By Mitchell Lee, KB6FPW, and Dennis Monticelli, AE6C

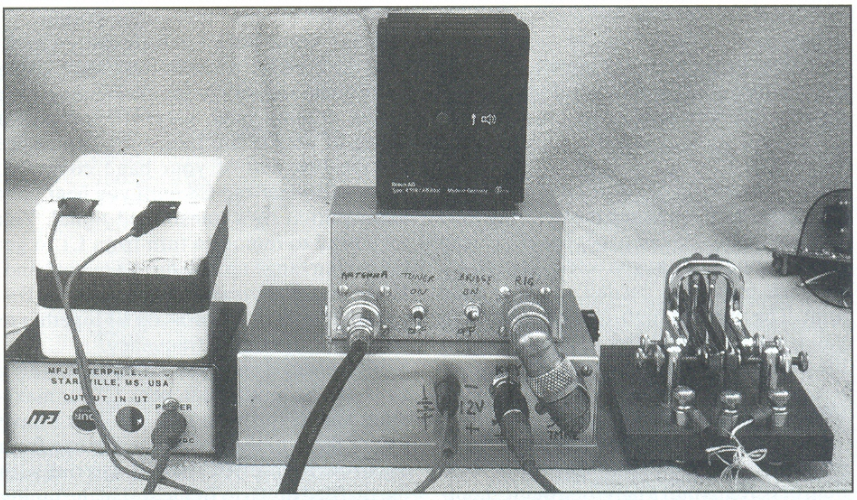
Revisiting the 40-40

Those of you who might have passed over the 40-40 QRP article by Dave Benson, NN1G, in November 1994 *QST*, missed a good thing. This little CW rig is well designed, features a stable, varactor tuned VFO, 1-W 2N3553 output stage, QSK, true sidetone, single conversion and crystal IF filter. If you order the kit, be advised it all fits on a high quality 3×4-inch circuit board. The rig uses the same VFO for both receive and transmit, and is based on three NE602 oscillator/mixers. It is essentially equivalent to the popular NorCal 40, but the spectral purity problems associated with that rig's transmitter have been eliminated. The 40-40 schematic and block diagram are reproduced in **Figs 1 and 2**.

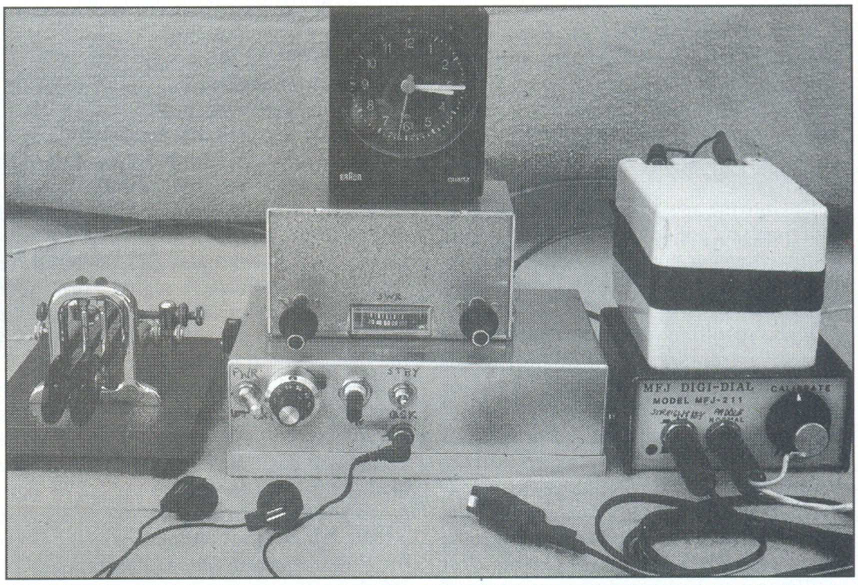
Make no mistake: this rig is not a "one of a kind" circuit hack; it is very cleverly and carefully designed, reproducible and highly tolerant of component substitutions. It lends itself to mass ordering of parts for club or school group projects, and is available in kit form for the reasonable price of only $50 for the solo homebrewer.

KB6FPW and AE6C, experienced homebrewers with engineering backgrounds, each constructed a 40-40, but took their projects one step further by making a number of simple modifications and component changes that greatly enhance the performance of the 40-40. If you built, or are contemplating building a 40-40, you're undoubtedly going to want to add these modifications.

KB6FPW built the 40-40 kit and also rolled his own 20-m version, while AE6C opted for a bare circuit board and scrounged his own parts. Let's eavesdrop as they discuss their approach to their projects.



KB6FPW: The most interesting part of any station setup is the rear. Pictured here is the 40-40 hooked up to the SWR bridge/Transmatch, Curtis keyer, 12-V gelcell, and 40-m dipole. Note the UHF U-turn connecting the rig to the SWR bridge/Transmatch. Topping the stack is a Braun travel clock.



KB6FPW: Reversing the view, we see the user controls for the rig and Transmatch. Earbuds are connected and ready to go, as well as the remote microswitch hand key.

AE6C: Having been a homebrewer and QRPer since my Novice days with a 1-W rock-bound 6AG7 rig, I religiously read every QRP project that passes through *QST*. I learn a little something from each one, but the 40-40 really caught my eye. This diminutive superhet delivered the three S's (sensitivity, selectivity and stability), while being small, low in current consumption and easy to reproduce. I know from experience that doing all this isn't easy. Inasmuch as I felt I could scrounge up just about all the parts locally, I couldn't resist sending for the board this past December. By Christmas I had collected the parts (with liberal substitutions) and got the receiver up and running. And what a nice little receiver it was! Dave Benson, NN1G, did a fine job.

The tuning was smooth and the reception single-signal; a real treat for die-hard direct-conversion fans. Sensitivity was decent and selectivity surprisingly good. Stability was better than I expected from varactor tuning. I played around with it each evening for about a week and it was a delight to operate. Naturally, I couldn't help boasting about the rig during my regular sked with KB6FPW (Mitchell Lee)

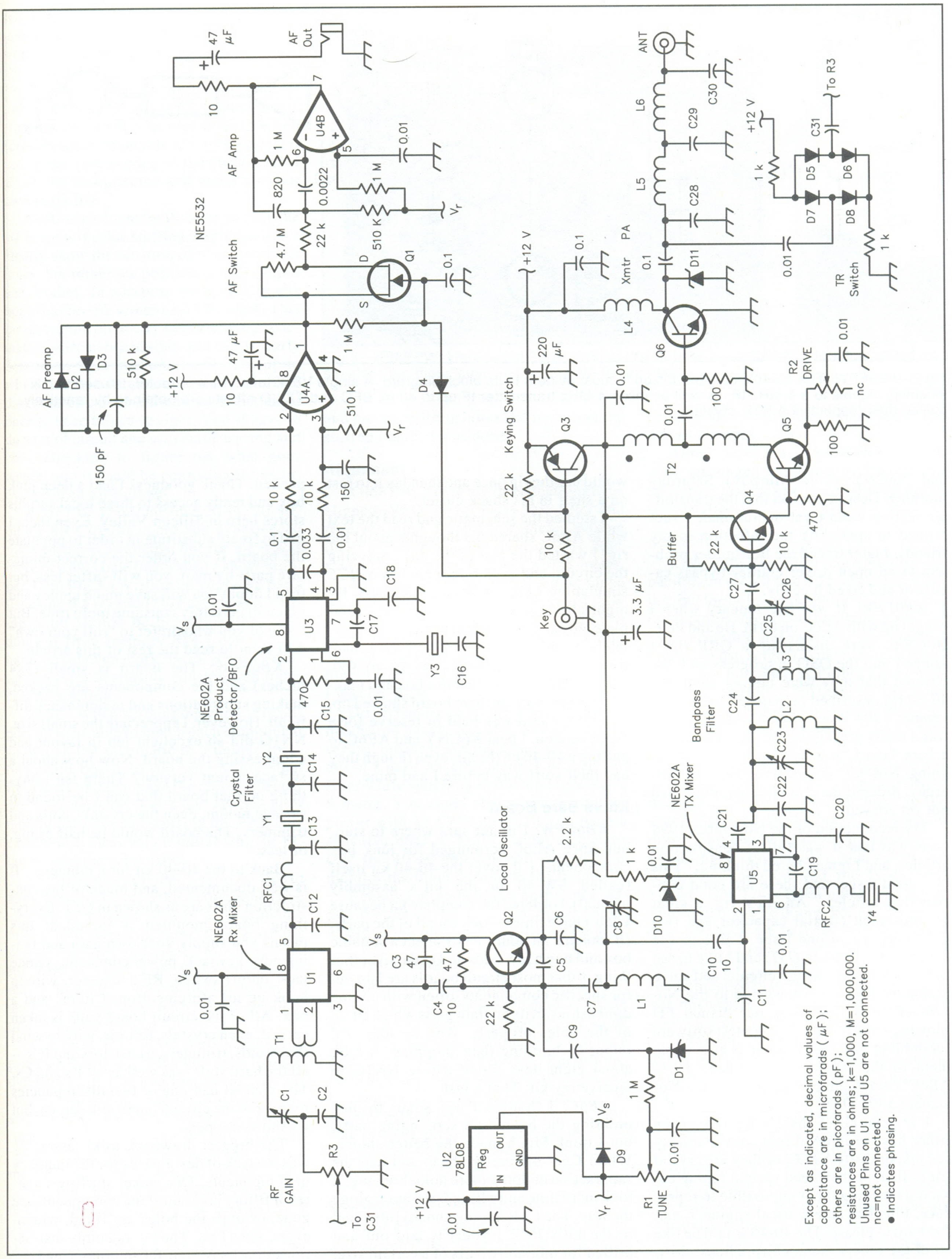


Fig 1—This is the 40-40. You'll want to refer to this schematic as you read along in the text. A 30-m design is discussed in the original article printed in November 1994 *QST*.

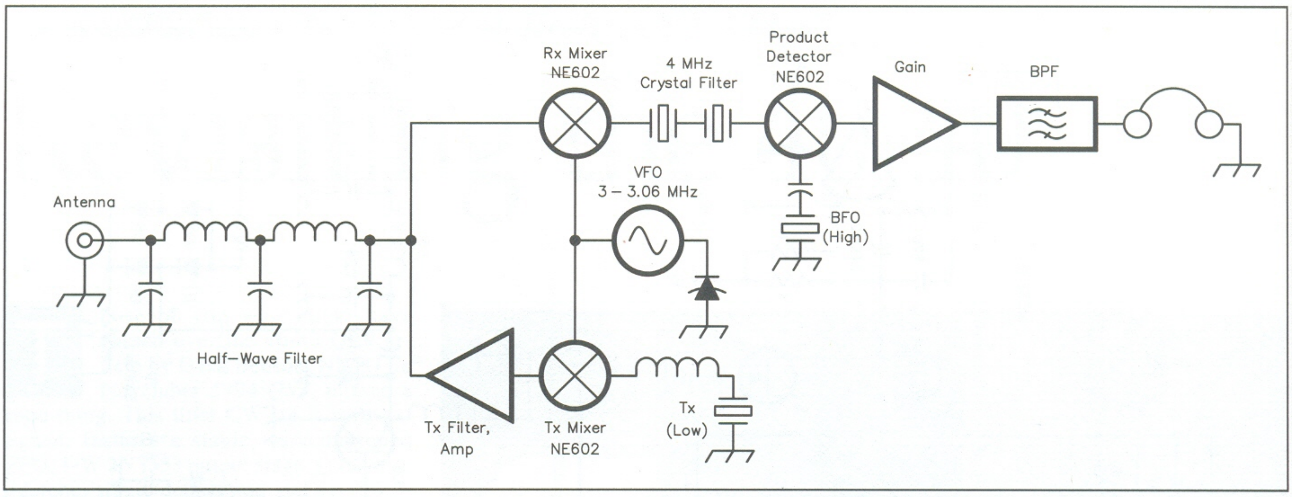


Fig 2—KB6FPW: The 40-40's elegant design is most evident in its block diagram. A single VFO, tuned by a varactor, is used to mix incoming signals to a 4-MHz IF, as well as mix a 4-MHz transmitter IF up to 40 m. BFO and TX LO offsets are obtained by reactively pulling their respective 4-MHz crystals.

and N6CNY (Pete Murphy) Saturday morning. Despite the fact that the transmitter section wasn't yet operational, I succeeded in spreading the infection to my friends. I later traced the transmitter problem to an open driver emitter-bypass capacitor and fixed it easily.

KB6FPW: It was late January when I caught up with AE6C on 80 m. He and Pete, N6CNY, were discussing a QRP rig. I jumped into the QSO in progress and discovered that they were talking about the 40-40 rig described on page 37 of the November 1994 issue of *QST*. AE6C said it was a really great QRP rig. He had ordered a bare board, and now had his receiver going. N6CNY, infected the previous Saturday, ordered the complete kit, but it had not yet arrived.

My recollection of the November 1994 issue was that it was full of construction articles, and I remembered thinking, "This is a good issue, and these are good construction articles." An ATV rig, a great remote-tuned coaxial capacitor and two QRP rigs, all in one issue. I like to see homebrew articles in *QST*, and I like to see how other people design circuits and solve problems. The only downside to the November 1994 issue was our dismal FD showing—the result of our contest software scrambling our 1100+ contacts as it wrote them to the floppy drive. Listening to AE6C's sales pitch, I pulled out the November 1994 *QST*.

I've seen all of these QRP rigs. They either have crummy direct conversion receivers, or drifty VFOs, or they are crystal controlled, or they need special tuning capacitors making them impossible to reproduce. Plus I'm an electrical engineer, and I'm hard to please. The 40-40 would be like all of the others: hum, chirp, clicks, drift, images, coils you couldn't reproduce and RX bandwidth as wide as a barn. AE6C would use the rig once and then lay it to rest on a shelf in his shack closet.

I studied the schematic and read the text while AE6C shared his thoughts about the rig. I wasted the rest of the day analyzing the circuit, and even running a few *SPICE* simulations of the audio and RF filters. By nightfall I was sold. My order for a complete 40-m kit was in the mail two days later. At the same time I ordered a bare board from FAR Circuits; my kit arrived, was assembled, installed in a box and making QSOs before the bare board showed up. The bare board was held in reserve for a 20-m version. I beat N6CNY and AE6C to putting a 40-40 on the air, even though they had their stuff way before I had mine.

Kit vs Bare Board

KB6FPW: I'm not sure where to start, but since AE6C scrounged for junk box components, I'll cover the 40-40 kit itself (called SW-40 in the kit's assembly manual). I ordered the complete kit because I don't have time to look for all of the parts. (It took me an hour just to select a suitable box and buy a few odds and ends.) Another thing is that most circuit boards are laid out for specific components, often with unique dimensions. Kits contain parts which fit all of the holes properly. And besides, I'd rather be building than shopping. It took about eight days round trip to NN1G to receive my kit. That's fast.

AE6C: I thought I was smart by just ordering the board and scrounging parts, but I think Mitch made the better choice. While I got off pretty cheap and had the satisfaction of doing more homebrewing, it took more time and a little frustration along the way. The FAR Circuits board [identical to the kit's PCB layout] is laid out and drilled for miniature parts of a certain size. The 40-40 is small partly because of this choice of parts and also because it is tightly packed. Thank goodness I had a deep junk box and ready access to three local surplus stores here in Silicon Valley. Even then, I had to freely substitute in order to populate the board. If you order the correct miniature parts by mail, you will suffer less, but then I doubt you will save much money and you will certainly consume more time. But those of you who prefer to "roll your own" will want to read the rest of this article.

KB6FPW: The board is small (3×4 inches) and the components are packed, making substitutions and maintenance difficult. However, I appreciate the small size. NN1G did an excellent job in layout and compressing the board. Now how about a surface mount version? There isn't anything on that board that can't be found in surface mount, even the crystals, coils and trimmers. The board would be half as big, or less.

