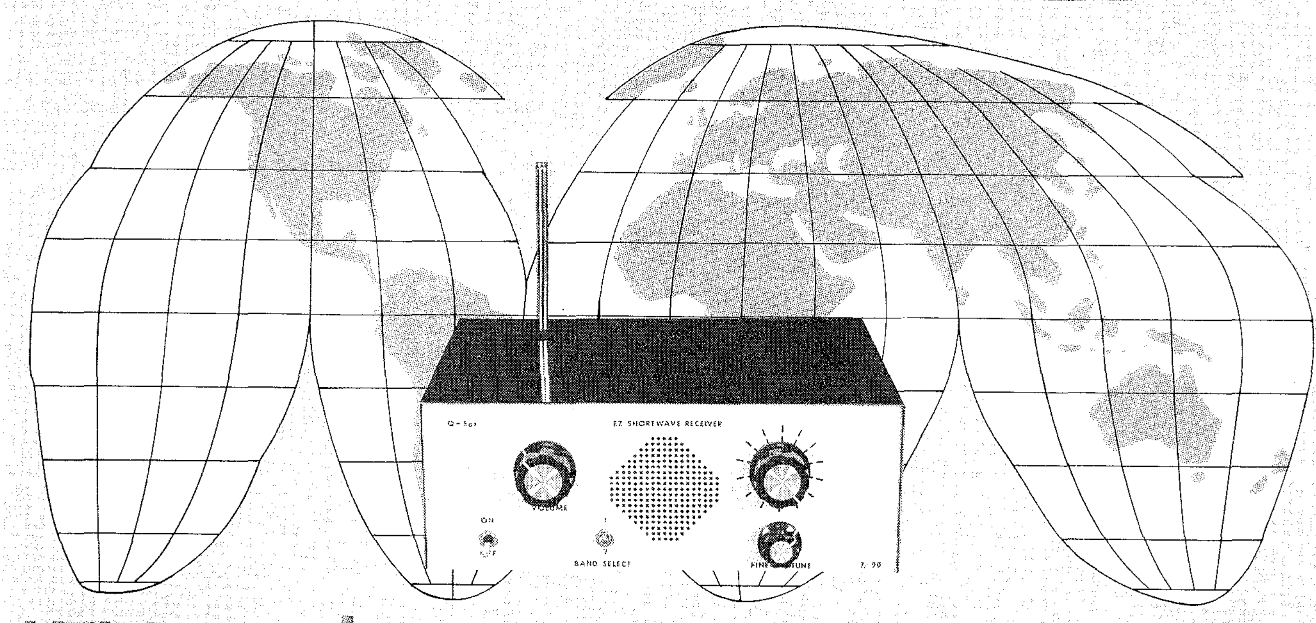
TUNE IN THE WORLD



With R·E's EZ Shortwave Receiver

If you're looking for a fun project that won't break the budget, here's a shortwave receiver that's not short on performance.

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IF YOU'VE ALWAYS WONDERED WHAT you might hear on shortwave radio but didn't have the time or the money to get involved with it, then our simple, inexpensive shortwave receiver is the perfect project for you. It will have you tuning in on shortwave in no time—as a matter of fact, the first evening after the prototype was completed, stations from Germany, England, Cuba, Canada and France were easily copied.

The shortwave receiver is a no-crystal set with an audio amplifier. It's a true superheterodyne that tunes 8.5 to 11 MHz in two bands and includes a 455-kHz IF filter, automatic gain control (AGC), tracking RF tuning, and a very sensitive detector. It's sensitivity of under a microvolt puts it in a class with some high-performance receivers.

Theory of operation

The shortwave receiver takes a very straightforward approach to the classic superheterodyne receiver. The basic block diagram of our "superhet" is shown in Fig. 1, and the schematic is shown in Fig. 2.

