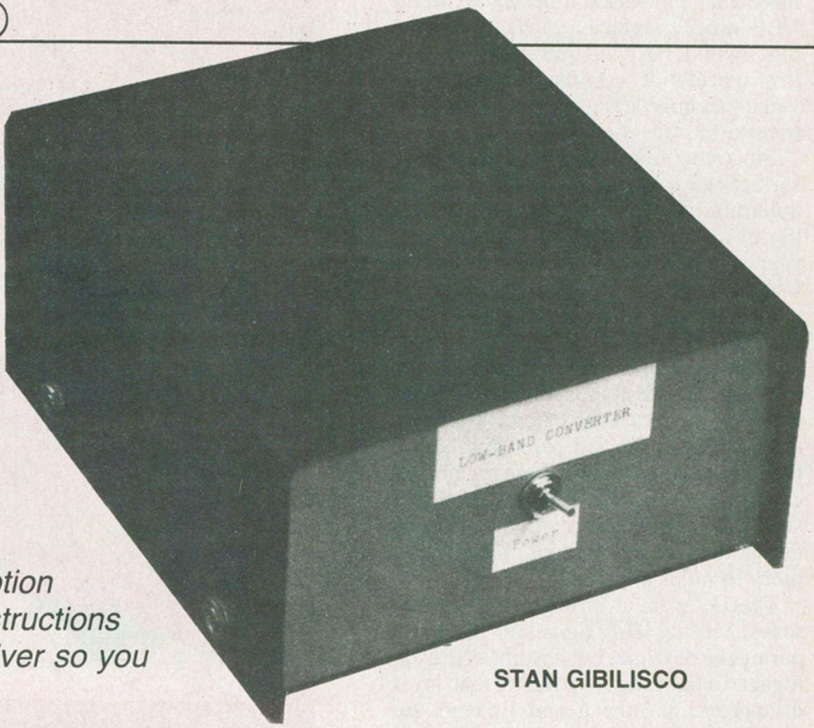
BUILD THIS

LOW-BAND CONVERTER

There's a world of interesting activity on the frequencies below the AM broadcast-band. Here's a description of what happens down there, and instructions for building a converter for your receiver so you can listen in.



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THOSE OF US WHO HAVE SHORTWAVE communications receivers have heard, and are familiar with, the range of the radio spectrum between 535 kHz and 30 MHz; that is the extent of coverage of most of today's shortwave receivers. Some receivers have a "longwave" band with a low-frequency limit of around 200 kHz. There aren't many receivers that operate lower than that; the ones that do are rather expensive. This article is concerned with the relatively-little-known part of the electromagnetic spectrum below the standard AM broadcast-band. In particular, we will be looking at the VLF (*V*ery-*L*ow-*F*requency) and LF (*L*ow-*F*equency) bands, ranging from 3 to 300 kHz. (The VLF band extends from 3 to 30 kHz, and the LF band from 30 to 300 kHz.)

It is not difficult or expensive to receive signals in those frequency ranges. A simple converter can be built from easy-to-find parts for a moderate price, allowing VLF and LF reception with a shortwave communications receiver.

What's below the broadcast band?

There is plenty of activity below 535 kHz, all the way down to 10 kHz in the VLF spectrum. Table 1 shows the frequency allocations below 535 kHz on a worldwide basis. Below 10 kHz, there are no allocations—those frequencies are considered essentially useless, for reasons we will discuss later.

Especially toward the lower part of the LF band (below 150 kHz), and throughout the VLF band, voice-modulated signals will not be found. Such transmissions require too much bandwidth to be used in a part of the spectrum where bandwidth conservation is extremely important. An AM signal takes up at least 6 kHz, and the whole VLF band is only 27 kHz wide! An AM signal at 15 kHz would have to be at least 40 percent as wide as its carrier frequency! Because of those factors, all signals in that frequency range are modulated by means of narrow-bandwidth techniques, such as CW (Morse code) or frequency-shift teletype.