Back to the 40-40 kit for a moment... It is well documented, and much of the construction hints are as shown in *QST*. Everything board mounted is included; this means you supply your own gain and tuning pots, key jack, power connector, phone jack, on/off switch, RF connector, wire to hook up all aforementioned items and a box. All of the circuit board stuff is taken care of, even crystals, toroids, wire to wind the toroids, trimmers, transistors and ICs—all the hard stuff—as well as all Rs and Cs. The manual had one or two discrepancies relative to the circuit-board silk screen, but no show-stoppers.

The biggest drawback to kit assembly was the lack of designators for the majority of components. This makes stuffing a matter of filling holes until the components are gone, or until the holes are filled, whichever comes first. The kit assembly instructions don't say "put R1 in holes 1 and 2," but rather "stuff all of the Rs and Cs into the circuit board." If you aren't good at reading schematics and tracing circuit boards, you may find this kit a bit frustrating, but it's worth it. Find an experienced helper to lend you a hand.

AE6C: The lack of component designators is a major problem for homebrewers stuffing the FAR Circuits board. When scrounging components it will be easiest if you make a photocopy of the circuit, label all of the components and make up your own parts list.

Another problem for those bypassing the 40-40 kit is that the stuffing diagram doesn't clearly show the position of the component holes, but rather the position of the component bodies. In addition, the FAR Circuits board has no silk screen or solder mask. This increases the difficulty in correlating schematic to circuit board since you can't clearly determine what pins and leads hook up to which traces—it takes schematic, stuffing diagram, circuit board and parts list all at once to keep things straight. You'll have to do a lot of circuit and schematic tracing and cross-checking to figure out what goes where, and it could be confusing for an inexperienced kit-builder.

KB6FPW: I built my own 20-m "20-40" on a FAR Circuits board and experienced some of these problems, but for me it was more of a nuisance factor than a show-stopper. (See **Fig 3**.) Writing up your own parts list using the original *QST* article as a starting point should be helpful, rather than doing it from memory like I did. Patient hams could even mark the PCB with a felt-tip pen prior to starting construction to facilitate stuffing.

AE6C: When scrounging parts it is important to be able to match each component shown on the schematic to a unique location on the board, so you can find ones that fit exactly and that have the correct electrical characteristics. Let's just say that after buying parts for and stuffing my FAR Circuits board, I was very familiar with the PC layout and the schematic.

FAR Circuits provides a good service to homebrewers by offering a comprehensive catalog of project boards at reasonable prices. But anything more than a simple project requires experience to be successful. And you don't get many chances to rectify mistakes either as the traces have a tendency to lift, even with careful application of soldering heat.

KB6FPW: Free of the parts-scrounging process, it took me only two nights to build the 40-40 kit. I wound the toroids and installed a few items one night (two hours), and finished construction the next night (three hours?), skipping the part that said "before applying power check the following. . ." That's for sissies. I jammed in 12 V, put it on the air, and immediately contacted NA5N/QRP, in Socorro, New Mexico. I gave his 4-W MFJ rig a 599; he gave my sub-320 mW output a 459 (I thought I was running a watt). I spent a Saturday afternoon picking up a suitable box, various bits and pieces, drilling holes and installing the stuffed board. I was done.

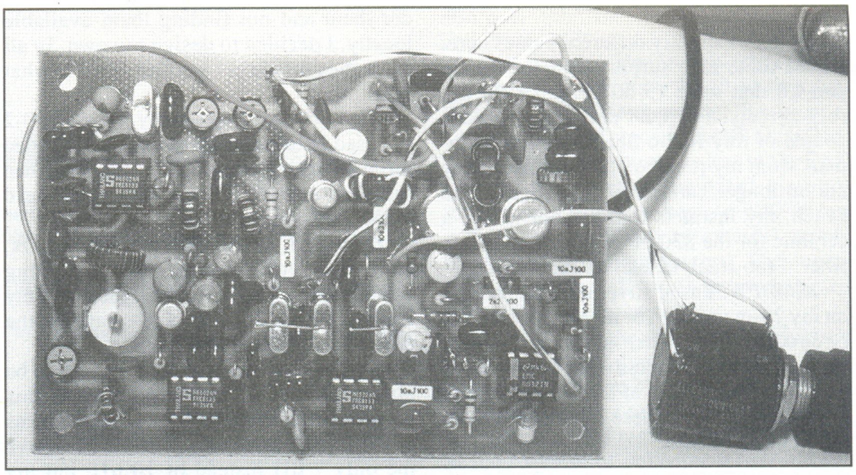


Fig 3—KB6FPW: Here is the 20-m version I built, prior to packaging. Note that toroids smaller than those specified for the 40-40 are used.

Alignment

KB6FPW: There are three sections to be aligned: VFO, driver band-pass filter and receiver input. I had no problems making these adjustments, and used no test gear, aside from a second receiver with S-meter.

As for the VFO, my initial tuning range was from 7020 to 7053 with C8 almost fully meshed. I set this by monitoring 7020 in a second receiver, and keying the 40-40 into a dummy load with the tuning pot set to the lowest frequency. Then I adjusted C8 until I was on 7020.

Driver band-pass filter tuning is peaky—maybe too peaky. But after 85+ QSOs and several business and backpack trips, it still doesn't need an alignment. I peaked the filter while watching my second receiver's S-meter. You could also watch the output power with an SWR meter (if you have a sensitive one), or build a simple detector (see the 40-40 construction manual), or monitor the input current to the final.

Receiver alignment is a no-brainer: adjust for maximum received signal somewhere in the middle of the tuning range.

Hot Transistors:

KB6FPW: When aligning the transmitter, use caution because driver Q5 gets warm. Some copper or brass shim stock could be soldered to the transistor can for a heat sink. Under normal QSO conditions, the temperature rise will be only slight and is nothing to be concerned about. Q6 doesn't get hot when correctly loaded. I did add a small press-on heat-sink to Q6—maybe I'm superstitious; I happened to have one that fit nicely.

Component Substitutions

KB6FPW: Although I built the 40-40 and operated the stock version for a short time without modification, I compiled a list of changes I wanted to make. Some are component substitutions, others are slight design changes.

AE6C: Since I built mine from scratch with scrounged components, I tended to anticipate and make changes during initial construction.

Capacitors:

KB6FPW: The 10-nF ceramic disc capacitors in the kit had 0.25-inch lead spacing, but the holes were spaced 0.2 inch. The instructions suggested breaking away the excess ceramic and narrowing the spacing; I opted to use some 0.2-inch spaced units I had in my junk box. All other kit components fit like a glove. No holes too big; none too small. Very professional job, and very high-quality circuit board complete with solder mask and silk screen.

AE6C: The only problem I had here was with size. Half the time, the cap I wanted to use was either too big for the holes or the space allocated on the board. So I would either find another part or get creative in mounting it. Fortunately, the values are relatively common and the types well known. Don't mix types unless you really know what you're doing. For example, the disc ceramics are best for RF bypass and remember to use the NP0 variety around the VFO. I stuck with Polystyrene where recommended in the VFO. You can use silver mica there if you wish, but the holes aren't set up for that style cap.

KB6FPW: I just couldn't bear to pass audio signals through ceramic capacitors, so I replaced the 10 and 100-nF caps feeding U4A with films, and I did the same for the 820 pF (actually I put in a SM) and 2.2-nF caps in the U4B audio filter. I substituted a few films elsewhere for better bypassing, where it made sense. RF stuff is best bypassed by ceramic. This I learned the hard way. . . see my comments on the transmitter stage.

AE6C: I also sought out the better quality ceramics for the PA harmonic filter. The trimmers gave me some trouble but only because of the space constraint. Don't be afraid to use slightly different values here. I used some nice surplus trimmers at C1 and C8 that were 15-60 pF and 8-26 pF, respectively. For C23 and C26 I used a couple of tiny Radio Shack 5-60 pF trimmers from my junk box that unfortunately are no longer carried by that chain. Like Mitch, my instincts told me not to use a ceramic for the 820 pF in the audio active filter. I too stuck in a silver mica instead.

KB6FPW: I used silver mica capacitors on my 20-m version for the output filter. It is possible to find half-sized silver mica capacitors in the surplus stores which have very thin leads—sort of like a Polystyrene in that regard—and these fit nicely into the 40-40 circuit board.

Main Bypass Capacitor:

KB6FPW: The day after I stuffed the board, I was sitting at my bench at work and spied a slightly used Sanyo OS-Con capacitor. I wasn't very satisfied with the low-quality 220-µF electrolytic bypass cap supplied in the kit, so I put in that OS-Con instead. These are hard to find, but a Panasonic HF or HFQ-series cap would be a better choice than the kit's no-name electrolytic—especially in cold weather.

Inductors:

AE6C: I have a reasonable supply of cores in the junk box, but I sure struck out for this project. Being too impatient to order them and not finding them available locally, I decided to design my own. In all cases they turned out just fine. Here is what I did.

L1, VFO Coil: Fortunately, I had a T50-2 so I used 25 turns for the inductance I needed [original design calls for 27 turns]. You can substitute a mix 6 (yellow), but you will need to use more than a single layer of wire.

L2 and L3, Driver Filter: I had no T37s, and since you have to use something smaller than a T50 here, I designed with my stash of T30-6. 26 turns of #28 gave me the desired inductance of 2.5 µH.

L4, Collector Choke: Just my luck to be almost all out of ferrite going into this project. Instead of a T37-43, I used 47 turns of #28 (single layer) on a T50-10. This gave me only 7 µH instead of 10 µH, but my calculations showed that this would be adequate for the impedance at that node. Anything more on that toroid would risk high frequency self-resonance behavior. Powdered iron was a bit of a force fit here, but it worked out just fine.

L5 and L6, Output Pi Filter: I made use of those T30-6s again by winding 17 turns of #28 on them to make the required 1 µH for the output filters. My calculations showed that the smaller cores were in no danger of saturating under worst case load conditions.

T1, Tuned Receiver Input Transformer: Another case of applying powdered iron where ferrite was called out. However, this was a narrow-band application (the input filter), so I felt good about using a T50-2 here. Fortunately the board could handle the extra room. 48 turns on the primary and 12 turns on the secondary, both #28, did the trick.

KB6FPW: In spite of the Secret Knowledge (see the **sidebar** entitled "Secret Toroid Knowledge Revealed"), winding the toroids is one of the most time-consuming chores. The kit includes not only the cores, but also the wire. The instructions say to scrape away the insulation of the enameled wire. As I was scraping the wire, wishing they had instead supplied Polythermalese or Solderese-insulated wire, I absentmindedly picked up my soldering iron and balled up some solder on the end of the wire. To my amazement and delight, the insulation retracted—it was directly solderable wire after all! This made the job much easier and saved me a lot of time.

The toroids supplied with the 40-40 kit were oversized for the power levels involved, so for the 20-m version, I pulled much smaller units from my junk box, scaling the inductances and number of turns to compensate for frequency and differences in A_L.

Back to the 40-40 kit: Some of the coils and some capacitors end up a little on the floppy side, given the size of the parts relative to the wires holding them down. A small bit of paraffin can be melted and dripped over any loose components to help secure them to the board. Superglue or RTV works

Secret Toroid Knowledge Revealed

KB6FPW: If you work in the electronics industry, and work anywhere near toroids, then you have undoubtedly been "inducted" into the Secret Circle of Toroid Winding Knowledge Keepers. But for the rest of the plebiscite, I will now reveal this secret knowledge, breaking the vows that have for so long bound me to silence.

Winding a toroid can be done two ways: the right way, and the wrong way. With the exception of those in the Secret Circle, everyone winds toroids the wrong way. Winding is accomplished by first passing an appropriate length of wire through the center of the toroid, thereby forming turn 1. Next, one end of the wire is passed through the toroid to form turn 2. This process continues for turns 3, 4, 5 and so on, until the appropriate number of turns have been wound. Unfortunately, the Uninformed Technique causes the wire to kink, and causes much frustration and cramping of the hands.

The Right Way is as follows (refer to **Fig A**):

a) pass the appropriate length of wire through the toroid.

b) bend the wire tightly around the toroid so the ends point in opposite directions, forming the first turn.

c) pass the Secret Tool (a bent piece of heavy-gauge wire or paper clip) through the toroid, and hook the wire.

d) pull the wire back through the toroid.

e) using either the hook or you finger, pull the wire all the way through the toroid, and pull now-complete turn 2 tight.

f) return to step (c) for turn 3.

Using this technique of "backing" the wire through the toroid, rather than passing the end of the wire through the toroid, prevents kinks and frustration. This is the way electronics professionals in the industry hand-wind toroids in the lab.

The process can be sped up by clamping about a third of the toroid in a soft-jaw (wood or plastic) vise, and using one hand to operate the tool and the other to handle the wire. An experienced winder can apply about one turn every two or three seconds using this method.

By the way, the Secret Tool is simply a hook made out of 12, 14, 16 or 18-gauge wire (depending on the size of the toroid and the size of the wire you're pulling), long enough to hold onto, and bent to a radius tight enough to pass through the toroid. Paper clips work, too.—*KB6FPW*

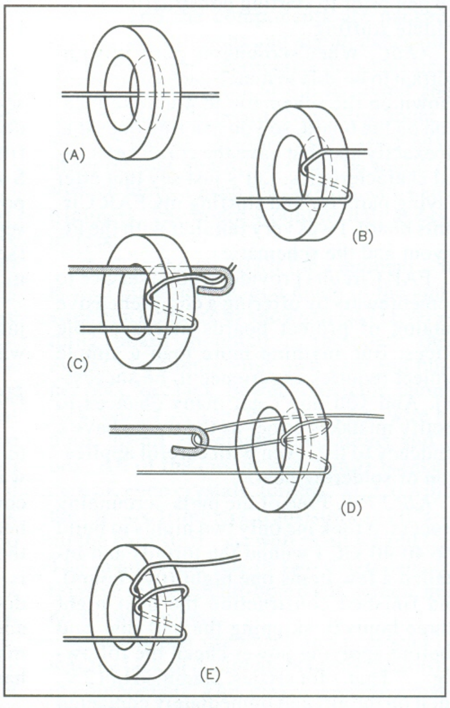


Fig A—KB6FPW: (A) Pass wire through toroid; (B) wrap turns around in opposite directions. (C) pass Secret Tool through toroid and hook wire. (D) Pull Tool and wire back through toroid. (E) Pull wire clear through, and wrap back around toroid.

Table 1

Performance Summary

Receiver	*AE6C*	*KB6FPW*
Tuning Range:	70 kHz	63 kHz
Sensitivity:	0.26 µV	0.31 µV (10 dB (S+N)/N)
Gain:	89.5 dB	89.0 dB (into 80-ohm headphones)
Image Rejection:	53.3 dB	46.1 dB

Note: The image falls within the AM broadcast band (950 kHz in the case of a 4.000 MHz IF and 7.050 kHz receive frequency), so an input filter or trap may be necessary if you live close to broadcasters.

Selectivity	340 Hz	360 Hz (–3 dB points; combined IF plus AF response)
Unwanted Sideband	–48.5 dB	–44 dB
Stability	–360 Hz	–13 Hz (for 30 minutes, following a 10 minute warm-up)
Supply Current	6.5 mA (9.5 mA with 78L08)	6.3 mA
Transmitter		
Power Output	1.2 W	1.0 W
Supply Current	215 mA	260 mA

too, but these methods are a little more permanent. Whatever method you choose, take care to keep the substance out of the IC sockets and well away from variable capacitors.

Crystals:

AE6C: I thought the use of four matched crystals in this design was really clever. Small microprocessor crystals in the HF range are commonplace and readily available surplus. I took my Kenwood Dip Meter (it has a socket for exciting a crystal) and a portable shortwave receiver to the local surplus store. Within 10 minutes I had matched a little pile of 3.932-MHz rocks to within 50 Hz. You can't beat that for 50 cents each.

KB6FPW: The kit included matched crystals, so I had no work to do here. Note that offsets for the BFO and transmitter LO are provided by a capacitor and inductor. In my assembled kit, the BFO offset was centered right down the middle of the IF passband and the transmitter LO offset was frighteningly symmetrical. When I built my 20-m version, I thought I'd get smart and find two matched crystals for the IF, and use high and low crystals for the BFO and transmitter LO. This was a mistake. I had to play with the components of both crystal oscillators to get proper alignment.