The RF input tank, unlike many simple designs, provides "tracking," in that the input tuned circuit changes frequency when the oscillator is tuned. RF tuning is performed by D1, and oscillator tuning by D5. Both diodes are Motorola MV209 varactors, which act as voltage-variable capacitors. RF energy is coupled into pins 1 and 2 of IC1, the Signetics NE602 double-balanced mixer.

The mixer combines the incoming RF signal with the local oscillator and produces an intermediate frequency or IF of 455 kHz. Both mixer and oscillator functions are provided by IC1. Table 1 shows its specifications.

To simplify construction and enhance performance, a ceramic IF filter, FL1, is used instead of a more common tunable IF transformer. That results in a very clean IF that never needs tuning. The filters are available with bandwidths from 4 to 12 kHz to suit individual needs. The shortwave receiver will accept filters with input and output impedances of 2000 ohms.

Turning to the detector circuit, D2 and D3 provide a 1.2-volt bias for diode D4 and Q3. The bias keeps both D4 and Q3 slightly on, so only a small signal is necessary for detection, reducing the gain needed before the detector and improving sensitivity.

The signal at the base of Q3 contains two components. The AC component is the demodulated audio, and the DC component is proportional to the strength of the incoming signal. The DC component is filtered by R20 and C17 and is used to provide an AGC signal to Q2 via AGC amplifier Q4. That helps to reduce fading that is so common on the shortwave bands.

The audio output stage, IC2, is a Motorola MC34119 audio amplifier. It provides about ¼-watt of audio into speakers of 8 to 64 ohms. No large output-coupling capacitors are needed, but a large power-supply decoupling capacitor provides excellent stability.

The prototype operates on a 9-volt battery and, if you listen at moderate volumes, they give you reasonable service. For longer service, use a pack of 6 or 8 "AA" cells, or an AC supply.