TABLE 1

Frequency—kHz	Service
Below 10.00	Not allocated
10.00–14.00	Radio location, radio navigation
14.00–19.95	Fixed, maritime mobile
19.95–20.05	Standard frequency
20.05–70.00	Fixed, maritime mobile
70.00–90.00	Fixed, maritime mobile, maritime radio navigation, radio location
90.00–110.0	Fixed, radio navigation, maritime mobile
110.0–130.0	Fixed, maritime mobile, maritime radio navigation, radio location
130.0–160.0	Fixed, maritime mobile
155.0–281.0	Broadcasting (Europe, N. Africa, and Middle East)
160.0–200.0	Fixed
200.0–285.0	Aeronautical radio navigation, aeronautical mobile
285.0–325.0	Maritime radio navigation, aeronautical radio navigation
325.0–405.0	Aeronautical radio navigation, aeronautical mobile
405.0–415.0	Maritime radio navigation, aeronautical radio navigation, aeronautical mobile
415.0–490.0	Maritime mobile
490.0–510.0	Mobile (distress and calling)
510.0–525.0	Mobile, aeronautical radio navigation
525.0–535.0	Mobile, broadcasting, aeronautical radio navigation

Propagation below 535 kHz

Radio signals at VLF and LF travel by three basic long-distance modes: surface-wave, sky-wave, and waveguide propagation. Particularly below about 100 kHz, the characteristics of radio-signal travel are alien to the short-wave listener; there is no rapid fading, backscatter, or selective distortion such as commonly occurs at high frequencies.

Surface waves

At VLF and LF, radio signals can travel along the surface of the Earth for great distances, without relying on the ionoshpere for propagation. This mode of propagation (sometimes mistakenly referred to as 'ground-wave' propagation) gets better and better as the frequency decreases. At 535 kHz, surface waves can be heard out to distances of 200 to 300 miles when conditions are good. But, since the Earth is a poor conductor at that frequency, and the return circuit for surface-wave travel is the Earth, the useful range is limited. Most of the energy gets used to heat up the ground.

As the frequency decreases, the ground becomes a better and better conductor. At frequencies around 100 kHz, it is not unusual to hear surface-wave signals from more than a thousand miles away. In the VLF range, surface propagation combines with ionospheric propagation to allow worldwide communications, provided that huge antennas and high-power transmitters are used.

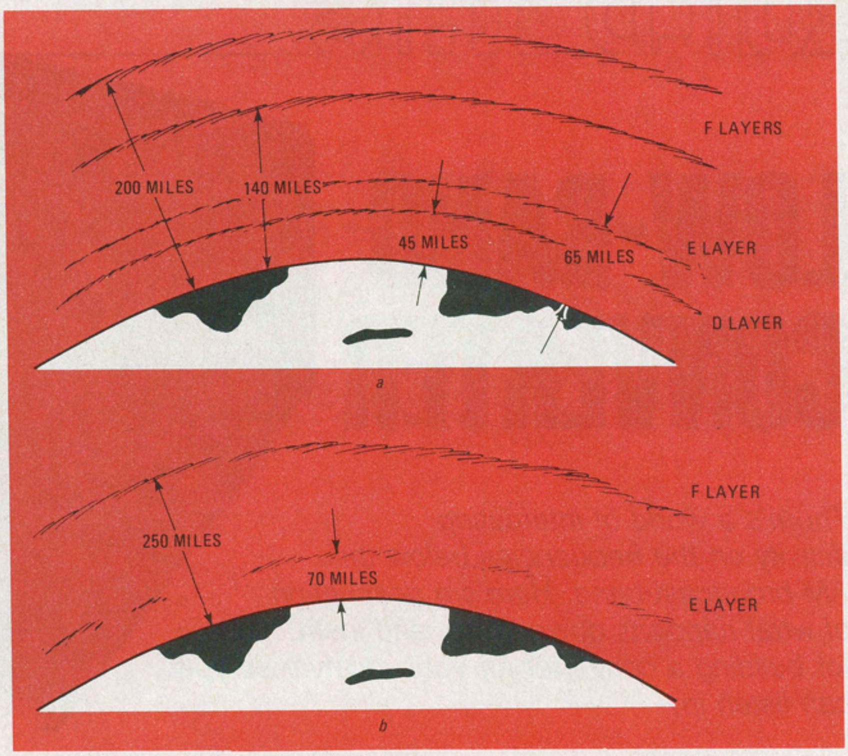

FIG. 1—"D," "E," and "F" LAYERS of the ionosphere assist in LF and VLF propagation. Typical daytime configuration is shown in *a*; "D" layer disappears at night (*b*).