Transistors:

AE6C: This design is pretty tolerant except for the PA [treated in the next section]. I used 2N5669 for the audio switch Q1; 2N2222A TO-18 cans for Q2, 4 and 5 (VFO and drivers); and a 2N4403 for the transmit switch Q3.

KB6FPW: Except for the final, I made no substitutions for the transistors in either my 40-40 kit or my 20-m version.

Transmitter Stage Comments and Modifications:

AE6C: Lacking the 2N3553 called out, I first tried an MRF475 left over from my 40-m Cubic Incher project (July 1982 *QST*). That device was designed for CB service so it's rugged and beefy enough for 4 W output. But being a relatively large chip, it turned out that a simple class A driver wasn't enough to excite it. So I then dropped down to the smaller commonplace 2N3866.

The 2N3866 worked out okay, but I kind of got interested in the experimentation game and started plugging in all kinds of transistors (by this time I had gravitated to a socket on the board). It turned out that the best junk-box transistor I found was a TO-18 style device that was originally designed for core memory driving. It had lots of breakdown (translation: tough to destroy with high SWR), and was capable of relatively fast switching. Low saturation (0.5 V) was possible up to 0.5 A and drive needs were modest. This transistor comes under several part numbers such as 2N4014 and 2N3725. But it may be as hard to find today as the core memory it used to drive. Mitch did a more thorough search for a good PA and has a better recommendation.

KB6FPW: I initially had my R2 throttled all the way back, because this resulted in about 100-125 mA transmit current—just right for a pack of eight AA alkaline cells. Later I decided it was worth turning up to 160-170 mA, which I thought put out about 1 W. I was wrong. The figure is closer to 330 mA for 1 W output from a 2N3553 operating on a 12-V supply. This was not portable-friendly.

Transmitting efficiency was poor, but the final transistor wasn't getting particularly warm. I surmised that it took a lot of drive power to reach 1 W.

Like Denny, I too conducted a transistor bake-off. I tried the 2N5108 (315 mA for 900 mW—couldn't reach 1 W with 12.0 V supply); Denny's core memory driver—he sent me a sample—(280 mA for 1 W); a 2N3866 (same basic results as the 2N5108); and finally a 2N3924 (260 mA for 1 W output). Of course not all of the supply current actually reaches the final, but this is still a valid means of comparing final transistors. By the way, the circuit board supplied with the kit survived all of my soldering and de-soldering intact without resorting to a socket.

You'll notice Denny gets more output for less current with his 40-40, as shown in **Table 1**. The difference is in the driver (I ran stock bias; Denny reduced his), QSK (in transmit some power is lost in the QSK switch, and Denny eliminated his altogether), and supply voltage (my 40-40 has a diode in series with an external supply used for the power output test). The important thing is that all transistors were tested under the same conditions.

So what's wrong with the 2N3553 used in the original design? The problem, I discovered, is that the 2N3553 is designed for 28-V service. As a result, the transistor has an unnecessarily high breakdown voltage at the expense of collector resistance, resulting in poor performance on 12-V supplies. I spent some time looking at an old edition of the Motorola *RF Device Databook* before finding the 2N3924 and deciding to give it a try. All of the favorites, such as the 2N3866 and 2N3553, are designed for 24-28 V supplies, where higher collector resistance has only a minor impact on efficiency in Class C service. At 12 V collector resistance is critical.

Finding a 2N3924 posed a problem, however, as Motorola has obsoleted most of the RF transistors in the 1-10 W class, retaining only a couple of dice in eight-pin surface mount packages—unusable at full power. Put another way, Motorola's two-volume *RF Databook* set has been reduced to one volume in the latest edition. The 2N3924 was available in March 1995 through Richardson Electronics from a mystery manufacturer. Although the packaging quality isn't up to Motorola standards, mine won the 40-40 efficiency bake-off as expected. It beat AE6C's core memory driver by a percentage point.

By the way, if you have a personal affection for any of the old favorites such as the 2N5160 (the world's fastest power PNP and complement to the 2N3866 NPN), MRF475, MRF476, MRF479, MRF237, 2N5108, 2N5179, 2N3866, 2N3553 or any RF transistor sold in a TO-5/18/39/72/99 or other metal can package, or if you have any projects or equipment containing these devices, you'd better buy now, because they are as obsolete as the 807. Purchasing activity in March 1995 was brisk on these devices; I called perhaps eight major distributors before locating anyone who could quote 2N3866s, 2N3553s and 2N3924s. Unfortunately, I was too late for 2N5160 PNPs. Boy, there are going to be a lot of function generator owners out there with scrap to sell if they blow their output stages!

One last thing I did was add a back-biased 1N4148 across the base-emitter junction of my final transistor (it fit nicely on the copper side of the board). This precludes exceeding the emitter-base breakdown rating of 3 V under conditions of high drive. It makes less than a 1 percentage point dent in

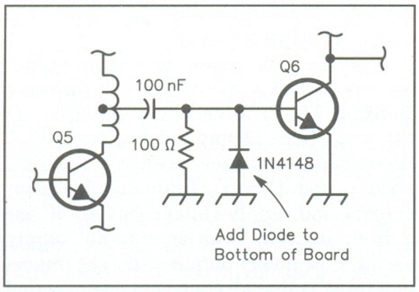


Fig 4—KB6FPW: A protection diode isn't a bad idea for the final, especially for those transistors with 3 V_{ebo} maximums.

the transmitter's efficiency. See **Fig 4**.

As an aside, when I adjusted my output power, I noticed a slight hysteretic effect in the control pot at the highest output levels. I wasn't sure what caused it, but I eventually traced it to poor bypassing on V+, in and around Q6. I had substituted a Mylar unit for the input bypass cap on the voltage regulator. That's good for the regulator but bad for the final. (Here's an example of where component designators would have saved me some time, because I would have paid more attention to the physical location of the capacitor, instead of just trying to find its location.) I added a 10-nF disc ceramic under the electrolytic power supply bypass capacitor, eliminating this effect.

QSK:

KB6FPW: The first time I keyed the rig (using a Super CMOS Keyer II) I thought, "Hey, this isn't QSK; I've got an HW-7 that sounds like this." The 1-MΩ/100-nF combination on Q1 slows receiver recovery to "semi-QSK." By wetting a finger I was able to selectively "recover" Q1 at a faster rate, discovering a happy medium where I got QSK, without too much pop. Later I changed to 2.2-M and 10-nF film. With the RF gain at zero, the pops sound a little annoying. However, real signals going through the receiver mask the pops and the QSK sounds great.

AE6C: I eliminated the QSK switching to reduce current consumption, and instead added a manual SEND/RECEIVE switch (more on this later). Maybe we ought to talk about quiescent current first, since we both added a number of mods to reduce it.

Q Current:

KB6FPW: A big defect in the original design is the receiver's copious quiescent current of 22 mA. I measured this current in the receive mode with no input signals before making any modifications; my supply was 12.0 V at the circuit board. 5 to 8 mA of the 22 are wasted away warming the NE5532 (a JRC device was supplied as a substitution in the kit).

AE6C: You don't have to use the current-hungry op amp in the kit. The dual pinout is an industry standard and many newer products will give you equivalent or better

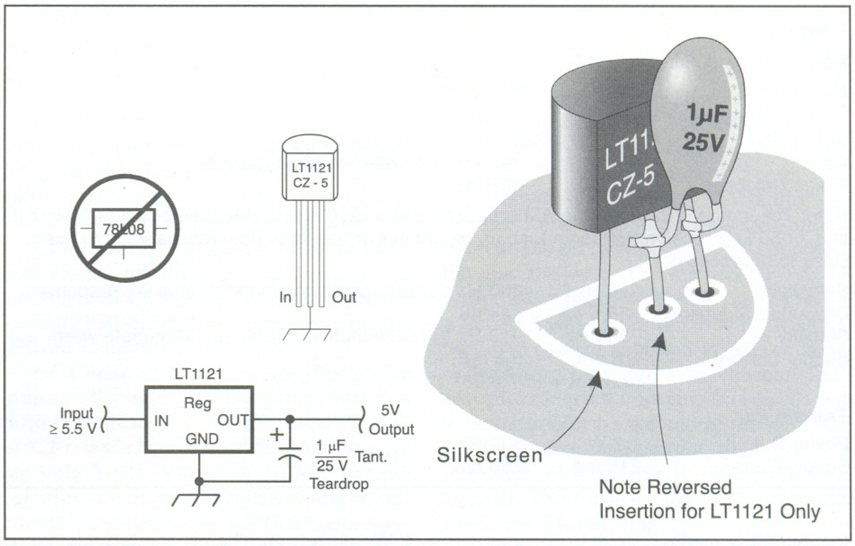


Fig 5—KB6FPW: Save and extend battery life two ways; with reduced operating current and lower dropout. The LT1121, if used, must be inserted opposite to the keyed package outline of the silkscreen. Note the difference in pinouts. Also, a 1-µF tantalum teardrop should be added to the regulator, either on the bottom of the board or as I did, directly to the leads.

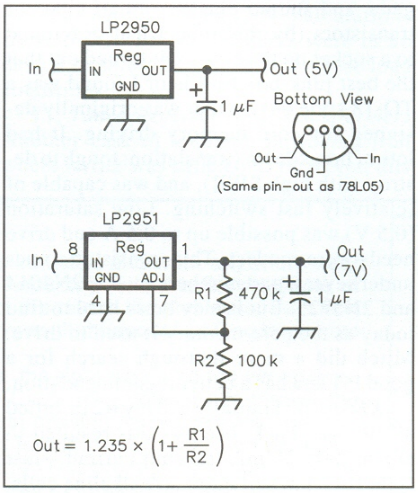


Fig 6—AE6C: A couple of ways to improve on the battery-unfriendly 78L08 regulator. The LP2950 is virtually a drop fit. The DIP style LP2951 lets you choose your optimum operating voltage; I recommend 7 V.

performance for far less current. I chose an LMC662 (Digi-Key #LMC662CN-ND; price $2.28) which is a CMOS part that can literally drive rail-to-rail at the output. Its CMOS inputs do not generate current noise that manifests as voltage noise across the large input resistors. Supply current consumption is only 750 microamperes vs many milliamperes for the older bipolar NE5532. Do not use just any CMOS op amp here as most have feeble output stages that are not able to drive headphones.

KB6FPW: AE6C identified the op amp as a likely candidate for replacement (the kit comes with sockets, making substitution and A/B comparisons easy). Although I had a junk box device that worked well, Denny sent me a '662 and since it beat mine by 50 µA, I condescended to use it.

AE6C: The voltage regulator in the design was evidently chosen because of its availability and small size, but there are two major drawbacks to the 78L08. First and foremost, it will begin to dropout when the battery voltage sags to only 10 V.

KB6FPW: When that happens, the VFO is going to pull badly. The second major drawback is the 78L08's battery-hostile quiescent current. You'll hear a sucking sound when you apply power.

AE6C: Better, newer devices of the "low dropout" variety are available. You can use an LP2950 (Digi-Key #LP2950CZ-5.0-ND; price $2.07) for 5 V output or the adjustable LP2951 (Digi-Key #LP2951CN-ND; price $2.52) for 8 V or anything in-between.

KB6FPW: My junk box produced an LT1121CZ-5 (5 V micropower regulator), and I substituted this in place of the 78L08. As a bonus it offers protection for downstream circuits against accidental reverse battery. Note that the LT1121 pinout is opposite that of the 78L08; I had to mount it backward relative to the 40-40 silk screen. See **Fig 5**. Don't worry, if you insert it incorrectly and apply power, no harm is done to the regulator or the downstream circuits. Just pull it out and put it in the right way.

AE6C: Equivalent parts and alternate sources are available from several manufacturers. The TO-92 style LP2950 is the best board fit, but you are pretty much stuck with 5 V. A little more voltage is better because the receive mixer will give an extra dB of large signal handling when at the higher voltage. The 40-40 needs every dB it can get in this regard. **Fig 6** shows the circuit options.

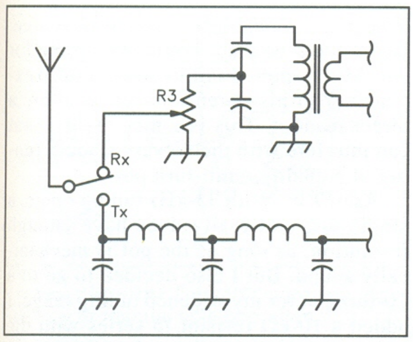


Fig 7—AE6C: A low-tech alternative to the diode gated QSK scheme. This conventional TX/RX switch consumes zero current and provides maximum sensitivity.

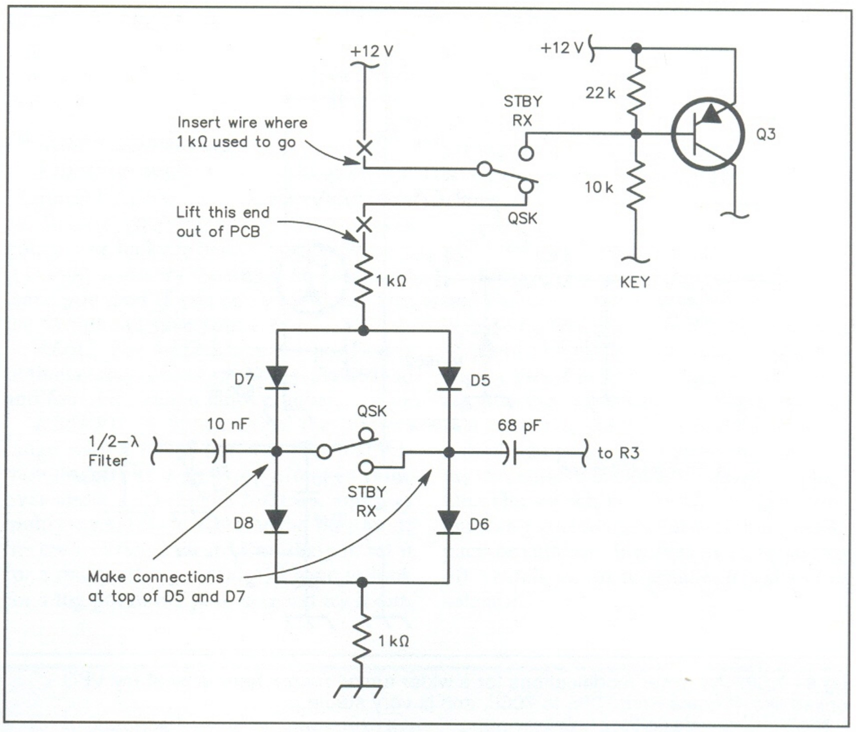


Fig 8—KB6FPW: Save 6 mA with a DPDT toggle switch. Keying the rig in the standby mode will cause no harm since the TX/RX switch is disabled.

KB6FPW: Both the LT1121 and LP2950/1 need 1 µF output capacitors for stability. I used a dipped tantalum—a very tiny unit that fit right on the regulator's leads (Fig 5). Although changing the regulator has a ripple effect on the VFO, the circuit will still function perfectly well with a 5 V regulator. We'll get into the VFO later. This regulator also supplies the receiver mixers through D9. According to NN1G, D9 serves to keep the mixer supply voltage below 8 V, which is uncomfortably high for the NE602. With a 5-V regulator, there is no need for D9's 700-mV drop, so I shorted it.

Hey, we can't forget to talk about the QSK feature. A full 6 mA is wasted away in the receiver's QSK switching. This is more than ¼ of the original power budget.

AE6C: Diode gating burns current if large signal handling is to be preserved. A low cost rig cannot afford to use costly PIN diodes. QSK is a deluxe feature to have on a relatively simple rig, but the implementation on the 40-40 does have another drawback of which you should be aware. The receive sensitivity is adversely affected and this IF-stageless design does not have gain to burn. So, I opted for a simple TX/RX changeover switch (**Fig 7**), eliminating the diode switching altogether.