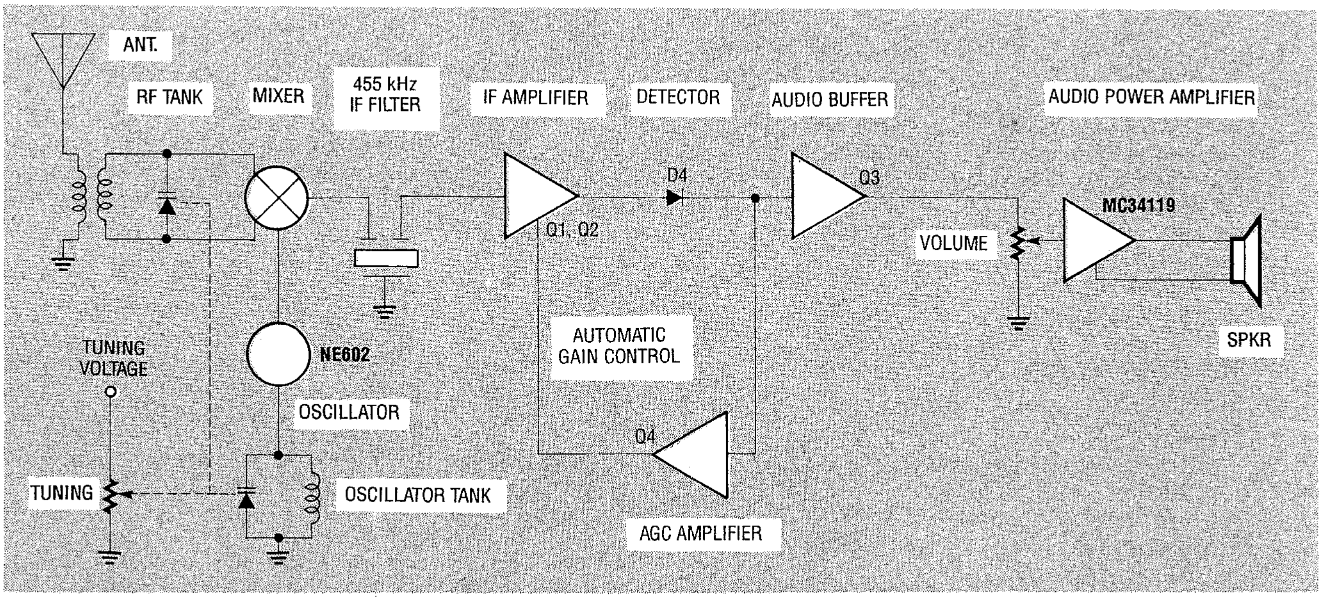


FIG. 1—BASIC BLOCK DIAGRAM of our superhet shortwave receiver. It's a true superheterodyne designed to tune 8.5 to 11 MHz in two bands.

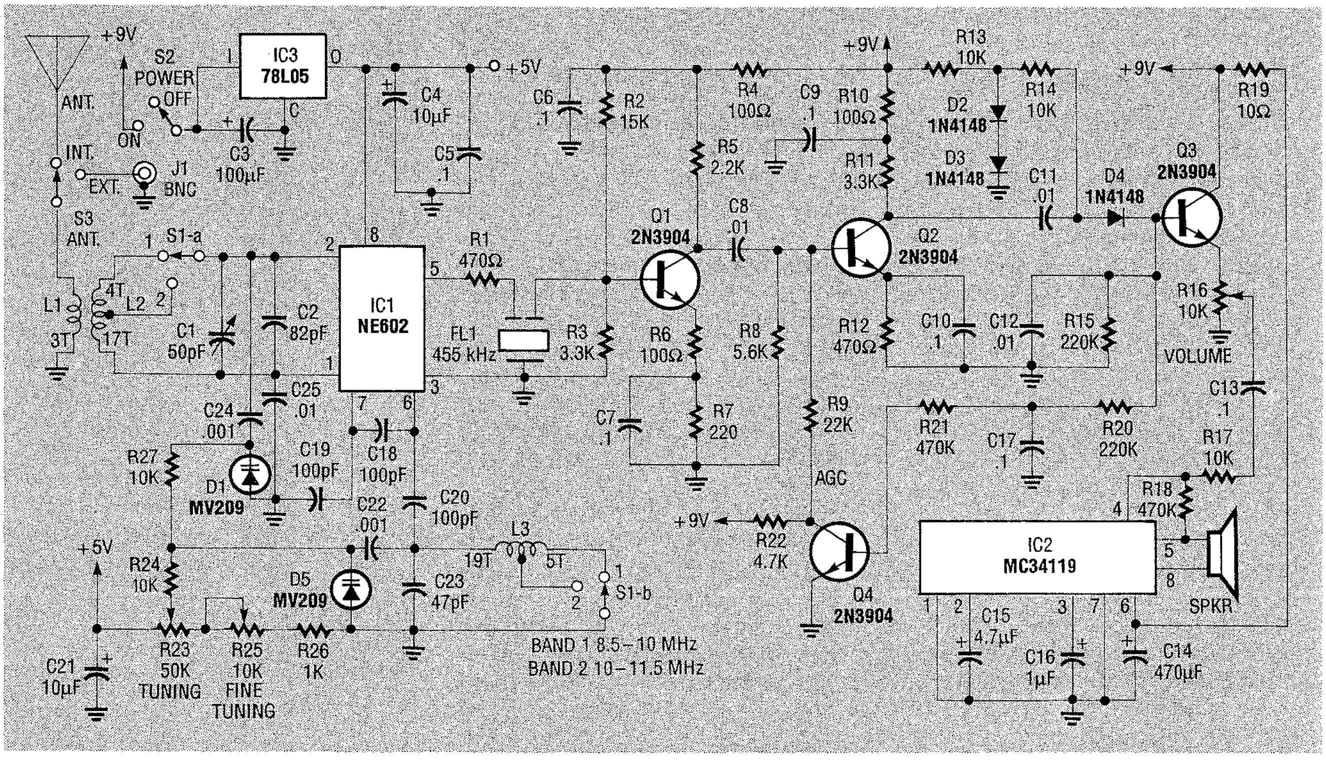


FIG. 2—SCHEMATIC FOR THE SHORTWAVE RECEIVER. The unit is powered from a 9-volt battery, making it very portable. It's sensitivity of under a microvolt puts it in a class with some very high-performance receivers.