Since the ionosphere plays no role in surface-wave propagation, VLF and LF communications may someday prove useful on planets with no ionosphere to support other modes of over-the-horizon links.

Sky waves

All radio waves having frequencies below 535 kHz are dramatically affected by the earth's upper atmosphere. There are three layers of ionized gases high above the surface of our planet; those regions are called the D, E, and F layers. Figure 1 shows the arrangement of those layers during the day and at night. Typical altitudes in miles are shown.

The D layer, at a height of 37 to 57 miles, returns VLF signals to the Earth during the daytime, but absorbs energy at higher frequencies. At night, that layer disappears, and the E and F layers are responsible for VLF and LF sky-wave propagation. The E layer varies in altitude from about 62 to 71 miles and the F layer may be anywhere between about 130 and 261 miles up. The F layer is generally higher at night than during the day.

VLF and LF energy is almost totally reflected by the ionosphere, and hardly any of it escapes into space; furthermore, no VLF or LF signals from outer space can penetrate to the Earth's surface. That creates a "trap" for such energy, and insures that over-the-horizon communication is always possible.

Sky-wave and surface-wave modes, acting together, don't always reinforce each other. If, at a certain distance from the transmitting station, the surface-wave and sky-wave signals are equally strong but opposite in phase, they will cancel each other, and no signal will be heard. That effect becomes more common as the frequency increases.

Also, as frequency increases, the D layer gets more and more absorptive. That reduces the effectiveness of sky-wave communications during the daylight hours. But the D layer disappears at night, and that is why we usually hear LF stations from farther away at night. The same effect occurs throughout the AM broadcast band, and no doubt you have observed the difference between daytime and nighttime propagation there.

Waveguide effect

The ionospheric D layer and the Earth's surface both form almost perfect reflectors of VLF energy. At VLF, the waves are so long that the distance between the ground and the D layer is only a few wavelengths. (For example, a 10-kHz signal has a wavelength of 18.6 miles, but the D layer is 37 to 57 miles high—just two or three wavelengths.) That gives rise to a daytime condition where VLF energy travels within the chamber between the Earth and the D layer as if that space were a waveguide transmission-line.

Waveguide propagation is an extremely reliable means of communication at VLF, with no fading or "dead zones." Waveguide propagation is best during daylight hours, since the D layer disappears at night, leaving only the E and F layers, which are too far above the Earth to serve as good waveguide reflectors.

Since all waveguides have a high-pass frequency response, there is a lower limit on the frequencies that can be used for long-distance propagation. If the wavelength is too great, the Earth-to-D-layer waveguide will be too small to support propagation. The frequency at which attenuation begins to increase rapidly is about 10 kHz. Below that, especially during the daylight hours, the waveguide effect is of little use for long-distance communications. So severe is the loss, in fact, that frequencies below 10 kHz are not allocated for communications.