KB6FPW: No wonder it took you so long to come back the other night during our QSO.

AE6C: You're not so quick with a micro-switch style key yourself. It is not elegant, but it works well. Mitch has a good idea to implement current savings when not in "QSO Mode."

KB6FPW: I fixed this by using the circuit shown in **Fig 8**. All it takes is a DPDT switch. In the QSK position everything operates as originally intended, but in the STANDBY RX mode the TX/RX switch is locked in receive, and I remove bias from the diode bridge, instead passing signals through directly with the second switch section. 5.5-6 mA saved. If you key the rig in STANDBY RX no harm is done and you won't hear any sidetone.

Incidentally, sensitivity suffers about 1 dB in the QSK position.

AE6C: My total receiver current is 6.5 mA—outstanding for a rig of this quality.

KB6FPW: My receive current in STANDBY RX is now 6.3 mA—very respectable.

The rig will run continuously for more than two weeks on a load of AA alkalines, perfect for portable camping/backpacking operation. D cells would last three months or more.

VFO:

KB6FPW: There were several improvements to be made in the VFO. My initial tuning range, before modification, was 33 kHz, not 40 kHz as claimed in the original article. Changing the regulator took the varactor potentiometer reference voltage from 8 V down to 5 V, further reducing my tuning range to about 22.5 kHz. I wasn't happy with 33 kHz to start with, so to increase the tuning range, I dropped C6 to 1.8-nF Polystyrene, increased C9 to 160 pF SM and reduced C11 to 100 pF SM. I added a 12 pF SM across C8, the VFO trimmer, and now my rig tunes from 7005 to 7068, a range of about 63 kHz. Dropping the value of C11 also restored my injection level to U5. See **Fig 9** for a summary of the changes.

AE6C: I had Motorola HEP2503 and MV209 varactor diodes on hand, so I thought I might give those a try. Although they proved to be good stable tuning devices, they lacked the capacitance swing necessary to give the frequency range I wanted. Even when I took C9 all the way up to 300 pF, I maxed out at 32 kHz of tuning range. Further, the tuning was very non-linear. It wasn't until Mitch rescued me with a genuine MV1662 that I got the 70-kHz range I was seeking. The non-linearity was less as well. Stick with the recommended unit.

KB6FPW: I steered clear of the bottom of the band for fear of operating outside the band edge owing to VFO drift. In three months of operating the VFO has shown no long-term drift; my only drift is less than ±300 Hz temperature drift. Now that I'm more confident in the oscillator, I may eventually go back and adjust for 7001 to 7064.

AE6C: Maybe that will get your country total up. You missed out on Kermadec.

KB6FPW: I didn't take the tuning range as far as Denny; operation above 7065 is mostly RTTY modes anyway and there is nothing to be gained.

Nevertheless, if you want to also cover the Novice band, the VFO should swing 150 kHz by juggling the frequency-determining capacitors, and possibly reducing the VFO coil inductance. I have no idea what the drift performance will be like afterward. The receiver input and driver band-pass filters are quite narrow and can be expected to show some roll-off over a 150-kHz bandwidth.

VFO Potentiometer:

AE6C: The best decision I ever made on this project was the use of a nice, smooth 10-turn pot for tuning. Wow, what a difference! Mine was a 100k Helipot. These babies can set you back $10 to $20 (for example, Clarostat Series 73JB from Digi-Key, #73JB104-ND; see also Circuit Specialists, DC Electronics or Hosfeldt Elec-

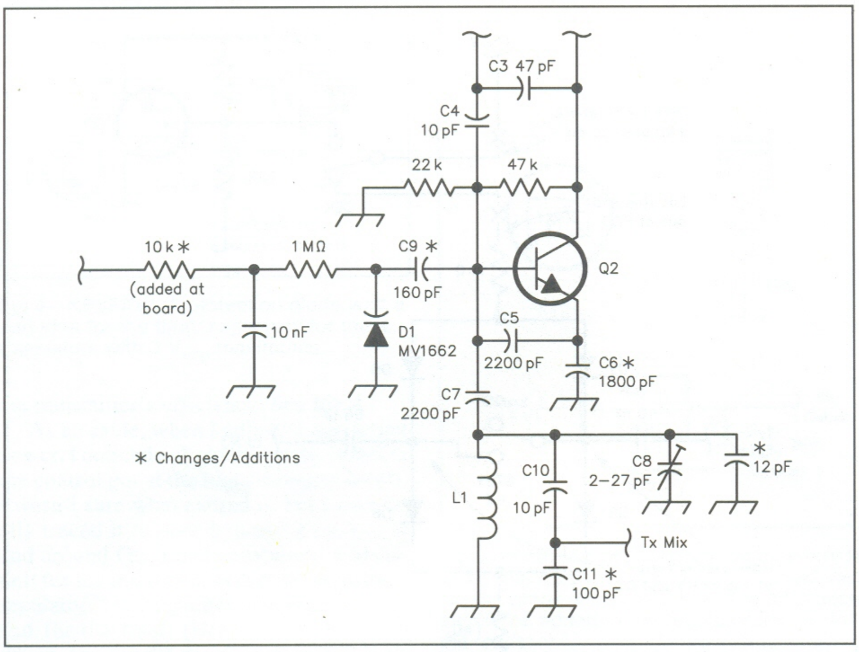


Fig 9—KB6FPW: After modifications for a wider tuning range, here is what my VFO looked like. It tunes from 7005 to 7068, and is very stable.

tronics) if you can't find a surplus source, but you will be glad should you spring for one. Mitch applied a turns counter (also expensive) to his potentiometer to allow a direct readout. This is a nice feature, but can interfere with the velvety smooth tuning of a quality multi-turn pot.

KB6FPW: With 33-kHz tuning range, a single-turn pot really does have enough resolution, as long as the pot is mechanically sound. But I also decided to go to a 10-turn pot for my widened tuning range. I added a 10-kΩ resistor in series with the wiper to clean up pot noise. Initially I made a simple calibration chart showing the operating frequency for each complete rotation of the pot. This works well, giving about 4 kHz per revolution at the bottom of the tuning range and closer to 8 kHz per revolution at the top end.

Ultimately I added a turns-counting dial and made a calibration chart in 1-kHz steps to keep track of my frequency. The addition of the dial didn't impede the feel of my 10-turn pot very much, and it has a mechanical brake to lock the tuning knob—a great feature for use in a sleeping bag. (See the **sidebar** entitled "Linearizing the 40-40 Tuning Dial.")

Linearizing the 40-40 Tuning Dial

The first thing I did when I got my 40-40 on the air was compile a calibration chart to help me keep track of my operating frequency. Connected to a Dentron dummy load and Heathkit IM-4100 frequency counter, I tuned the 40-40 from one end to the other, stopping at 1-kHz intervals and recording the reading on my turns-counting dial.

Unfortunately, the tuning was not linear. At the bottom end of the band the tuning rate was about 23 counts per kHz, and at the top end of my tuning range the rate was about 11 counts per kHz. The problem is complex, involving not only the non-linear characteristic of the tuning diode, but also the effect of the oscillator's various series and parallel capacitors that make up the frequency determining components.

Another problem was that at mid-scale, my turns counting dial (1002 counts full-scale) had an "integral linearity error" (INL) of approximately 125 counts. In other words, when tuned half-way between the top and bottom of the rig's tuning range, the dial reads 626, not 501. Most operators wouldn't care, but my curiosity led me to stumble upon an amazingly simple and current-conscious solution to the problem.

After much algebra and computer simulation, I found that by adding a resistor from the potentiometer's wiper to the reference regulator's output (see **Fig B**), I could reduce the INL to about ±35 counts—an improvement of about 4×. The error would peak at approximately 1/4 and 3/4 full scale, for an error of 2 kHz by dead reckoning. Error at

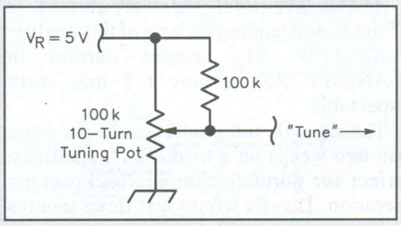


Fig B—KB6FPW: By simply adding a resistor, the tuning linearity can be improved by a factor of 4.

mid-scale is essentially zero. In my case the potentiometer is 100k ohms, so I would need a 100-kΩ resistor. At the bottom end of the tuning range this resistor adds 50-µA current consumption to the circuit.

Upon further investigation I discovered that a current source of 20.5 µA, injected into the wiper of the pot, would reduce the INL to less than 25 counts—more complicated, but a definite improvement over the resistor. **Fig C** shows a possible implementation using an LM334 constant current source. Temperature compensation is introduced with a 1N4148 diode. Note that this solution adds 20.5 µA to the receiver's current budget, regardless of tuning.

I added this modification to my 40-40 and improved my INL to about 27 counts (less than 2-kHz error) at mid-scale, in close agreement with predicted performance. There are a number of variables, including the accuracy of the current source (I did no trimming), the accuracy of the potentiometer (100 kΩ

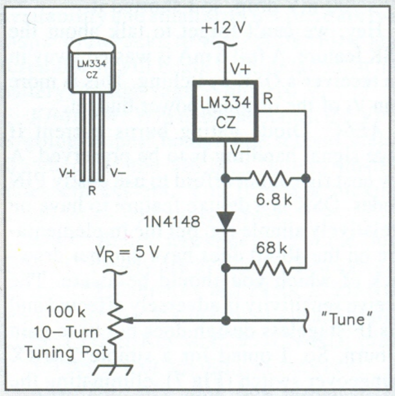


Fig C—KB6FPW: Taking it one step further, this temperature-compensated constant current source will improve tuning linearity by a factor of 5. With this in your 40-40, you have full on-the-air bragging rights.

±5%), and the linearity of the potentiometer (3%). My potentiometer must be a good one, because my current source ended up just a bit on the low side, and this would account for the INL being slightly greater than 25 counts. Note that my tuning rate is about 66 Hz per count.

These modifications are strictly fringe optional, but if you're a perfectionist, you'll no doubt be eager to implement at least the resistor fix. Don't forget to make a new calibration chart. And if you add the 20.5-µA current source, you'll definitely have on-the-air 40-40 bragging rights.
—KB6FPW

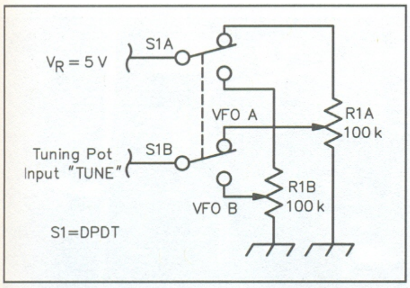


Fig 10—KB6FPW: Dual VFOs for pseudo-memory or manual split operation.

You can have dual VFOs by simply adding a pot and a switch (see **Fig 10**). This is a nice feature. Since most battery-conscious QRP operation involves tail-ending QSOs, you can leave one VFO parked on a strong QSO, while scanning up and down the band with the other. Another idea is to use a 10-turn pot for high-resolution tuning on one VFO, while using normal, single-turn pot for quick scanning on the other. I was going to add this mod, but ran out of room in my 2×4×6 box. Small size was ultimately more important. See the **sidebar** entitled "Further Tuning Tricks for the 40-40" for more VFO tuning ideas.

RF Gain Potentiometer:

KB6FPW: While I was building the kit I figured I'd leave the volume control out. No IF amp, QRP rig, crystal filter—I was going to be lucky to hear anything. Wrong. It is loud, and very sensitive. S6 noise will leave you deaf if you run wide open. Use the 5k pot and save your ears.

AE6C: The 5-kΩ attenuator pot, R3, is of linear taper. I used an audio taper instead and found the range more gradual.

KB6FPW: I didn't think the control range with a linear pot was that bad, although there is a shelving effect in mine over about a 90-degree rotation, and it is highly compressed right at the bottom of the control range where I'm likely to set it for a really strong signal. I'll have to look for a log pot in my junk box and try it out.

As far as sensitivity, Denny already touched on this in his opening comments; I've heard KP4, Cuba, Italy, Korea, Russia, Philippines, Australia, KH6; wish they could hear my 1 W! I was able to work JH1EHO with 1 W output, through about 50 feet of RG-58 and another 65 feet of RG-213, into a Butternut HF-9V. I was elated.

Reverse Battery:

KB6FPW: The kit instructions say U2 and Q6 will be toast. Well, my LT1121 is reverse battery proof, but the best solution is to add a blocking diode in series with the supply (see **Fig 11A**). I added this on my rig, plus the switch shown in **Fig 11B**. Note that I don't waste the internal batteries on a diode drop. If I plug more than 50% of my AA cells in backward, I deserve to lose Q6. The switch is a locking toggle type, and can't accidentally turn on in my backpack or suitcase. It serves as either an on/off switch, or an internal/external power selector.

Further Tuning Tricks for the 40-40

Dual VFOs (see text) is only one possibility for 40-40 tuning options. Another enhancement that may be of interest to many operators is a crystal switch. Well, not a real crystal switch, but one such as shown in **Fig D**. Crystals are replaced by 10-turn Trimpots, picked off by a selector switch. This switch enables the operator to choose among any of several preset frequencies, or one or more conventional tuning knobs. This way popular frequencies such as 7040, or net frequencies can be "programmed" into the rig, and selected instantly without resorting to a frequency chart or look-up table. This option requires no modification of the basic 40-40 circuit board.

Some operators may miss the availability of big-rig features such as RIT, or separate VFOs for transmit and receive. While the fixed-tuned option requires no modification, you'll want to reduce the size of the varactor control voltage bypass cap for this one, to about 1 nF.

Two potentiometers, serving as transmitter and receiver VFOs, are selected by an analog switch. The smaller 1-nF capacitor is necessary to allow the frequency to settle before the transmitter is up and running, thereby eliminating chirp. A selector switch allows "reverse" operation or selection of either VFO A or B. While this example uses three front panel holes (one switch, two pots), a clever operator could reduce the front panel space used to two holes by using a dual pot with concentric shafts.

The entire circuit can be assembled as a module at the back of the tuning pots and grafted into the 40-40 via three wires (V_r, Key and V_{tune}), plus ground. I didn't use this circuit in my 40-40 because I wanted minimum size and simple controls, but I have added it to my 20-m "20-40," where size isn't important and split operation and QRP DX are a more likely combination than on 40 m.—*KB6FPW*

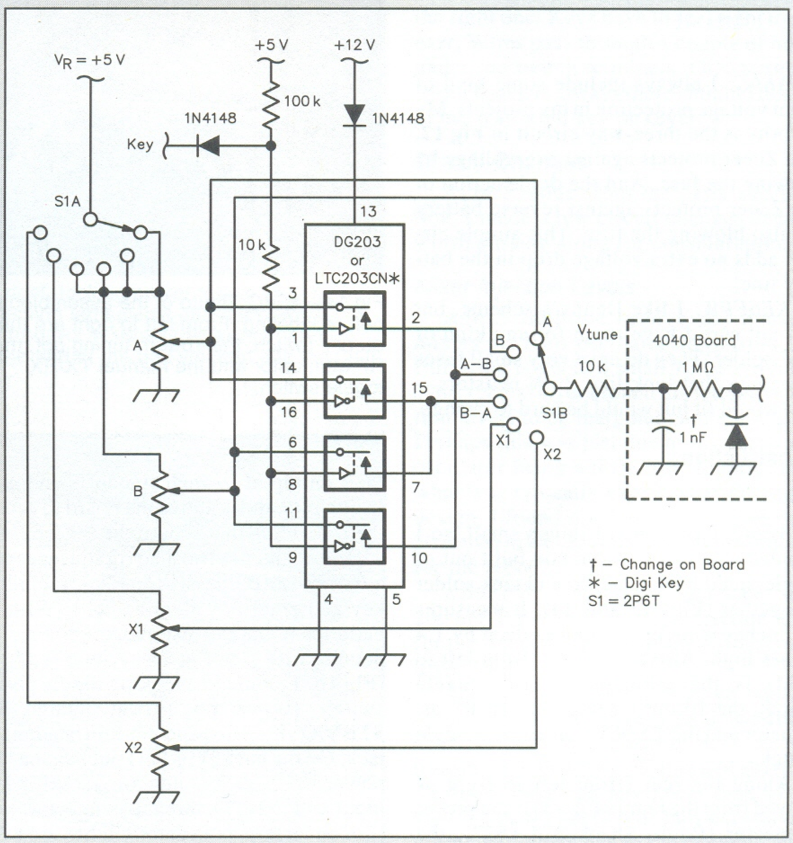


Fig D—KB6FPW: Deluxe frequency control with two VFOs, reversible split operation, and two crystal positions. X1 and X2 are 10-turn Trimpots.