Modifications and compromises

Every engineer learns early on that to design is to compromise. Usually performance is traded off for reduced cost. This design is no exception. The basic design philosophy was to produce a reasonable receiver at a reasonable price. In that regard we're very happy with the outcome. We did, however, omit some features, as a result.

Most modern shortwave receivers include a beat-frequency oscillator or BFO. The purpose of the BFO is exactly as its name implies, to beat a local oscillator (LO) signal against the incoming RF to produce a heterodyne frequency in order to copy code (CW) or single side band (SSB). That can be done at either the RF frequency or the IF, although IF BFO's are much more common.

The shortwave receiver's input coupling network provides tuning and impedance matching from the 50-ohm antenna input to the 1500-ohm input of the NE602. A really good receiver would use double or even triple tuning here, for better image rejection and overload performance.

Images, which are produced in the mixing of two signals, are

TABLE 1—BASIC SPECIFICATIONS OF THE NE602

Power supply	4.5V–8V	
Current consumption	2.4 ma.	(typical)
Maximum mixer frequency	500 MHz	(typical)
Maximum oscillator Frequency	200 MHz	(typical)
Noise figure	5 dB	(typical at 45 MHz)
Mixer gain	15 dB	(typical at 45 MHz)
Third order intercept	−17 dBm	(maximum)
Mixer input resistance	1.5k	(typical)
Mixer input capacitance	3 pF	(typical)
Mixer output resistance	1.5K	(typical)
Mixer output capacitance	3 pF	(typical)

very hard to eliminate. Remember that the output of a mixer is the sum and difference of two frequencies. For example, suppose we wanted to receive WWV on 10 MHz using an IF of 455 kHz. Using low oscillator injection, we would generate a local oscillator of 10 MHz minus 455 kHz, or 9.545 MHz.

However, if a frequency of 9.09 MHz was also present at the mixer input, we'd also have an output frequency of 455 kHz because 9.545 MHz minus 9.09 MHz equals 455 kHz. That other undesired frequency (9.09 MHz) is called the image frequency. Some sophisticated techniques, such as image-reject mixers or up-converting receivers are available, but almost all receivers reject the 9.09 MHz at the input tank. The tracking RF tank on our shortwave receiver helps a great deal, but doesn't eliminate the problem.

Overload performance is another important aspect concerning a shortwave receiver. If the RF tank is tuned to 10 MHz, it will let 10-MHz signals pass and attenuate—but not eliminate—signals of all other frequencies. If a 50,000-watt AM station is located close to the tank, *some* of the signal will get through. If enough of it does, you'll hear the AM station as well as the shortwave.

Tests on our active antenna (**Radio-Electronics**, February 1989) proved that an AM-reject filter was necessary to "clean up" our own local 50-kilowatt station. A high-pass filter that will attenuate AM stations by 40 dB is shown in Fig. 3; its low-frequency cutoff is about 2.2 MHz. The filter can be constructed on a piece of perforated construction

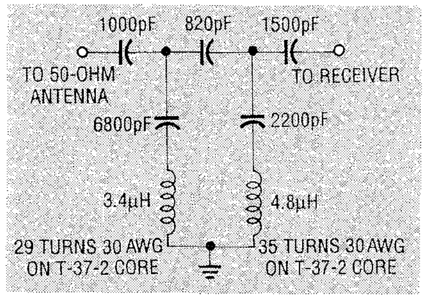


FIG. 3—THIS HIGH-PASS FILTER will attenuate AM stations by 40 dB. Its low-frequency cutoff is about 2.2 MHz.

board using point-to-point wiring.