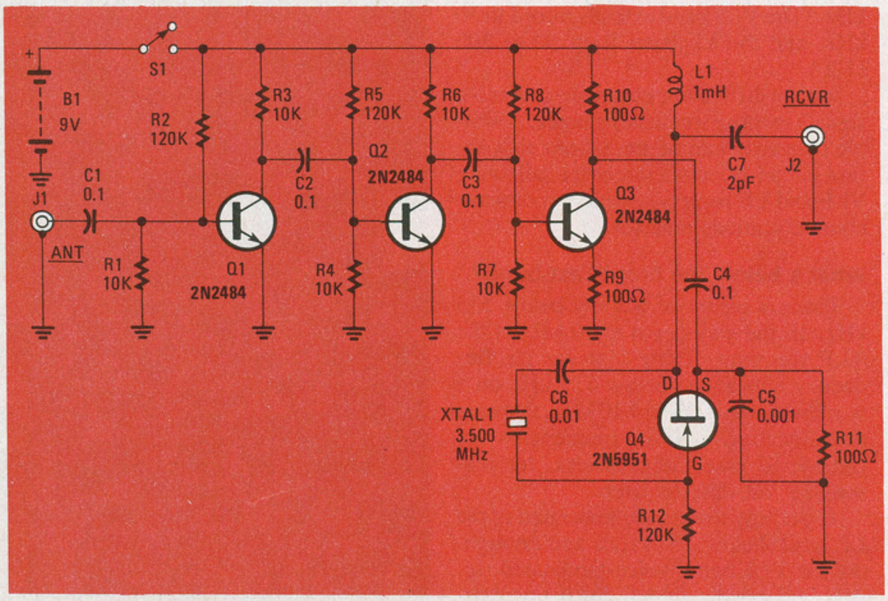

FIG. 2—COMPONENTS USED IN LOW-BAND CONVERTER are readily available. Crystal may be ordered from companies advertising at back of magazine.

Methods of reception

Building a complete, self-contained, receiver that covers 10 to 535 kHz is not easy. The top frequency is more than fifty times greater than the low one; that's equivalent (in terms of percent) to the range from the middle of the AM broadcast-band to TV channel 2! The only practical way in which you can obtain reception over such a wide band is to build a converter for an existing high-frequency receiver.

The converter described here "moves" the 10-to-535-kHz band to the 3.510-to-4.035-MHz range for reception on shortwave receivers. That output range was selected so as to be compatible with amateur-band equipment. The converter's output falls nicely into the 80-meter ham band (3.5–4.0 MHz).

What kind of receiver should you use? It must have a BFO (*B*eat- *F*requency *O*scillator). It should be frequency-stable (as drift-free as possible) and have good selectivity. A ham receiver is ideal, especially if it has a narrow-bandwidth filter for CW reception. It also helps to have a noise blanker or limiter, because man-made impulse-noise is a problem at VLF and LF. Other than those requirements, any sort of receiver with fairly accurate dial-calibration is alright: solid-state or tube-type, battery-powered portable or a 50-pound boat anchor from the pre-World-War-II era!

A simple converter

Figure 2 shows the a schematic diagram for a low-band converter. Three stages of broadband amplification (Q1, Q2, and Q3) are used. The crystal oscillator/mixer, Q4, provides an amplitude-modulated (AM) signal, with the carrier at 3.500 MHz. That signal is fed to the antenna input of the receiver. The VLF and LF signals appear as sidebands above and below the carrier. The upper sideband (3.510 to 4.035 MHz) is easier to use because the signal frequency is easier to determine—just subtract 3.500 MHz from the receiver dial readout. (If you use the lower sideband the reception will be just as good, but the band will come out "upside down" in the receiver, and frequency determination will be tricky.)

The parts for the converter are inexpensive and easy to find. Most, if not all, should be available from advertisers in **Radio-Electronics**. Parts for antenna construction will be described in the text, and are not included in the Parts List.

Construction

The converter circuit can be built on perforated construction board or on an "experimenter board" such as those available from Radio Shack and others; I used the latter.

If you use an "experimenter board," note that the holes are interconnected by foil on the underside of the board in groups of four. The 20 × 20 matrix of holes is labeled on each axis by the numbers 1 through 20 and the letters A through T printed on the underside of the board. It helps to place a piece of adhesive paper on top of the board, punch out all the holes with a sharp instrument, and label the rows and columns for easy reference.