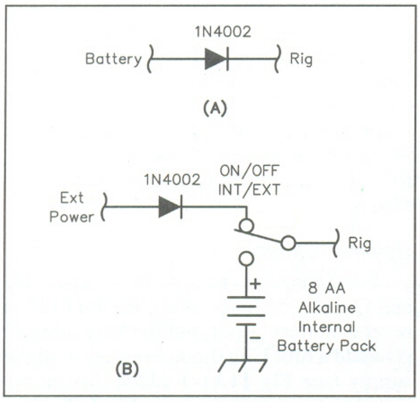


Fig 11—KB6FPW: (A) Simple reverse battery fix to protect final. (B) This is what I ended up with, but protecting against reversed external supply connections only.

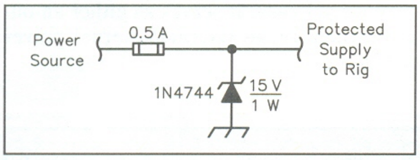


Fig 12—AE6C: A simple three-way input voltage protector. The fuse blows if either (1) the polarity is reversed, (2) the voltage is above 15 V or (3) the rig draws excessive current.

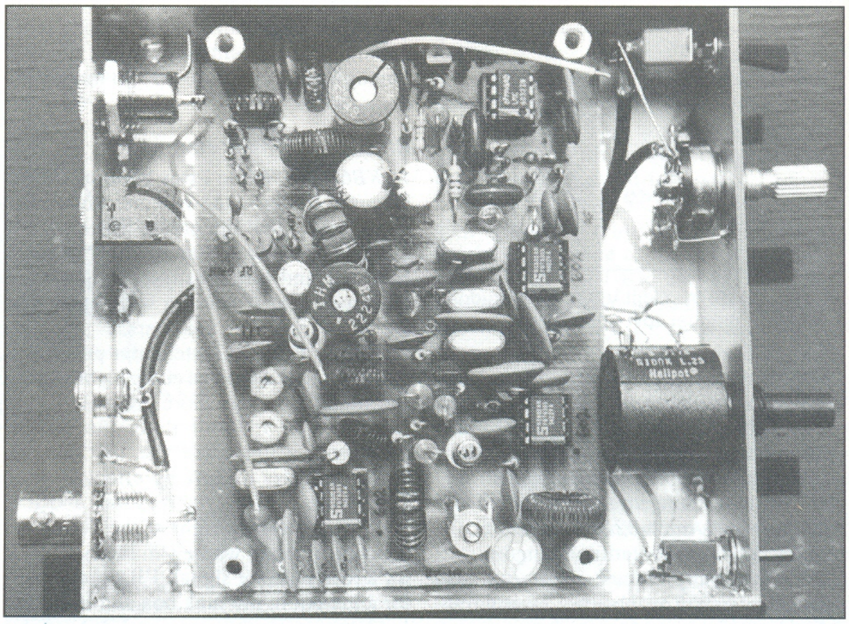


Fig 13—AE6C: Photo of interior PCB style cabinet during assembly. Small heat sinks are evident on Q5 and Q6 as is the 10-turn tuning pot. The rear panel houses, from left to right, connectors for ant, key, phones and power.

AE6C: I always include some kind of input voltage protection in my projects. My favorite is the three-way circuit in **Fig 12**. The Zener protects against overvoltage by blowing the fuse. And the diode action of the Zener protects against reverse battery by also blowing the fuse. This simple circuit adds no extra voltage drop in the battery line.

KB6FPW: I like Denny's scheme, but I'm not sure I have room for any kind of fuse holder. They do have very small fuses nowadays that look like $^1/_4$-W resistors—that would fit but would be hard to change.

Construction

Box:

AE6C: I am fond of things small, so I decided to craft a custom box built out of single-sided PCB material and tack solder it together (**Figs 13 and 14**). It measures 4.2 inches wide by 4.5 inches deep by 1.4 inches high. Along the front (from left to right) is the miniature ON/OFF toggle switch, the 10-turn tuning pot, the RF attenuator and the TX/RX changeover toggle switch.

Along the rear (from left to right as viewed from the rear in Fig 13) is the power connector (Radio Shack 274-1577), the chassis-isolated headphone jack (Radio Shack 274-250), the 3.5-mm key jack and the BNC antenna connector. I stood the

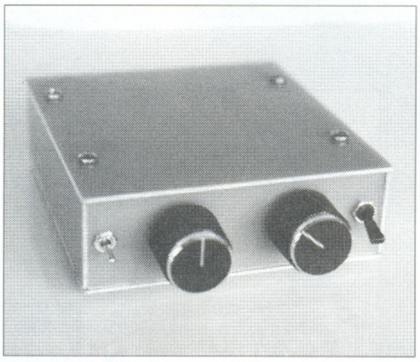


Fig 14—AE6C: Photo of the assembled rig before labeling. From left to right are the ON/OFF switch, the 10-turn tuning pot, the RF attenuator and the manual TX/RX toggle switch.

PCB on top of $^1/_4$-inch standoffs and used $^5/_8$-inch standoffs above the board to accept the 6-32 bolts that secure the top lid.

KB6FPW: My finished rig squeezes into a 6×4×2 LMB chassis (#642C), including key and eight AA alkaline cells. With no batteries it weighs just under a pound, 1.5 pounds with (see **Fig 15**). Along the front (**Fig 16**) I mounted a locking toggle power switch, 10-turn pot, RF attenuator, RX STBY/QSK switch and 3.5-mm headphone jack. On the back (**Fig 17**) I put bananas for power, $^1/_4$-inch 2-conductor jack for key input and SO-239 antenna connector.

Connectors, pots and switches are a big space and weight factor in a small QRP rig. There is a temptation to use tiny little connectors on QRP rigs so that the finished product is impressively small. Unfortunately, small connectors, pots and switches are usually frail, flimsy and prone to failure at inconvenient times. I want something sturdy that won't break in the field.

I learned my lesson long ago not to compromise the hard work that goes into a homebrew project with inferior controls and connectors. Take my advice: use quality heavy-duty connectors, pots and switches with solid, non-metric hardware (a sure sign of low quality consumer-grade components). You can determine the quality of the inside by checking the finish on the outside. Precision machined and finished bushings and hardware are indicative of quality product, as well as high cost.

Speaking of cost, the prices of high quality potentiometers have gone up by a factor of 6 over the past 5 years (wish I could say that about my paycheck!). The cost of decent connectors and controls can double the price of a simple QRP project, but it's worth it.

I broke my rule and used a small, plastic 3.5-mm stereo headphone jack. Big mistake. Yes, now I can scratch a $^1/_4$-inch to 3.5-mm stereo adaptor from my checklist (see **sidebar** entitled "40-40 Accessories"), but I can also scratch using my 40-40 in the middle of a skiing trip if the 3.5-mm jack fails. It is a rather meager, minimum-geometry affair, guaranteed to be the first to fail (contacts are already getting flaky). My only consolation is that it will be easy to replace.

AE6C: One definite advantage of big connectors is that adapting a small plug to a large jack is easier than the other way around. Try converting a 3.5-mm head-

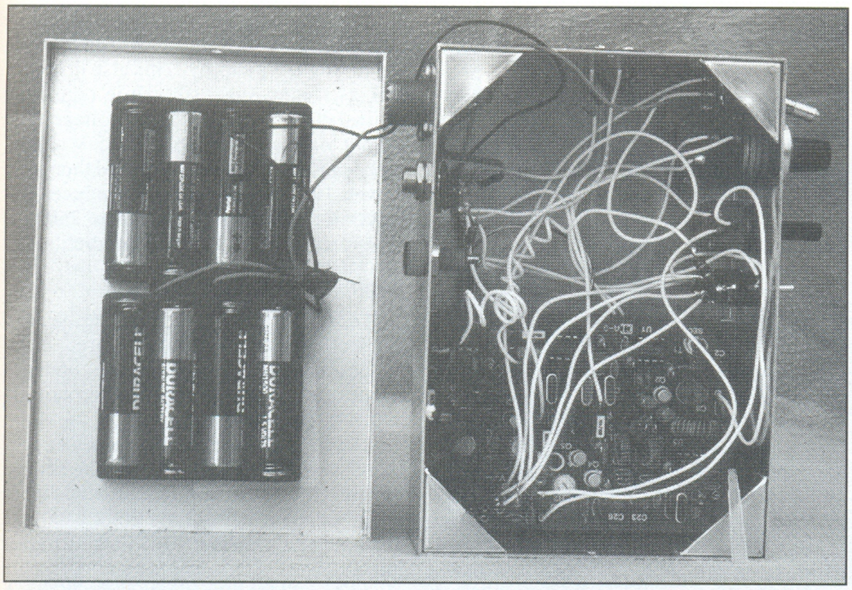


Fig 15—KP6FPW: Opened like a clamshell, here is the inside of my 40-40. Eight AA alkaline cells line the lid (left), and the 40-40 circuit board and controls and connectors are attached to the body of the chassis. The white, curlicue wire connecting the audio output to the 3.5-mm headphone jack shows up quite clearly on airport X-ray machines.

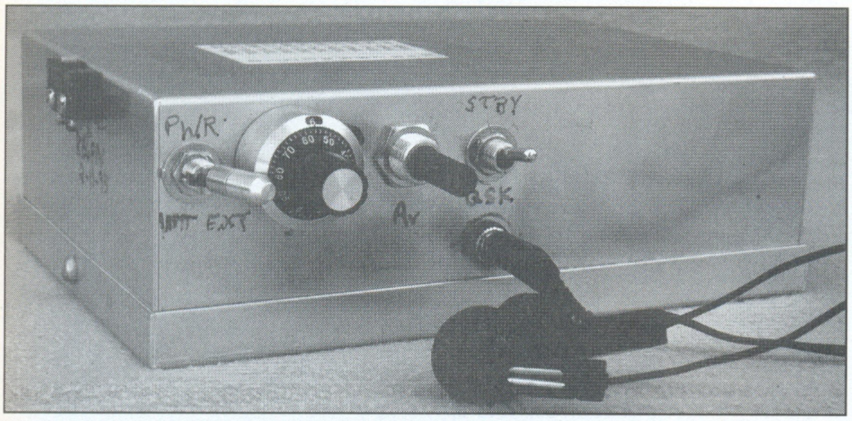


Fig 16—KB6FPW: 40-40, front view. From left to right, locking power toggle switch (switching to the right selects external power, switching left selects internal power); 10-turn dial for tuning; RF attenuator (volume control); RX STANDBY/QSK switch; and 3.5-mm insulated headphone jack. To the left at the end of the box you can see the built-in microswitch key.

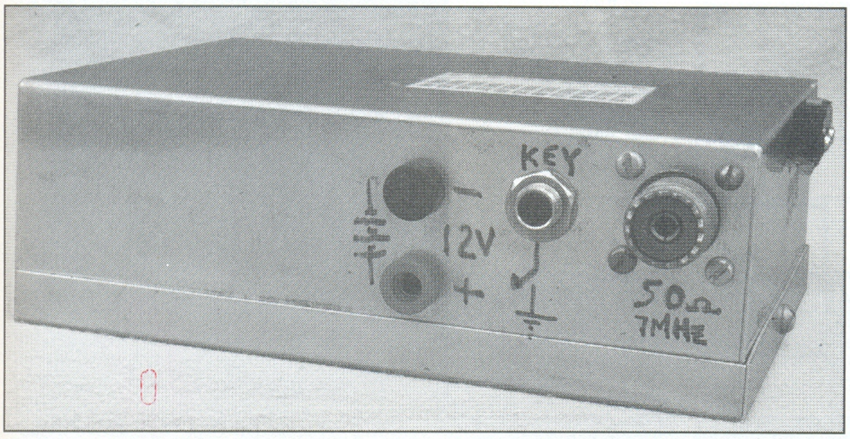


Fig 17—KB6FPW: Available on the rear skirt (left to right) external 12-V input bananas; $^1/_4$ inch external key input; and SO-239 antenna connection.

phone jack to accept a $^1/_4$-inch plug. You can do it, but it isn't as clean and rugged as adapting a 3.5-mm headphone plug to a $^1/_4$-inch stereo jack.

Keys:

KB6FPW: I used a tiny microswitch, mounted on the end of my enclosure as a key (you can see it pretty well in Figs 16 and 17). This way I don't have to remember to pack an external one, or carry the added weight. I can go a solid 18 wpm in short bursts with the microswitch, without cramping my hands and fingers.

AE6C: No argument here. Who wants to lug around a key as big as the entire rig? Microswitches can be pressed into service if you find one with the right feel. I searched around the local surplus shops until I found one that felt good and was large enough ($^5/_8 \times ^3/_4 \times 1^7/_8$ inches) to hold with the other hand. Its lever extends beyond the body where I attach a small plastic knob for a grip. It works pretty well up to about 15 wpm, but not for long stretches. I wouldn't recommend it for contesting either, but it travels really well and collects lots of funny comments.

KB6FPW: Mike Agsten showed a really nice homebrew, built-in key on page 33 of November 1994 *QST*, but I didn't want anything sticking out that might snag or bend in my pack. I went through a lot of microswitches at a surplus store to find just the right one. Keys have to feel right to the user. Wires pass through a couple of holes under the switch terminals. Of course the $^1/_4$-inch jack is always there should I decide to use a straight key or keyer.

Circuit Changes

AE6C: Aside from the parts substitution, I made a few circuit changes that are worth passing along for consideration.

Mixer Injection Levels:

AE6C: Both the receive and transmit mixers get their oscillator drive from Q2. Buffering is via two small 10-pF coupling caps, C4 and C10. I found the NE602 injection levels to be marginal on the low side. Perhaps this was just due to my particular oscillator being a little soft; I don't know what was typically expected of Q2 in the design. I found injection levels to be only 20 to 100 mV P-P, which is below optimum for the NE602.

KB6FPW: The NE602 data sheet says 200 mV P-P is the optimum injection level for the top quad (pin 6) of the Gilbert multiplier cell.

AE6C: Increasing C4 to 22 pF boosted receive gain and large signal handling. Correspondingly, lowering C11 at the transmit mixer to 47 pF boosted drive to the final. Don't go any lower than 47 pF for C11 or the VFO will pull excessively during key-down due to the dynamic loading of the keyed transmit mixer.

KB6FPW: I boosted my U5 injection

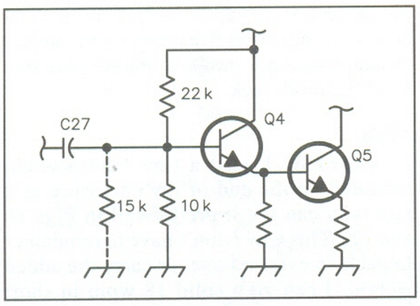


Fig 18—AE6C: Rebiasing the driver to both reduce the power dissipation in Q5 and save a little transmit current.

level to 50 mV P-P by reducing C11 to 100 pF. The VFO pulls about 38 Hz in transmit. I left my receiver's mixer injection level at 50 mV P-P (stock), and my sensitivity numbers compare favorably with Denny's. In my 40-40, a 91 pF C4 brings it up to 200 mV P-P, but I elected not to make this change.