Construction

Even though this is a low-frequency project, a PC board is recommended; you can make your own from the provided foil pattern or buy a finished version from the source mentioned in the parts list. Figure 4 shows the parts-placement diagram.

Inductors L1, L2, and L3 are wound on toroid cores, so they're much smaller than air-wound coils, and can still be "tuned" by stretching or compressing the turns on the toroids. Remember that a turn is counted on a toroid every time the wire passes through the center of the core. After you tune the coils, the wire can be held in place with epoxy.

Any speaker from 8 to 64 ohms will work with the MC34119. Expect slightly less audio output with higher-impedance speakers. The speaker leads should be twisted tightly and kept short.

If you use stereo headphones, don't connect the ground. Just feed the speaker output through resistors (you'll need to experiment with the value) to the left and right channels. Note that the MC34119 does not ground reference the speaker.

PARTS LIST

All resistors are ¼-watt, 5%.
R1, R12—470 ohms
R2—15,000 ohms
R3, R11—3300 ohms
R4, R6, R10—100 ohms
R5—2200 ohms
R7—220 ohms
R8—5600 ohms
R9—22,000 ohms
R13, R14, R17, R24, R27—10,000 ohms
R15, R20—220,000 ohms
R16, R25—10,000 ohms, potentiometer
R18, R21—470,000 ohms
R19—10 ohms
R22—4700 ohms
R23—50,000 ohms, potentiometer
R26—1000 ohms

Capacitors
C1—9–60 pF trimmer
C2—82 pF, ceramic
C3—100 µF, 16 volts, electrolytic
C4, C21—10 µF, 16 volts, electrolytic
C5–C7, C9, C10, C13, C17—0.1 µF (polyester or ceramic)
C8, C11, C12, C25—0.01 µF, ceramic
C14—470 µF, 16 volts, electrolytic
C15—4.7 µF, 16 volts, electrolytic
C1—1 µF, 16 volts, electrolytic
C18–C20—100 pF, NPO
C22, C24—0.001 µF, ceramic
C23—47 pF, NPO

Semiconductors
D1, D5—Motorola MV209 varactor
D2–D4—1N4148 diode
FL1—455-kHz ceramic filter (8-kHz bandwidth Toko HCFM2-455C)
IC1—Signetics NE602N mixer
IC2—Motorola MC34119 audio amplifier
IC3—78L05 5-volt regulator
Q1–Q4—2N3904 NPN transistor

Other components
L1—3 turns #30 wire on L2's toroid core
L2—21 turns #30 wire tapped at 17 turns on T-37-2 Micro Metals toroid
L3—24 turns #30 wire tapped at 19 turns on T-37-2 Micro Metals toroid
S1—DPDT switch
S2, S3—SPST switch
SPKR—8–64 ohm speaker
J1—BNC connector
Miscellaneous: PC board, metal cabinet, wire, solder, etc.

Note: The following items are available from Q-Sat, P.O. Box 110, Boalsburg, PA 16827. A PC board only (# EZSW-PCB) is $7 plus $1 shipping; a partial kit that includes a PC board (does not include potentiometers, switches, connectors, speaker, or case # EZSW-KIT) is $27 plus $2 shipping; a kit for the AM reject filter (# AMREJ-KIT) is $3 plus $1 shipping; a kit for the active antenna (# ACTANT-KIT, see text) is $15 plus $2 shipping. Pennsylvania residents must add 6% sales tax. Allow 3–5 weeks for delivery.

All receivers need a good antenna; this one is no exception. Although the first field trials were conducted in a state park with 30 feet of wire thrown over a tree limb, a good antenna will greatly improve reception. A dipole will give good results, but if you're cramped for space, try an active antenna (see **Radio-Electronics**, February 1989). A good ground also helps.

The receiver should be installed in a metal cabinet to reduce the effects of hand capacitance and provide some shielding from strong local AM stations. Figure 5 shows the prototype receiver. Note that the active antenna and the 2.2-MHz high-pass filter are used in the prototype, although they are not mandatory. The holes for the speaker were made using a neat trick: Draw the outline on a piece of perforated construction board, and tape the board to the cabinet. Then use the board as a drill guide.