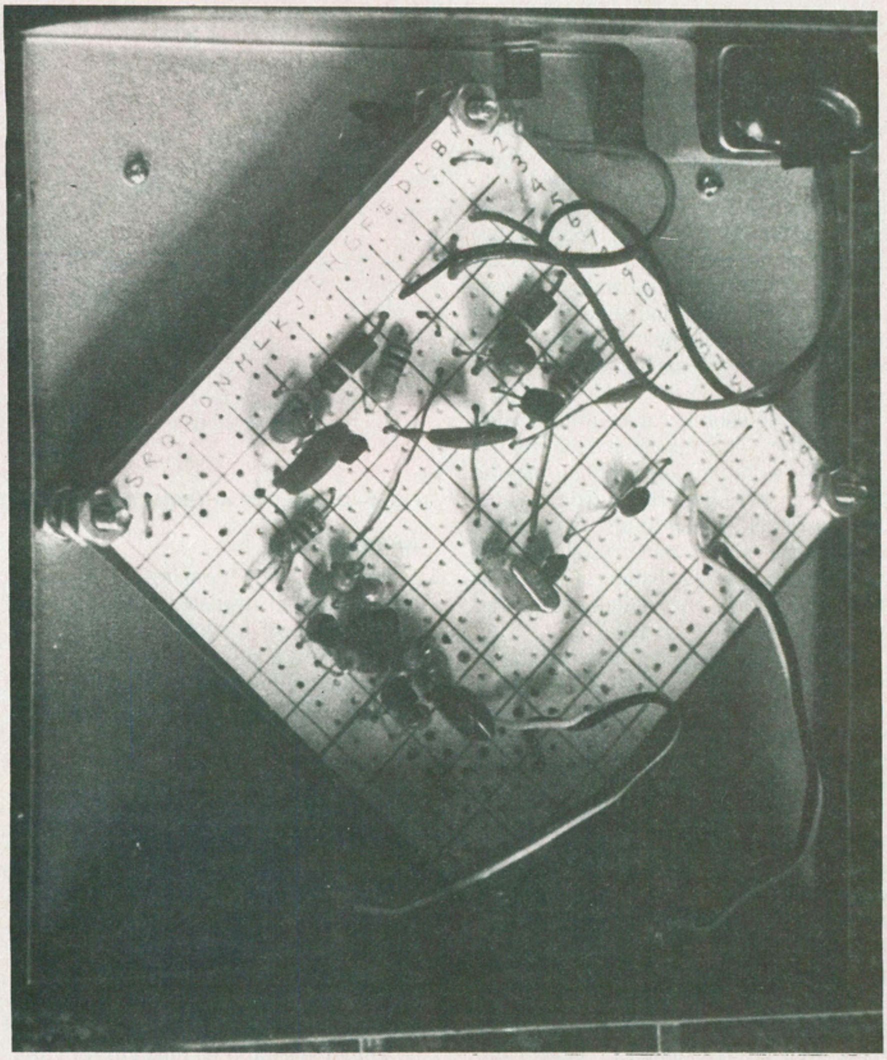

FIG. 3—COMPONENT PLACEMENT is not critical. Letters and numbers at edge of board simplify design work.

The parts layout I used is shown in Fig. 3. Install the jumper wires first. Then install the resistors, capacitors, crystal, and choke. Resistors should be mounted vertically when the holes are adjacent (as is the case with R1 through R6). Install the transistors and external-connection wires last. Be careful not to use too much heat when soldering the transistor leads.

Drill two ¼-inch holes in the rear panel of the metal cabinet, and one ¼-inch hole in the front panel. Also drill four ⅛-inch holes at the corners of a 3¼-inch square (assuming you're using the same type of board I did) on the bottom of the chassis. (It's not critical how the square is oriented, but the holes should be well away from the rubber feet on the underside of the chassis.) Mount the SPST switch on the front panel and the two female phono-jacks on the rear panel. Don't forget solder lugs for the ground connections to the phono jacks.

The four corner holes on the circuit board must carefully be enlarged with a drill to ⅛-inch before mounting. After that's done, put four 6-32 screws into the chassis mounting-holes from the outside of the enclosure, and secure them with one nut apiece. Put a second nut on each screw and move it down until it is ⅜-inch from the end.