Driver Dissipation:

AE6C: The PA driver, Q5, runs Class A and quite warm (to the extent that I put a small heat sink on it as well as Q6, which runs much cooler).

KB6FPW: I noticed this too...see my comments under "Alignment."

AE6C: You can run Q5 closer to Class B by rebiasing the base of Q4 (**Fig 18**) at a lower potential. As an experiment I paralleled the 10k resistor from the base of Q4 to ground with 15k. The emitter voltage of Q5 dropped from 2.2 V to 1.1 V, which halved the collector standing current. This trick saved 120 mW (10 mA) of battery power and cooled down Q5 at the same time. Going still lower, however, would risk loss of drive and increase harmonics feeding Q6 as Q5 would cut off during part of the cycle as the battery sags.

KB6FPW: I tried a more complicated modification, moving the 22k resistor biasing Q4's base to the 7.5-V Zener diode regulating U5's supply. This also drops the bias as Denny suggests, while regulating against changes in the supply voltage. You cannot bias Q4's base from the 5-V regulator because Q4's collector would then draw power 100% of the time. I reduced my transmit current from 260 mA to 250 mA, in agreement with Denny's prediction.

Headphone Connections:

AE6C: I have gotten into the habit of connecting the ubiquitous stereo headphones in series so as to boost the combined impedance 4 times to roughly 80 ohms (at 800 Hz).

KB6FPW: I like this idea, and I've used it in the past on other projects. The official impedance is 2×32 ohms, or about 64 ohms total, but I have measured "Walkman" type headphones with both lower and higher impedance.

AE6C: The higher impedance is much

Tip for Reducing Current Drain in Electronic Keyers

As an accessory for use with my 40-40, I completed a project that had been collecting dust for a long time: a Curtis keyer chip (8044) and matching circuit board from FAR Circuits. These were held in reserve for the day when I needed them, and that day had arrived. I populated only half of the FAR Circuits board, eliminating the weight control, sidetone and relay functions. This left a speed pot, ¼-inch jacks for straight key and iambic paddle, and an RCA connector for keyer output—a very compact unit.

Since the time when the Curtis keyer chip came on the market, some improvements have been made to the ubiquitous 9-V transistor battery. Present alkaline renditions boast a three-year shelf life, suggesting that the 50-µA quiescent current of the 8044 may be excessive. I devised a simple scheme for automatically disconnecting the battery when the keyer is not in use.

Shown in **Fig E**, my circuit uses a P-channel MOSFET to switch the battery voltage to the keyer board. When either paddle of my key is depressed, steering diodes pull down both the appropriate keyer input, and the gate of the MOSFET. This turns on the MOSFET, instantly applying power to the keyer. While a single dit is enough to get things going, one or two letters will store enough charge on the 100-µF capacitor to hold the MOSFET on for about 30 minutes.

The reason for holding the circuit on is that at power up, the Curtis keyer chip outputs a false dash or dot. This renders the circuit unusable if, say, power was applied for the length of only a letter or word. With a nearly 30 minute hold-up time I don't have to worry about a "wake up" call to the keyer, even after listening to the most monologulous over. The Curtis chip outputs no false keying as the power supply voltage slowly decays.

When not in use (the keyer could sit on the shelf for weeks or months between uses), the P-channel MOSFET shuts off and eliminates the 50-µA static current drain, allowing the battery to realize its full potential shelf life.

This technique can be extended to other keyer designs where the power supply voltage is high enough to enhance the MOSFET. On lower supply voltages, such as the 4.5-V supply of the CMOS Super Keyers, try substituting a Zetex ZVP4105A or frustratingly small International Rectifier IRF7202. Both have guaranteed enhancement (and accompanying low ON resistance) at 4.5-V gate drive.

Yes, the venerable Curtis Keyer Chip is still available, although now marketed by Mouser Electronics and others. The CMOS Super Keyer III is available from Idiom Press, PO Box 1025, Geyserville, CA 95441.—*KB6FPW*

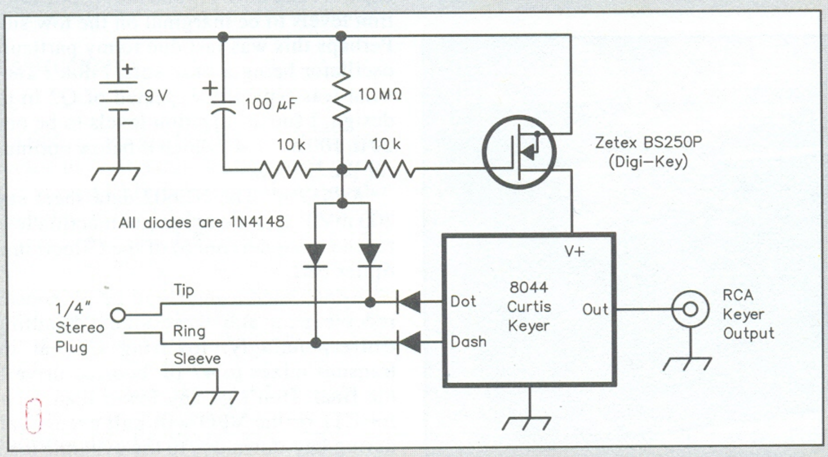


Fig E—KB6FPW: Eliminate quiescent current in the Curtis keyer chip with this automatic supply switch.

40-40 Accessories

While I tried to make my 40-40 completely self-contained, including batteries and key, and as small as possible, I've added a collection of accessories for use in a variety of operating situations. See **Fig F**. Perhaps building and gathering together these items was as much fun as building the 40-40 itself, and they add to the functionality of the rig. You may want to consider some for your own QRP station.

Outboard Equipment

Transmatch: Perhaps the most important station accessory is a means of resonating antennas and transforming the resultant impedance to 50 ohms. I must have a Transmatch for certain portable operation because my antennas are never ideal. The one I like best is described on page 228 of *QRP Classics* (from September 1988 *QST*). A Transmatch is useless without an SWR bridge, and my favorite follows roughly along the lines of the one shown on page 48, Fig 3-6 of *QRP Notebook*. I put a 40-m-only version of the Transmatch in a 2×2×4 aluminum box together with my SWR bridge (**Fig G**). The matcher has no trouble tuning up antennas that would have otherwise been 50 ohms, but for various installation reasons exhibit some unknown, often wild impedance.

One of the best things about the SWR bridge is that no inductors or transformers or trim caps are needed, and it isolates the final from severe mismatches. It doubles as a 6-dB attenuator for 250-mW QRPp operation. It has no problem indicating full scale with 1 W and a high SWR.

I made a few mods to the original published SWR circuit. I substituted 51-ohm resistors in place of the 47-ohm resistors shown, I used a 1N914 instead of a 1N34A, and I eliminated the CAL position and pot. The bridge resistors dissipate only 250 mW each with 1 W applied, so I used quarter-watt carbon film resistors. These are completely adequate for tuneups, QRPp operating (as an attenuator), and brief key-down tests, and they are easier to find than carbon composition resistors of higher wattages. This little accessory has more than paid for itself in several hotel rooms. For up to 2 W, parallel two 100-ohm, 1/4-W resistors to replace each 51-ohm unit.

–20 dB coupler: I mention a coupler here because there is no reason you couldn't build it into the SWR bridge/Transmatch with a little advanced planning. A digital frequency readout is an especially welcome addition to any analog rig. It's nice to glance at a counter instead of poring over a calibration chart when logging the frequency of a QSO. A –20-dB coupler is the ticket. I put two SO-239s back to back in a small aluminum box with a single insulated wire running between them (see Fig F). Threaded onto this connecting wire is a ferrite toroid wound with 10 turns of hook-up wire. I used an FT-114-64; an

Fig F—KB6FPW: This is the entire 40-40 accessory lineup. This stuff isn't used all at once, but I draw upon these items to satisfy various operating requirements such as business or camping trips, trips to visit relatives, RFI investigation, or operation at home. I've even operated mobile. Progressing from lower left to upper right are pictured remote microswitch hand key; ear buds in carrying case; spare final; SWR bridge/Transmatch with removable knobs; Braun QRP station clock; adaptors 1/4 inch to RCA, UHF to F, BNC, RCA and five-way banana; UHF U-turn consisting of two elbows and one male-male adaptor; the 40-40; log book; pen; Gates Cyclon 12 V/2.5 Ah six-pack; banana to alligator clip pair; shaving kit bag (black); tuned, shielded loop; Vibroplex iambic paddle; homebrew Curtis keyer in a gutted MFJ aluminum box; –20 dB coupler; RCA patch cord; Ault Model 5000 12 V/300 mA wall cube; lastly, in the back, a 40-m dipole with 50 feet of coaxial feed line and choke-style balun wound on an extension cord holder.

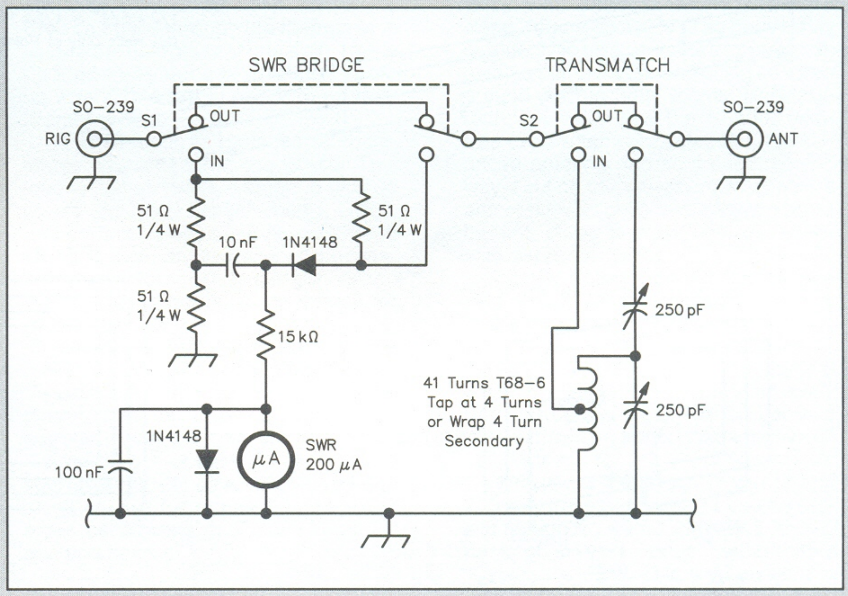


Fig G—KB6FPW: An SWR bridge and Transmatch will be one of the first accessories you'll want to add to any QRP rig. I cobbled this circuit together with material from several different sources, along with a little of my own ingenuity. There are two switches: one selects or bypasses the resistive bridge, and the other selects or bypasses the versatile tuner. Often times my portable dipole needs no tuning and I take the SWR bridge/Transmatch out of circuit altogether. The two 250-pF variable capacitors are fishpaper capacitors, #24TR222 (Mouser, Circuit Specialists, DC Electronics); parallel sections.

FT-114-A-61 is more readily available (Amidon) and will do nicely, as well as any number of type 43 or 61 toroids and sleeves.

The 10-turn secondary passes out of the box through a BNC to a 50-ohm terminator at my frequency counter. This absorbs only 1/100 (10 mW) of my output power—a small price to pay for a digital readout—but gives solid counts. If you want to get fancy, use a short length of 50-ohm coax to bridge the gap between the SO-239s. The braid acts as an electrostatic shield, but be sure you ground the braid at one end only, or it will shield the magnetic field too. Another option is to use a chassis isolated BNC connector and float the secondary winding. This keeps the counter from injecting ground noise into the 40-40's receiver.

Key: Although I built a microswitch into (onto) my 40-40, this wasn't especially convenient in a sleeping bag. Either I'd have to stick the cold rig in my bag, or stick my arm out of the bag into the cold air to operate the built-in key. For my brand of fourth-season mountaineering, I devised a simple key consisting of a ¼-inch plug and small microswitch joined by a couple of feet of light zip cord. The microswitch can be operated from inside my bag, while the rig remains outside. Some people may find this key difficult to operate, but 30 years of playing violoncello, 20 years of touch typing, and 10 years of operating a Vibroplex iambic paddle haven't exactly hurt my dexterity. AE6C built one too.

Keyer: Although I already had CMOS Super Keyers II and III, I decided to pull out an old 8044 Curtis Keyer chip and matching FAR Circuits circuit board and installed them in the smallest box I had on hand. I was able to out-do the other keyers in terms of size and weight, and now I don't have to tear down my home station when I need to take a keyer portable. Perhaps I'll next build a miniaturized version of the CMOS Super Keyers. See the sidebar entitled "Tip for Reducing Current Drain in Electronic Keyers" for a way to conserve keyer battery life.

Ear Buds: These are a great innovation. Headphones without a head-band. They roll up in a small coil and can be stowed in any little nook or cranny in a suitcase, pocket, or briefcase. They'll even fit inside the rig, if necessary.

Operating Aids

Logbook: Much to my dismay, Newington says that the *ARRL Mobile Logbook* is now out of print and no more will be produced. My XYL came to the rescue with a "Marble Memo" (The Mead Corporation, Dayton, OH 45463). This looks just like the lab notebooks I use at work; you know the kind—a green marbley cover with quadrille paper—but this one is only 4.5x3.5 inches. It compares favorably with the 4x6-inch footprint of my 40-40, and contains a full 80 sheets (160 pages). Nevertheless, scratch it off your Dayton list, because the binding allows pages to fall out after a little exercise. The binding isn't sewn like my lab notebook. A spiral-bound notepad may be a better choice. Try a Memo Book, No. 524352, from the Union Camp Corporation, Wayne, New Jersey 07470. It measures 5×3 inches and also contains 80 sheets.

Pen or Pencil: Now that you've got a log book, don't forget to pack a pen or pencil too. Pens run out of ink, pencils get dull or break. I don't know what the solution is other than to take a spare or check the ink tube inside the pen to see how much is left.

Flashlight: Not pictured. I keep a Mini-Maglite AAA (operates on two AAA cells) for use at night when ac-powered lighting is not available, such as when camping or emergency communications. Other flashlights abound that are much more "QRP" than a Mini-Maglite, such as key-chain types, and small single AAA cell flashlights built in the form of a pen.

Station Clock: This idea is not new, but it bears repeating here. Stick-on digital clocks are available for less than $5 at any variety or auto parts store. One can be attached to the rig or an accessory chassis. It's amazing that what once was a $100 station luxury is now a throwaway accessory for a QRP rig. I particularly like the ones supplied with a Velcro fastener, allowing for easy removal or

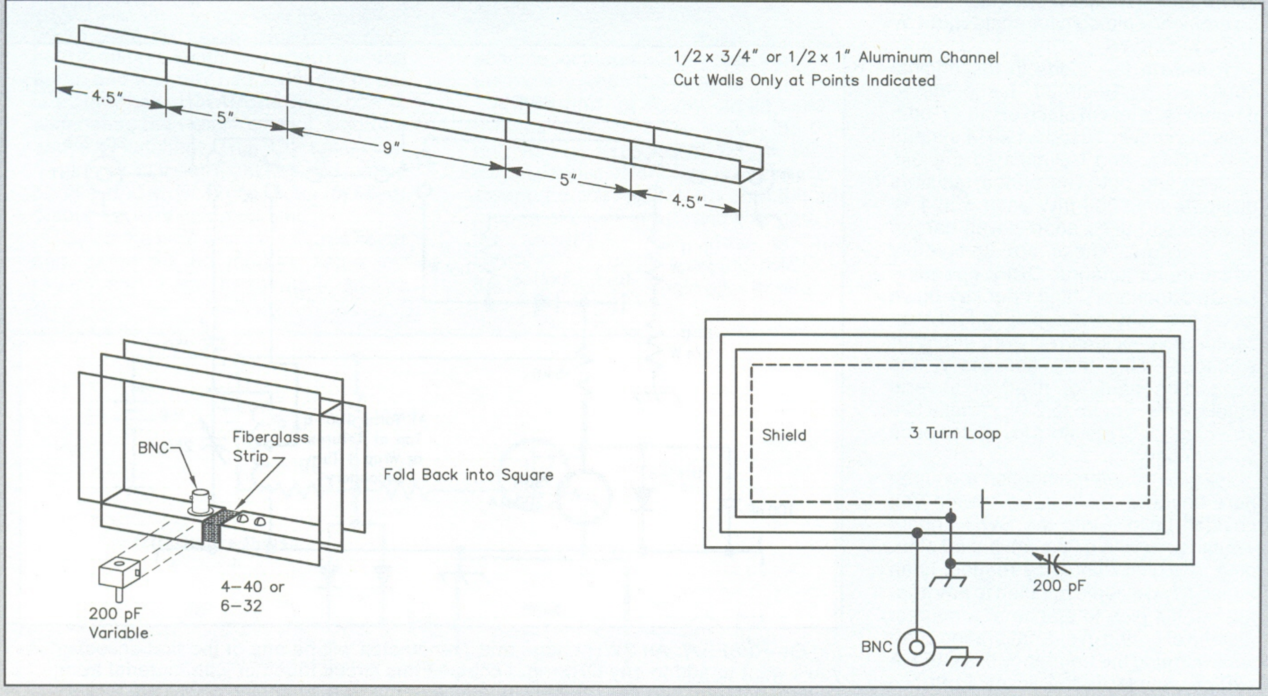


Fig H—KB6FPW: A tiny rig begs use as an RFI crime fighter. You can search out BCI, TVI and RFI from a variety of sources such as rectifying joints, the neighbor's television set, or a street lamp with this tuned loop. Simply cut the walls of a length of aluminum U-channel in four places and fold back into the shape of a square. I used a piece of stripped fiberglass and screws to secure the gap. This one is wound with three turns, tuned with a 200-pF air variable, and the output is sampled with a BNC tapped one turn up from the grounded end of the loop.