Table 2 is a guide to let you modify the receiver for frequency ranges other than 8.5 to 11.5 MHz (actually 8.5–10 MHz for band 1 and 10–11.5 MHz for band 2) used in the prototype. Don't think of L2 and L3 as tapped coils, but rather as "selectable" coils. For example, L3 is specified as a 24-turn coil with a tap at 19 turns. What that really means is that a coil of either 19 turns or 24 turns is switch-selectable. You could even wind a 45-turn coil with taps at 14, 15, 17, 19, 24, 29, and 34 turns for L3. With the right switch (good luck finding one), you could tune 5 to 16 MHz in 8 bands. Remember that it has to switch the capacitors, as well.

Since the coils must be hand-wound, there will be some variation. Wire size was calculated for no. 30 wire. Other wire sizes may be used but you will find it hard to get as many as 45 turns on a T-37-2 core with larger wire. The spacing of the wire on the core will also change the tuning frequency. The values are given as reasonable starting points. If you wish to build the receiver for some frequency other than the prototype, follow these steps:

1) Build the unit completely except for the two coils.

2) Using Table 2, wind the oscillator coil. Tack the coil into the circuit from ground to the junction of C20, C22, and C23. (That way you won't need the band switch.)

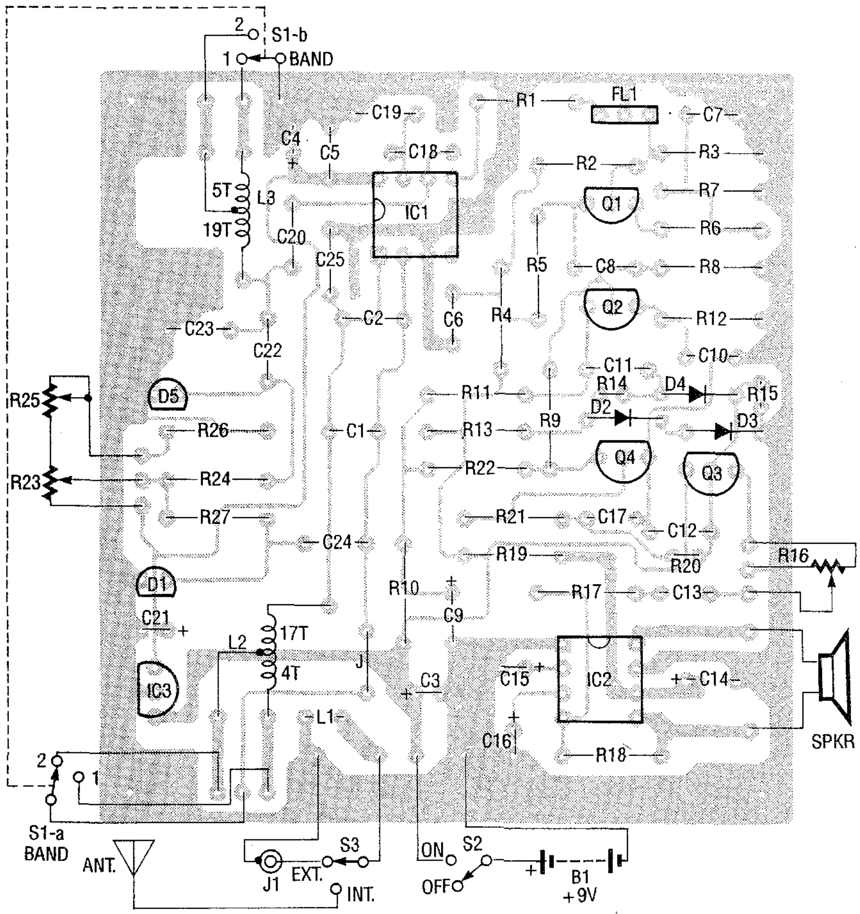


FIG. 4—PARTS-PLACEMENT DIAGRAM. Be sure to install the circuit in a metal project case to help reduce interference.