Push the circuit board down into the screws and, once the board has been pushed down to the middle nuts, screw on the last four nuts to keep it there.

Connect the SPST switch and the input and output jacks to the board; label the jacks to avoid possible confusion later. Connect the 9-volt battery, and secure it in a convenient place with a battery clip or double-sided tape. Be sure none of the wires short to any other circuit point.

Preliminary testing

Now you're ready to test the converter. Use a shielded cable to connect the output of the converter to the antenna terminals (or jack) of the shortwave receiver. Tune the receiver to 3.500 MHz. When you switch the converter on you should hear a strong unmodulated carrier on or near that frequency. Turn the receiver's BFO on (or switch the receiver to the USB position), and tune in the carrier until you get a zero beat (the tone pitch gets too low to hear). Set the receiver's dial to read exactly 3.500 MHz. If your receiver has both "main-tuning" and "bandspread-tuning" controls, set the bandspread control to 3.500 MHz and tune the main-tuning knob for zero beat. Leave the BFO on, or leave the MODE switch in the USB position.

What if you don't hear anything around 3.500 MHz? That means that the oscillator is not working. The problem may be improper wiring, including solder bridges or cold-solder joints; an incorrect component-value; a bad crystal; a faulty component; or a dead battery. (I had a lot of trouble getting my oscillator to start up until I replaced the crystal.)

To check the amplifiers and modulator, plug a piece of wire about 20 feet long into the input of the converter. You should hear a loud buzz at VLF frequencies, and possibly well up into the LF band. You may also hear a lot of carriers. If you don't, there is something wrong with one of the amplifier stages. Again, check for improper wiring, an incorrect component value, a faulty component, or a weak or dead battery. Once you are sure that the circuit is working, you're ready to put up an antenna.

Not just any old wire lying on the ground, or thrown up into a tree, will work well at VLF and LF. Unless the right kind of antenna is used, all you'll hear is an overwhelming conglomeration of interference including AC-line buzz and cross-modulation products from the AM broadcast band.

Antenna systems

The importance of a good ground system cannot be overemphasized for low-band reception. Preferably, the house utility-ground should be used; look for a pipe running down the electric meter into the ground. Cold-water pipes will also work fairly well, but don't try hot-water or heating-system pipes. The ground connection should be made to the shield at the antenna-end of the coaxial cable used to connect the antenna to the converter.

For low-band reception, a loop antenna generally works best. It should be in a vertical plane, since VLF and LF signals tend to be vertically polarized. Such an antenna can easily be tuned to the desired frequency, and has a narrow bandwidth, which is a necessity for rejection of noise and cross-modulation distortion products. There are two possible configurations for a loop-type receiving antenna: the open loop and the ferrite loopstick. Both are shown schematically in Fig. 4.

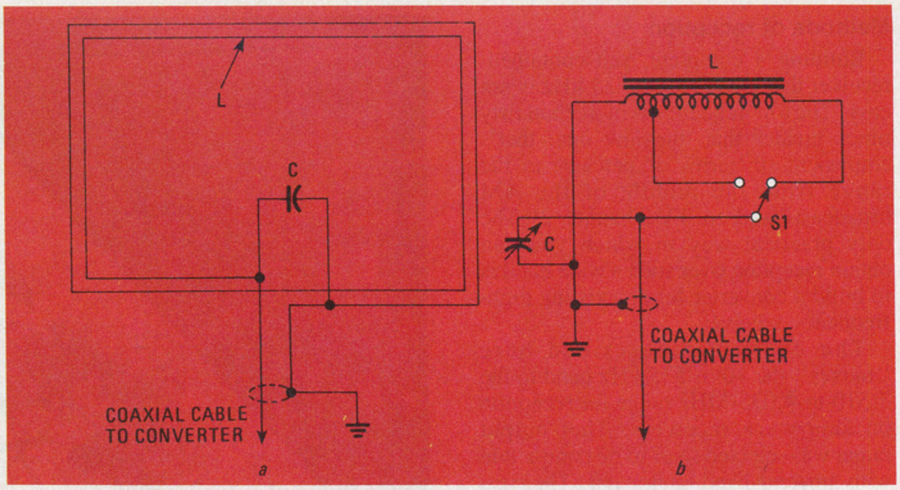

FIG. 4—OPEN-LOOP ANTENNA is shown in *a*; ferrite loop at *b*.

