 2.2-µF tantalum electrolytics (a size sufficient for any type regulator) on hand. Two of these are installed directly at each regulator. Also, a 1-Ω, 1/2-W (or a higher wattage where needed) series resistor is installed at the input and output of each regulator. A DMM set to the millivolt range and connected across the shunt will read out in milliamperes directly. This helps to monitor current drain and locate defects. The resistors also serve as fuse in cases of shorts. This note affords a chance to insert a bit
of voltage-regulator trivia. This concerns the LM317, used to power the counter in this radio. There are several misconceptions involved in use of the LM317 as commonly seen in published schematics. Most often one sees a 240-Ω resistor used to establish the minimum load current and the bias current for the control terminal. This value is seen in the data books and is apparently simply copied without further thought (see Note 24). However, there is nothing special about this particular value, which is not a common 10% value normally stocked by hams. It is never good to specify unusual components when common types will suffice. The data sheet specifies a minimum current for proper operation; with the 1.25-V reference voltage maintained between the output and control terminals and a specified 5-mA minimum load current, this works out to 250 Ω. The next lower 5% value of 240 Ω (available for factory design) is shown in the data books. In a ham workshop, the next lower 10% value of 220 Ω may be used. Of course, the required resistance at the control terminal must be calculated using the bias current obtained and chosen to provide the desired output voltage. Nonetheless, 220 Ω would still be wrong! The second common misinterpretation of the data sheets stems from the fact that the application diagrams are shown using the military or industrial versions of the regulator, the LM117 or LM217. The LM117/LM217 does have a 5-mA minimum load-current specification. This version is seldom seen at ham suppliers, and it would cost too much even if located. A careful reading of the specification sheet shows that the commercial/consumer version, the LM317, has a minimum load current of 10 mA. Thus the resistor should be a maximum of 125 Ω; either 120 Ω or 100 Ω could be used. All this is really trivia, of course; the circuit usually draws more than the required minimum. But an LM317 with a 240-Ω resistor in a schematic for a weekend ham project needn’t send readers rushing out to look for a precise component.

Mouser Electronics, 2401 Hwy 287 N, Mansfield, TX 76063; tel 800-346-6873, fax 817-483-0931; sales@mouser.com; www.mouser.com.
20 Thanks to Harold Johnson, W4ZCB, for information on the construction of the Signal/One PTOs.
21 Hosfelt Electronics, 2700 Sunset Blvd, Steubenville, OH 43952; tel 800-524-6464, fax 800-524-5414; hosfelt@clover.net; http://www.hosfelt.com/
22 Digi-Key Corp, 701 Brooks Ave S, PO Box 677, Thief River Falls, MN 56701-0677; tel 800-344-4539 (800-DIGI-KEY), fax 218-681-3380; http://www.digikey.com/