TABLE 2

Frequency (MHz)	**C2** (pF)	**C18, C19** (pF)	**C23** (pF)	**L1, L2 (Ant)** (# of turns on T-37-2 core)	**L3 (Osc)**
5	100	120	68	5, 41	45
6	100	120	68	4, 30	34
7	82	100	47	4, 26	29
8	82	100	47	3, 22	24
10	82	100	47	3, 17	19
12	82	100	47	2, 15	17
14	68	82	33	2, 14	15
15	68	82	33	2, 13	14

TABLE 3

	NE602	**MC34119**
Pin 1	1.27 V	0V
Pin 2	1.27 V	4.15 V
Pin 3	0V	4.11 V
Pin 4	3.64 V	3.97 V
Pin 5	3.59 V	4.14 V
Pin 6	4.99 V	9.09 V
Pin 7	4.33 V	0V
Pin 8	5.05 V	4.20 V

	Q1	**Q2**	**Q3**	**Q4**
Emitter	0.95 V	0.80 V	0.27 V	0V
Base	1.61 V	1.45 V	0.82 V	0.58 V
Collector	2.56 V	3.30 V	9.17 V	7.41 V

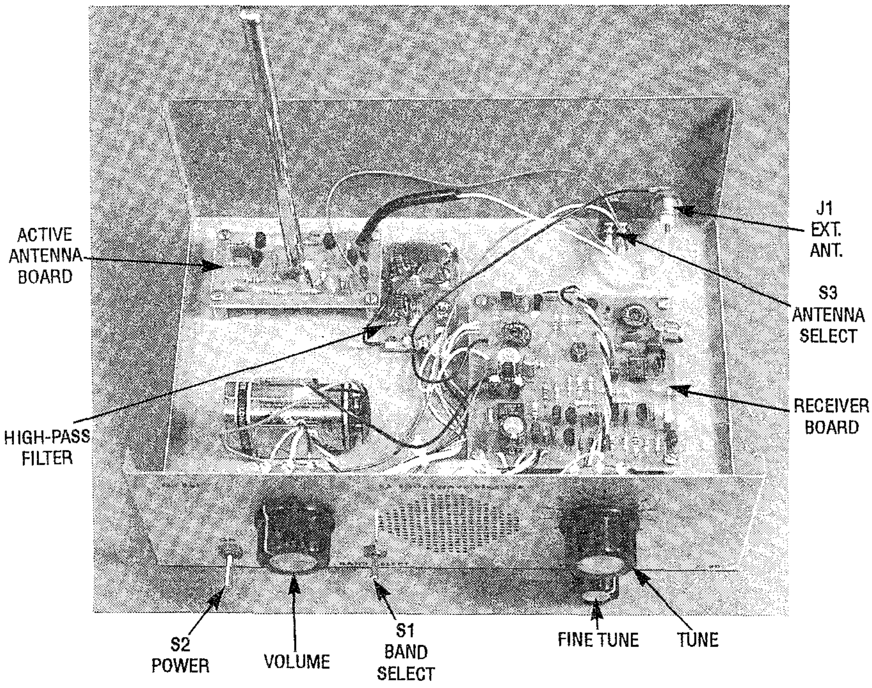


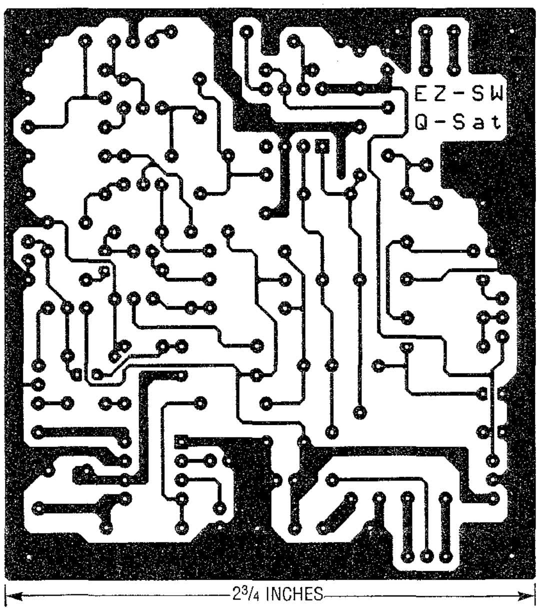
FIG. 5—THE INSIDE OF THE PROTOTYPE RECEIVER. Note that the active antenna and the 2.2-MHz high-pass filter are used in the prototype, although they are not mandatory.

3) Lightly couple a high-impedance scope or frequency counter to pin 7 of IC1; note that the NE602 will not drive a 50-ohm input without a buffer. A 10-pF series capacitor is therefore recommended.

4) Turn the tuning and fine tuning, if you are using one, completely counterclockwise and measure the frequency. Now turn the tuning and fine tuning all the way clockwise and measure the new frequency. If it's lower than the first frequency, you've got the potentiometer in backwards.

5) Add 0.455 MHz to the two frequencies that you have just measured. This is your tuning range.

If you are building the unit for a higher frequency range, say on the order of 14 or 15 MHz, you will find that the tuning range is 2 or 3 MHz. On the other hand, units built for 3 or 4 MHz will tune only about 0.5 MHz. That is caused by the rather small capacitance change of the MV209. Typically, capacitance vs. (reverse) voltage of the MV209 is 40 pF at 1 volt, 26 pF at 5 volts, 14 pF at 10 volts, and 9 pF at 20 volts.



THE FOIL PATTERN for the single-sided board.