PARTS LIST

All resistors ¼-watt, 5%, unless otherwise specified
R1, R3, R4, R6, R7—10,000 ohms
R2, R5, R8, R12—120,000 ohms
R9–R11—100 ohms
Capacitors
C1–C4—0.1 µF, ceramic disc
C5—0.001 µF, ceramic disc
C6—0.01 µF, ceramic disc
C7—2 pF, ceramic disc
Semiconductors
Q1–Q3—2N2484 or equivalent
Q4—2N5951 or equivalent N-channel JFET
XTAL1—3.500 MHz, parallel-resonant, 20 pF (if necessary, a crystal of another frequency may be used)
L1—1 mH
J1, J2—RCA phono jack, chassis mount
S1—SPST toggle switch
B1—9-volt transistor battery
Miscellaneous: "experimenter board" (see text), wire, battery clip, metal enclosure, antenna materials (see text)

An open loop

An open loop consists of eight to twelve turns of insulated wire, mounted in the shape of a square, rectangle, or circle against a non-metallic wall, or between two non-metallic supports. The loop should have a radius of at least two feet. The larger the enclosed area of the loop, the better the signal pickup will be; reception also improves with the number of turns used. Excessively large loops, however, will pick up a great deal of AC buzz and appliance noise, so there is a practical maximum size-limit. That limit will depend on the amount of noise in your area, and will have to be determined by experimentation. The loop should, of course, be placed as far away from AC wiring as possible.

The loop should be tuned to, or close to, resonance at the desired frequency by means of a capacitor connected in parallel with it. The resonant frequency for a given capacitance C depends on the loop inductance L. Assuming that the loop is at least several feet away from large metallic objects, its inductance can be found from the formula:

$$L = \frac{N^2 \sqrt{A/\pi}}{9000}$$

where L is in millihenries (mH), A is the enclosed area of the coil in square inches, and N is the number of turns. If the coil is a perfect circle of radius r inches, then:

$$L = \frac{N^2 r}{9000}$$

Once you know the inductance of the loop, you can determine the amount of capacitance needed for a given frequency *f*, according to the formula:

$$C = \frac{1000}{4\pi^2 f^2 L}$$

where L is again in mH, *f* is in kHz, and C is in microfarads (µF).

The capacitance values generally required to tune an open loop to resonance range from about 100 pF at 535 kHz to as much as 0.5 µF for small loops at VLF. It is impractical to use variable capacitors for tuning an open loop over a wide range of frequencies, simply because they don't make them big enough! That means you will have to switch among several fixed capacitors to obtain wide-band coverage. The easiest way to do that is to use a decade capacitance-box. Ceramic, Mylar or mica capacitors are best; don't use electrolytics.

It is important that the tuning capacitors be placed at the antenna, and not at the converter end of the feed line because the line capacitance will have a detrimental effect on selectivity toward the upper end of the LF band. That will allow more cross-modulation distortion from the AM broadcast-band and give the illusion of LF signals where there are none.

A ferrite loopstick antenna

The inconvenience of having to switch among fixed capacitors for frequency adjustment can be overcome by the use of a ferrite loopstick antenna. (That's the kind of antenna that you find in most

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small, transistorized AM radios.) The arrangement shown in Fig. 4-b can be tuned from 10 to 60 kHz or from 60 to 360 kHz, depending on the amount of inductance that is switched in by S1. The ferrite rod should be as big a one as you can get—5 × ⅜-inches is a good size to work with. The capacitor can be any common 365-pF or 400-pF receiving-type air variable. The exact number of turns needed on the ferrite rod, and the position of the tap, will depend on the size and permeability of the ferrite rod used. The inductance required to tune 10 to 60 kHz is 685 mH, and the inductance required to tune 60 to 360 kHz is 19 mH. Winding data is generally given with ferrite rods; the values can also be found by trial and error. Use fine enameled wire, such as No. 30 or 32, for winding.