Table A
KB6FPW: Handy Adaptors to Have on Hand

Source	*From Type*	*To Type*	*For Connecting*
Transceiver or Transmatch	PL-259	Fem. BNC	Short runs of RG-58 or BNC-equipped accessories
	PL-259	Fem. F	TV-grade coax with crimped F connectors
	PL-259	RCA jack	RCA equipped coax or accessories
	PL-259	5-way banana binding post	End-fed antennas
External key input	1/4 inch plug	RCA jack	RCA-equipped external keyer or keys
External power input	Banana plug	Alligator	External 12-V batteries or power supplies

Also:

UHF U-turn; consists of two elbows and a male-male adaptor; used to connect rig directly to SWR bridge/Transmatch.

RCA Patch Cable; 1 to 3 feet long, shielded, with RCA plug at each end; used to connect external keyers (RCA is almost universal in this regard).

replacement of the clock. You can also find pens with clocks built in—this is a great way to combine two accessories. Now if I could just find a pen with a built-in clock and light I'd have it made. When traveling I just use my Braun travel clock. It's the QRP equivalent to a 12-inch wall clock, and it has built-in incandescent illumination, but no pen.

Checklist: This should be compiled while the 40-40 is installed and in use, so that you don't forget any essential elements. Although my checklist (inventory, actually) is hand written inside my logbook, it could be compiled on a computer and printed in shrunk form and taped inside the logbook or taped to the bottom of the rig.

Calibration Chart: I attached an abbreviated calibration chart this way, but taped to the top of the rig. The log is another handy place to keep it.

Transportation and Repairs

Shaving Kit: How could this be a radio accessory? I can carry my 40-40, and any necessary accessories all in a small zippered shaving kit. Small pouches and containers like this abound, at low cost. Look for food/beverage totes, camping pouches and packs, bicycle accessories, and commercial airline overnight kits and bags.

Spare Parts: AE6C suggests taping an extra final transistor and fuse to the inside of the box, just in case your luck runs out and you're not at home. I also put the small tuning tool, which was included as part of the 40-40 kit, inside my rig for field adjustments should they become necessary.

Tools: Not pictured. For opening the rig, I carry a very small blade-type screwdriver. This way I can change batteries or get in to make adjustments should they become necessary.

Antennas

Dipole: I fabricated a dipole using *Handbook* dimensions as a guide. The dipole itself is made out of stranded twisted pair for strength and flexibility, with nylon strings attached to the ends. A center 1:1 insulator/balun feeds 50 feet of TV-grade RG-59 coax prewired with type-F connectors. I also attached about 50 feet of Dacron cord to the balun for inverted-V use, or to support the weight of the coax. All of this is wound on an extension cord holder for easy transportation and deployment.

Portable Loop: A small, compact QRP rig like the 40-40 begs service as a QRM fighter, searching out local man-made interference like broken power poles and other neighborhood malfunctions. I took a 28-inch length of 1×1/2" aluminum U-stock and cut the walls of the channel at 4.5, 9.5, 18.5, and 23.5 inches; then folded the U-stock back on itself to form a rectangular frame (see **Fig H**). The gap was secured with a strip of insulating fiberglass PCB material (stripped of copper) and 4-40 hardware. I added a 200-pF air variable and BNC, attached right to the loop frame (the BNC can pass through the fiberglass to secure the fiberglass at one end). Lastly I added three turns of insulated hook-up wire with a tap at one turn up from [frame] ground.

A BNC male-to-male barrel completes connections to the 40-40. This loop is just sensitive enough to pick up strong signals (I haven't tried a QSO), and perfect for sleuthing neighborhood QRM. It also couples well into household conductors such as rain gutters and water pipes, simplifying the search for rectifying joints.

End-fed Wire: Not pictured...You can make contacts with nothing more than a 1/4-wave (33 foot) wire strung up to the nearest skyhook. Don't forget you need a ground. I carry a matching 33-foot radial made out of light zip cord, and a shorter length of heavy wire with a large alligator clip for connecting to water pipes, car chassis, or whatever ground I can find nearby.

Connections

Adaptor Kit: For the antenna connections, you can never tell what you'll run into, so I keep an assortment of UHF-to-whatever adaptors on hand. These include BNC, F, RCA, and a five-way banana binding post for end-fed wires. Other adaptors get me in and out of the 1/4-inch key jack and banana power jacks. See **Table A**.

Power Sources

Power Supply: This rig is a lot of fun, and you're going to want to operate it at home, but without wasting money on batteries. A power supply is required. I should give up building power supplies, what with the ready availability of wall cubes. These run from 50 cents to $2, depending on whether you buy them at a flea market or retail store, regardless of condition or size. Normally despised because of their proliferation in the consumer industry, these are a handy source for ready-made power supplies.

I bought a wall cube at the store for $1.50. Manufactured by Ault, it is an exceptionally nice one weighing about twice what it should, and it puts out a clean, regulated +12 V. The heavy-duty output cable also contains a ground connection that is handy for picking up a free ground path in hotel rooms. Unlike direct-conversion rigs, the 40-40 is hum-free even when connected to an unbalanced antenna and ac ground. By the way, I cut off the weird connector on the end of my wall cube and installed some banana plugs to mate with my 40-40 external power jacks.

Infinite Power Source: Clearly, the load of eight AA alkalines is for use only in the most portable of circumstances, such as when skiing or backpacking, or perhaps for emergency communications. But for portable operation away from power lines where I'm not carrying the weight on my back, I take a rechargeable battery.

With only 6.3-mA receive current and 260-mA transmit current, I couldn't resist mating my 40-40 with a 2.5-Ah six-pack of surplus Gates rechargeable "Cyclon" gelcells. This is equivalent in capacity to the AA alkalines, with enough reserve to last an entire contest or through a weekend of intense operating. 2.5 Ah will supply the 40-40 through 38.5 hours' worth of QSOs, or two weeks of monitoring. See the **sidebar** entitled "Batteries" for further information on battery operation.—*KB6FPW*

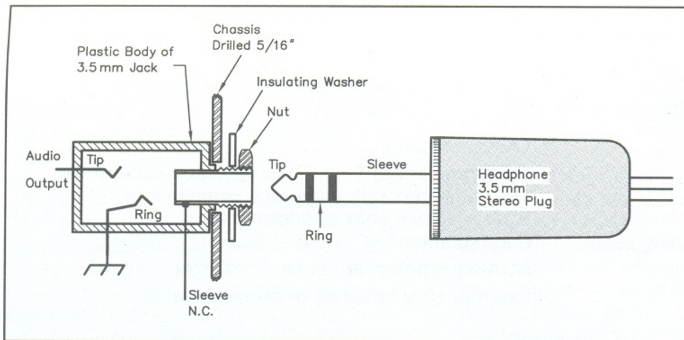


Fig 19—KB6FPW: Float the bushing and the two headphone elements can be series connected for a better match to operational amplifier output stages.

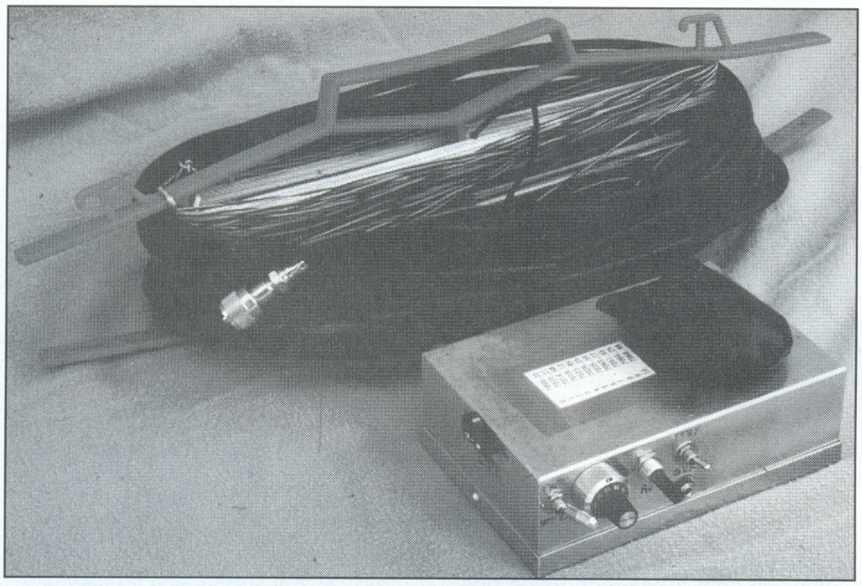


Fig 20—KB6FPW: The bare essentials. This is the minimum configuration for a weekend (or longer) trip. Only three items need be packed: ear buds, 40-40 and 40-m dipole on extension cord holder. Forgetting the ear buds isn't a show-stopper as a new pair, sold in a wide variety of stores, can be purchased almost anywhere anytime day or night for well under $5. My calibration chart is affixed with packing tape to the top of the rig.

Fig 21—KB6FPW relays FD site status to AE6C, 150 miles distant. KB6FPW got a 589 using a dipole only 6 feet off the 8-foot snowpack, and what was later verified as 320-mW output power. The little 40-40 is well-suited for these harsh conditions.

more friendly to op amps and low power discrete audio circuitry, often mitigating the need for current-hogging IC audio amps. Most op amps have plenty of voltage compliance, but little output current.

KB6FPW: Even driving 80 ohms, most op amps will current-limit before hitting the rails, but you'll get 4 times the peak audio power (+6 dB) by putting them in series. Sort of like having an "11" on your volume control. See **Fig 19**.

AE6C: When the protective overcurrent clamps engage, boy, is it hard on the ears.

KB6FPW: But the extra output is handy in noisy environments, like in a tent during a windstorm.

AE6C: You don't have to rewire your favorite headphones to make the series connection, just use a headphone jack that is electrically isolated from the chassis. The "shell" of the plug is allowed to float and the signal is fed across the tip and ring sections.

KB6FPW: Radio Shack makes an ideal 3.5-mm headphone jack (#274-249) which when installed in a 5/16-inch hole, becomes isolated from ground. Be sure to use an insulating washer under the nut. It's a good thing there are two per package, because the connectors are flimsy.

I've noticed a slight amount of BCI from local stations with my floating headphone ground. A solid ground at the rig minimizes this pick-up. It has only been a problem at home in the middle of RF Gulch.

Headphone Selection:

AE6C: To carry miniaturization to its logical conclusion, the headphones should be small. This suggests the use of "earbuds" as supplied with many of today's portable radios, tape players and CD players.

KB6FPW: I agree with AE6C. "Earbuds" are the way to go. Unlike conventional 'phones with a headband, you can wear earbuds under a warm, wool watch cap in a sleeping bag. They are also small and easy to carry in a backpack. And you can rest the side of your head on a pillow while wearing them. Try that with a pair of Sennheisers.

Conclusions

KB6FPW: I took the 40-40 on a cross-country ski trip in February with my family and N6CNY. We skied to our Field Day site to see if essential trees had survived January's 135-mph winds and record snowfall. We were able to report good news to AE6C with the 40-40 and a dipole only 6 feet off the 8-foot snow pack. The path was about 150 miles, and we made contact at both 9 AM and 4 PM. It was nice having the rig along to pass wakeful periods during the long nights. See **Figs 20 and 21**.

AE6C: I'm taking mine camping, too. I've built a lightweight dipole to complement the 40-40.

KB6FPW: Not long after building my 40-40, I ran across a Ø using the same rig!

Batteries

While my 40-40 contains a load of eight AA alkaline cells for portability, these are costly to replace so I use them only when necessary, such as when skiing, backpacking, wandering the neighborhood in search of RFI sources, or for on-the-spot emergency communications.

For sustained non-ac operation, a rechargeable battery of one type or another makes the most sense. NiCd batteries, while readily available, are the worst possible choice for emergency and portable power because they have high self-discharge rates, their charging efficiency is low, they cannot be "topped off" to maintain a full state of charge, they give no advanced warning of end-of discharge, and there is no way to know their state of charge without actually discharging them.

Lead-acid "gelcells" eliminate most of these problems. They have good shelf life, and can be topped off once a month or float charged indefinitely. The state of charge is simply monitored by measuring the terminal voltage (for a cell at rest 12.8 V full, 11.8 V empty, linearly extrapolate in between). The Gates Cyclon series includes two practical cell sizes that often show up in surplus stores and catalogs. The 2.5-Ah cell is about the size of a D cell alkaline, and the next size up is 5 Ah, which has the same form factor. These cells are often packaged in blocks of six (12 V), with the terminals spot welded together and housed in a plastic box.

Other gelcell types are potted in a plastic block or cube, with their capacity and voltage ratings printed on the side. They are available from many manufacturers including Yuasa, Sonnenschein, Panasonic, Globe and Power Sonic, to name a few. Potted cubes are available up to capacities of 48 Ah and more—too big for a 40-40.

Care for gelcells as you would any other lead acid battery. I've had good success charging gelcells at 14.4 V (2.4 V/cell), and floating at 13.8 V (2.3 V/cell). **Fig I** shows a circuit you can use to charge gelcells of up to 6 Ah capacity (larger batteries can be charged, but slowly). A low dropout regulator is used to extract as much power as possible from a 12.6-V transformer. Typically the peak rectified voltage is close to 18 V, but the LT1086 needs only 16 to 16.5 V to overcome the diode (D3) and still make 14.4 V at the battery.

The charging voltage is controlled by a center-off toggle switch. In position 1 the circuit floats at 13.8-V, position 2 "equalizes" the battery at about 14.8 V, and position 3 charges the battery at 14.4 V. Although gelcells can be floated indefinitely, long-term degradation can result if a fully charged battery is left in the charge position for many days, such as a week or more.

Equalizing should be done infrequently, and for only a few hours (2-6 hours on a fully charged battery) at a time. Equalizing essentially force-feeds the weaker cells in an attempt to completely restore all of the active plate material. If you use your gelcell often enough to charge it every week or two, equalize after every two to four charging cycles. If the gelcell gets less use, or if it is float or solar charged, equalize perhaps once every six months.

At 14.8 V damage occurs much more quickly than at 14.4 V—the curve is steep—so don't equalize for more than 6 hours or so. Discontinue equalizing (or any charging, for that matter) if the battery becomes noticeably warm to the touch.