Low-frequency tuned circuits require more capacitance than high-frequency tuned circuits. Since the change in capacitance of the MV209 is fixed, it becomes a smaller percentage change with low-frequency tanks than with high-frequency tanks. And you can forget about a series or parallel combination of MV209's. The percentage works out the same as a single one. If you require more tuning range, the best method is to provide a separate, stable tuning voltage of up to 20 volts. Since the current drawn by the diodes is in the microamp range, a separate 9-volt battery may be used. Just remember that as the battery ages, the tuning range will change.

6) If you are satisfied with the tuning range, wind the antenna coil with a turn or two less than the oscillator coil. This is necessary because the input tuned circuit operates at 0.455 MHz higher in frequency that that of the oscillator.

The varactors used in this receiver only need to vary by about 15 pF to cover 8.5 to 10.0 MHz or 10.0 MHz to 11.5 MHz. That can be from 25 to 40 pF, or 0 to 15 pF, or any combination that gives a change of about 15 pF. When the bias voltage is changed from 1 to 5 volts, the capacitance really changes from about 40 pF to 26 pF. If a well-regulated supply of higher than 5 volts but less than 20 volts is available, it may be used to increase the tuning range. Since we're running it on a 9-volt battery, we decided to regulate down to 5 volts. If you decide to operate the varactor on a higher voltage, remember that the NE602 is rated at a maximum of 8 volts. The high side of the tuning potentiometer can be connected to a higher voltage as long as the connection from the PC board to the high side of the potentiometer is left disconnected.

Tuning 1500 kHz with a single-turn potentiometer can be tricky. A "poor mans ten turn" can be made by putting a 10K potentiometer in series with the normal 50K potentiometer for fine tuning. Be careful with the leads going to the potentiometers; any AC signal will "modulate" the oscillator with disastrous results. Since the tuning of a varactor isn't linear with voltage, you may want to experiment with different potentiometers, such as linear, log, or audio.

Troubleshooting

If you have any problems, the DC voltages shown in Table 3 should help. All voltages were taken with a new 9-volt alkaline battery powering the receiver. The volume control is about ⅓ with no signal input. Total current is 22 milliamps. **R-E**