One advantage of the ferrite loopstick is that it can be easily positioned to null out man-made noise. Heating pads, electric blankets, vacuum cleaners, and hair dryers are notorious for their ability to saturate the electromagnetic spectrum with noise well up into the VHF range; at VLF and LF, they can be devastating! By turning the loopstick in both the vertical and horizontal planes, that kind of noise, as well as the AC buzz that always seems to hinder VLF reception, can be nearly eliminated. A ferrite loop will also provide you with a sharper degree of selectivity than an open loop. That insures still more noise immunity.

The principal disadvantages of the ferrite loopstick are lower signal-capturing ability because of its smaller physical size, and the difficulty of locating a rod big enough to wind an inductor of 685 mH. A military surplus shop is a good place to look for large ferrite rods. Electronics outlets also may carry them.

My preference is the open loop, primarily because of its superior signal-pickup and ease of construction. At times, someone runs a hair dryer or vacuum cleaner, but my ham-band receiver has an excellent noise blanker, and that is satisfactory under all but the worst conditions.

Dealing with noise

The tuned-circuit resonance provided by the parallel capacitors, both with the open loop and the ferrite loopstick, give some noise reduction because they cause the antenna to have a narrow-band response. Both antennas can be mounted on azimuth/elevation bearings (although that's very difficult with a large open loop), and positioned for minimum noise. If it cannot be rotated for a null in the noise, the open loop can be used with a noise-cancellation circuit that often works remarkably well. Such a circuit is shown schematically in Fig. 5.

Both the loop itself, and the noise-pickup wire P, receive impulse noise generated by the surrounding appliances and utility wires. But the loop receives far more of the desired signal-energy than wire P. Noise cancellation is obtained by first finding the loop connection (via S1) that causes the noise picked up by the loop to be out of phase with the noise from P. Capacitor C1 is then adjusted until the noise inputs from P and from the loop are equal in amplitude. At that point, there will be a sharp drop in the receiver noise, but the signal level will not be affected.

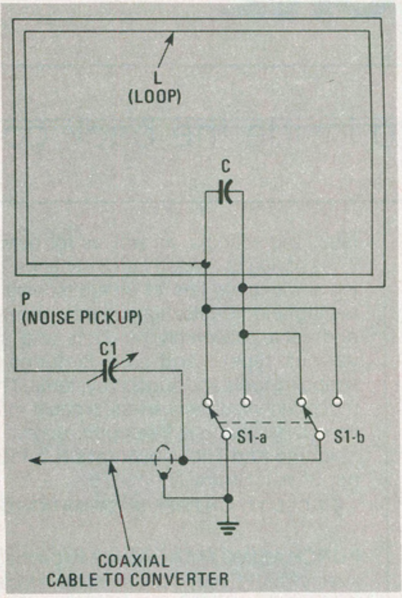

FIG. 5—OUT-OF-PHASE signals from wire "P" and loop "L" provide noise-cancellation.

It may be necessary to experiment with various lengths of wire for P. If your receiver has a signal-strength indicator (S-meter), the task can be simplified by noting the noise level with the loop only, and then adjusting C1 for an equal noise level using P only. If the noise level is always lower when using P alone than when using the loop alone, you will have to lengthen P. If the noise level is higher with P alone, you will have to shorten it. Ideally, C1 should be at the middle of its tuning range when the noise pickup is equal from both antennas.

Once the two antennas are tied together, there will be some mutual-coupling effects that will require you to change the setting of C1 somewhat. However, the above method should bring you close to the required length for P and the required setting for C1.

The noise-cancelling circuit just described usually works better at VLF than at LF-or-higher frequencies, and is more effective against some kinds of noise than others. It will be of little value in reducing AM-broadcast cross modulation or atmospheric static. Still, I've found that it allows much better reception in the VLF range, as compared with an open loop by itself. **R-E**