A six-pack of 5-Ah Gates Cyclon cells will go forever. After modification, my 40-40 would operate on a 5-Ah battery for three days of solid QSOing, or a month of continuous reception. Such a large capacity would only be justified for, say, a two-week camping trip or if the charging source was undependable, such as a solar charging system riding out a month's worth of fog.

Solar Charging

Years ago solar panel prices ran around $20/W new, and about $10/W for surplus seconds. This put them out of reach for most amateur use. Owing to improvements in fabrication cost, new panels today run about $8/W, and less than $4/W for seconds and used panels. These prices (for large panels) are well within reason for powering a QRP station. Cost per watt peak power is a little higher for small panels, since the manufacturing cost is dominated by packaging, and the total available market is much smaller than for mass-produced large panels.

As a very rough rule of thumb, solar charge gelcells with a panel that puts out about C/10 (ampere-hour capacity divided by 10). For example, a 2.5-Ah gelcell matches well with a 250-mA solar panel. Assuming an equivalent of six hours of full insolation per day, two days' worth of sunshine would fully charge the battery. In the winter, or during periods of adverse weather, it might take a week.

Solar panel ratings are normally based on the peak available power, measured in full sunlight at sea level, in a place like Arizona. This doesn't mean much for charging 12-V batteries, because the panel's terminal voltage is in the 16 to 17-V region at peak power. Since solar cells are largely constant current devices at lower voltages, the maximum available output current at 12 V is approximately equal to the peak power rating divided by 17 V. My surplus Solarex panel is rated at 6 W, and in full sunshine it delivers 330 mA into a 12-V battery. Altitude does make a difference, as I've measured as much as 400 mA at 7000 feet. On cloudy-but-bright days, I can still get 100 mA out of the panel. This panel isn't a bad match for my 2.5-Ah six-pack.

For panels of C/10 or greater, some form of charge-control is recommended. Most commercial charge controllers use a shunt regulator to limit the maximum battery voltage to a safe value. **Fig J** shows a simple shunt regulator you can build. I have designed all kinds of charge controllers using op amps, MOSFETs, hysteretic control, and even peak-power tracking switching regulators, but this one can't be beat for cost and foolproof operation.

This circuit dissipates full panel power once the battery is charged, so a heat sink is necessary. A 10-W, 10-ohm resistor is added in series with the Darlington transistor to help share the dissipation. Still, the transistor must be heat-sinked as it will dissipate a maximum of about 5-6 W at 1 A. The maximum voltage can be calibrated with the

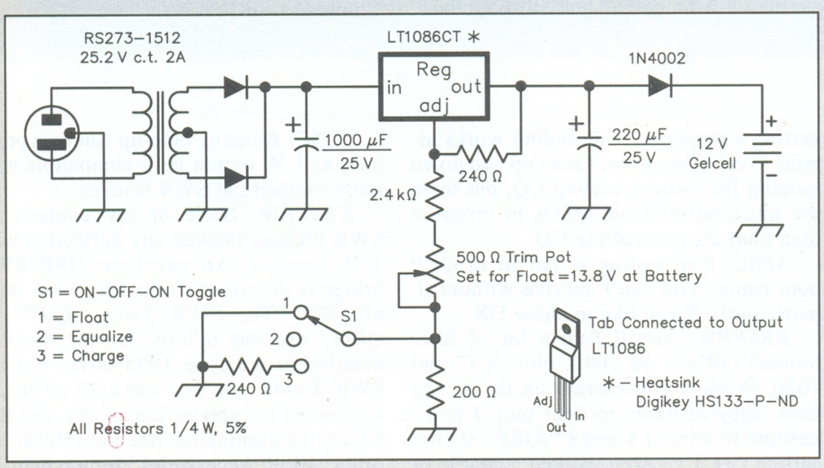


Fig I—KB6FPW: Here is a simple constant voltage charger suitable for floating, charging or equalizing 12-V gelcells.

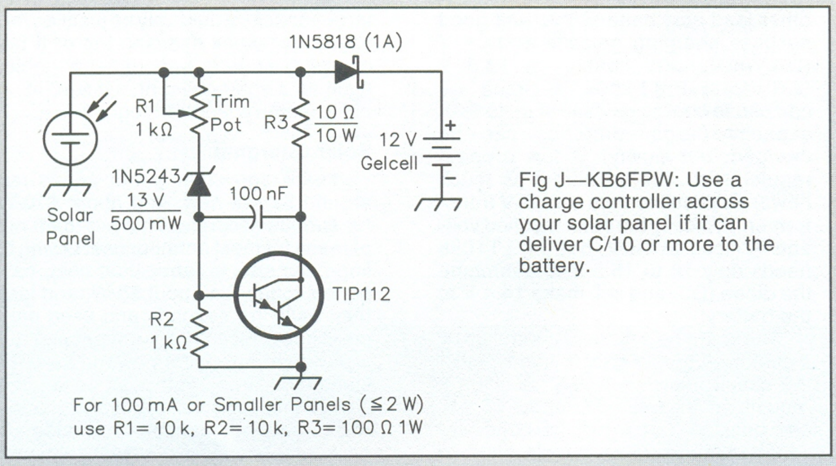


Fig J—KB6FPW: Use a charge controller across your solar panel if it can deliver C/10 or more to the battery.

trimpot to compensate for Zener voltage, V_{be} variations and Schottky forward drop at current. The knee of this circuit is relatively soft, eliminating stability problems. You can use this circuit up to about 1 A maximum. For sub-100 mA panels, increase R1, R2 and R3 by a factor of 10 each. R3 can be a 1-W unit, and the heat sink can be eliminated.

Sizing a QRP Solar Panel and Battery

Accurately sizing solar panels and batteries requires a series of educated guesses and compromises. Your operating habits must be considered to reach a reasonable solution. A general technique that works for most amateur habits is to add up a week's worth of operating current and self-discharge current; select a battery that can store this amount, and find a panel that can deliver anywhere from one to two times this amount, spread over a week's time. Here are the equations:

Battery capacity (Ah) = (total required ampere-hours per week) × 1.084

Panel capacity (Watts) = [(total required ampere-hours per week) × 1.1/42] × 17

Fudge factor explanation:

1.084 = battery self-discharge per week for a new battery, up to 1.2 for an old battery.

1.1 = battery ampere-hour charging inefficiency.

42 = average hours of maximum weekly insolation.

17 = panel voltage at rated power.

You can change the fudge factors to fit operating parameters peculiar to your situation. This method works great for those who concentrate their operating time in one or two chunks per week, but results in oversized batteries for those whose operating time is spread out evenly throughout the week.

These equations result in a "break-even" panel; it just keeps up with the demand under predicted insolation. After several days of cloudy weather the panel may get behind and since it can only keep up at best, it will never fully recharge the battery when fair weather returns. This is why the power of the panel should be as much as double the value calculated above.

Because the 40-40 uses so little current, a 1.2-Ah gelcell (this is about the smallest you can find) and a solar panel ranging from ½ to 2 W (depending on your operating habits and insolation) will work for everything from Field Day, to a daily net or sked, to one evening a week. If you oversize the battery, the self-discharge current becomes a major portion of the ampere hour budget, increasing the size and cost of the solar panel. Undersize the battery and you'll surely run out of power in the middle of a contest or DXpedition. Expect to pay a premium for such a small panel—as much as the rate of old, $20/W.

Throwaway Sources

A pack of eight D cell alkalines, although expensive to replace, will give their full 14 Ah at 40-40 current levels. This means three months of continuous reception, or 215 hours of continuous QSOing. The casual operator can easily expect a year's worth of use, filling a page in the log every two weeks.

I like to think of it in terms of total QSOs. A pack of D cells is good for 861 15-minute QSOs—that's more operating than I do in an entire year, all modes and bands combined! And alkalines are ideal for something like the mountain cabin scenario, because they have excellent shelf life. This attribute is essential for emergency communications.

A QRP rig like the 40-40 begs use for emergency communications. Although most of the local and regional traffic nets in my area are conducted on 80 m, 40 m has come alive with health and welfare traffic during major emergencies like the recent San Francisco and Los Angeles earthquakes. For emergency backup power you might want to consider a load of alkalines, or a gelcell, which can be solar charged, float charged, or topped off once a week.

In an emergency, don't forget about your car's battery. Typical capacities range from 50 to 75 Ah—months of continuous QSOing. Other impromptu household sources of emergency 40-40 power include motorcycle, snowmobile, lawnmower and camcorder batteries.—*KB6FPW*

His signal was strong, so I found it hard to believe I was listening to 1-1.5 W almost 1000 miles away. I've worked about four 40-40s so far.

A few weeks' casual and random operating netted 8 states and 23 QSOs. I think WAS would be a good goal for this rig. With falling solar activity, it should be possible. I now stand at 22 states, 3 provinces and 3 countries. Summer QRN is slowing my progress. . .

The most effective operating tactic, given my 1-W output power, is to tail-end QSOs. This is a common technique employed by veteran QRP operators that I was quick to adopt. I've called CQ with a memory keyer for up to an hour before getting a response. Tail-ending works almost every time. Also, I scan up and down looking for stations calling CQ, but there are more tail-endable QSOs in progress than loud stations calling CQ.

AE6C: Tail-ending is taught in QRP boot camp. You can't survive without it, particularly if you like to chase DX.

KB6FPW: You'll find a lot of like-minded QRPers on 7040, plus 7037 and 7030. While I concentrate on the strong ones (they're likely to hear me), I don't hesitate to answer a weak "/QRP" station calling CQ. I've even worked a couple of weak ones that were actually QRO. They must have much better receiving conditions than I have here in RF Gulch.

AE6C: Antenna tune-up can be a problem, as 1 W output isn't compatible with most commercial SWR bridges.

KB6FPW: None of my commercial SWR bridges showed any deflection with 1 W applied. An excellent QRP SWR bridge is described in the July 1986 issue of *QST*, "The SWR Twins—QRP and QRO," and one tailored for the 40-40 is detailed in the June 1995 issue. For the SWR Twins, you can use a 25 or 50 µA movement for greater sensitivity, and R1-R5 can be eliminated. See the sidebar entitled "40-40 Accessories" for a schematic of my matching SWR bridge/Transmatch.

Countless times, after exchanging the usual RST HR IS... NAME HR IS... QTH

HR IS. . . I get to the part where I send RIG HR IS 1 W QRP 4040 FM NOV 94 *QST*, and I get the response "TT RIG SOUNDS GREAT... CANT BELIEVE UR HOMEBREW... UR NOTE PURE ES NO CHIRP OR CLIX... FB SIG FER 1 WATT... UR RIG DOING FB JOB..." always unsolicited and without prompting. This rig is great.

Our 40-40 modifications increased battery life by a factor of more than 3, increased the tuning range by a factor of 2, and saved 70 to 115-mA supply current in transmit. I haven't had this much fun with a rig since I spent $2000. And this one cost much, much less.

AE6C: Having access to good test equipment in the home lab, I made a few measurements on my version (Table 1).

KB6FPW: I have so-so test equipment, and I made the same measurements.

I also checked the spectral purity. The 2nd harmonic was 34 dB down, and spurious responses were down more than 40 dB. These figures are in close agreement with those quoted by the ARRL Lab in the original article.

Yes, even in this simple, synthesizer-less design there are some in-band spurs, but they represent less than 100 microwatts of output power. Part 97.307(d) says the limit is 30 dB down minimum; 4 dB is a comfortable margin, as the relative strength of the distortion products isn't particularly sensitive to output power or loading.

Dennis Monticelli, AE6C, 44533 Parkmeadow Dr, Fremont, CA 94539-6528, was first licensed at age 16 in 1967. His Amateur Radio activities spurred his interest in electronics and led to the pursuit of a BSEE, which he earned from the University of California in 1974. Since graduation Dennis has worked for National Semiconductor Corporation, collecting 20 patents as an analog IC designer. He presently serves as the Vice President of the Power Management Business.

Dennis's favorite ham radio activities include homebrewing, HF DXing, antennas, QRP and CW. He lists his greatest accomplishments as DXCC, the Cubic Incher and cajoling a semi-legal, incorrigible low-band experimenter into becoming KB6FPW.

Now in his 12th year of hamming, Mitchell Lee's (172 N Twentyfourth St, San Jose, CA 95116) interest in Amateur Radio was spurred after earning a BSEE at California Polytechnic State University, San Luis Obispo, in 1980. Mitchell presently works at Linear Technology Corporation as an Applications Engineer.

Mitchell has also held the call VK4CFL, operating AM from the Brisbane area. Past QRP activity includes operating 10-m AM motorcycle mobile as KB6FPW/VE7, /VY1 and /VE8 from a large, dual-purpose enduro. He attributes much of his QRP interest to 15 years of completely legitimate 1750-m operation and Elmering from QRP folk hero W6TYP (SK), the first ham to break the "Million Mile Per Watt Input" barrier—accomplished on 40 m—and later 70 million miles per watt on 70 cm. Mitchell's father, Ed, is KB6JQK.

In addition to competing against each other at work and on the air, Dennis and Mitchell share an intense interest in the 40-40, both hold Extra Class licenses, and since 1984 they have annually joined forces operating AE6C Field Day.

Table 1

Parts List For The Transceivers

Designation *(See Figure 2)*	*40-Meter Version*	*30-Meter Vers*
C1, C23, C26	8 to 70-pF, 6-mm trimmer	8 to 70 pF, 6-r
C2	220 pF	150 pF
C3	47 pF	47 pF
C4	10 pF	10 pF
C5 to C7	0.0022 µF, 5% Polystyrene, radial lead	0.0047 µF, 5% radial lead
C8	2 to 27 pF (Digi-Key SG3004)	2 to 27 pF (Dig
C9	68 pF	150 pF
C10	10 pF	10 pF
C11	220 pF	220 pF
C12	47 pF	22 pF
C13	150 pF, 5%	270 pF, 5%
C14	150 pF, 5%	270 pF, 5%
C15	150 pF, 5%	270 pF, 5%
C16	68 pF	none (replace
C17	47 pF	68 pF
C18	47 pF	150 pF, 5%
C19	47 pF	47 pF
C20	150 pF	220 pF
C21	10 pF	10 pF
C22	150 pF, 5%	150 pF, 5%
C24	5 pF	5 pF
C25	150 pF, 5%	150 pF, 5%
C27	47 pF	47 pF
C28	470 pF	330 pF
C29	0.001 µF	680 pF
C30	470 pF	330 pF
C31	68 pF	47 pF
L1	3.65 µH (27 t #22 on T-50-2 toroid)	3.65 µH (27 t #
L2, L3	2.5 µH (25 t #26 on T-37-2 toroid)	1.2 µH (20 t #2
L4	10 µH (5 t #22 on FT-37-43 toroid)	7 µH (4 t #22 o
L5,L6	1.0 µH (16 t on T-37-2 toroid)	0.68 µH (15 t #
RFC1	22-µH epoxy RF choke	10-µH epoxy R
RFC2	22-µH epoxy RF ckoke	4.7-µH epoxy R
T1	Primary 16 t #26; secondary 4 t on FT-37-61 toroid	Primary, 11 t # on FT-37-61 t
Y1 to Y4	4.000 MHz (see text)	8.000 MHz (see

(Remaining parts are identical for both bands)

D1	MV1662 Varicap diode
D2 to D9	1N4148 or 1N914
D10	7.5-V Zener, 0.5 W, 5% (1N5236 or equiv.)
D11	33-V Zener, 0.5 W, 5% (1N5257 or equiv.)
R1	100-kΩ linear-taper pot
R2	200-Ω Cermet trimmer pot (Digi-Key 36C22)
R3	5-kΩ linear-taper pot
Q1	2N5486 (2N5485 or MPF102 substitutes)
Q2, Q4, Q5	2N2222A metal
Q3	2N3906 or equivalent PNP GP Switch
Q6	2N3553 (MRF-237 substitute)
T2	4 bifilar turns on FT-37-43 toroid (use 3-inch piece of two-conductor ribbon cable)
U1, U3, U5	NE602A(N) Signetics mixer/oscillator IC
U2	78L08 voltage regulator IC
U4	NE5532