VLF Active Antennas

Because of poor antenna performance, the low frequencies are, as a rule, neglected by shortwave listeners. This series of articles will show you how you can overcome those problems and hear what you've been missing. The principles we'll discuss can even be used for reception up to 30 MHz.

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GENERAL-COVERAGE COMMUNICATIONS receivers that are capable of continuously tuning from 10 kHz to 30 MHz are becoming ever more popular. However, users are often disappointed with their performance at the extreme low end of the spectrum—but it's not always the receiver that's to blame. Often, poor VLF (*V*ery *L*ow *F*requency) performance is due to the use of an untuned, random-length antenna. Such antennas are often used because of the difficulty of building a full-size VLF antenna. As, we'll soon see, however, full size antennas, aren't always necessary for good reception at low frequencies.

This series of articles will introduce you to practical active-antenna systems that are physically very short. For example, Fig. 1 shows some experimental wide-band active antennas using whips that are just one-meter long. The casual SWL or VLF-LF listener with an appropriate receiver will get good results using those—provided that appropriate attention is paid to such things as antenna location, interference considerations, circuit construction, and ground systems.

Active antenna basics

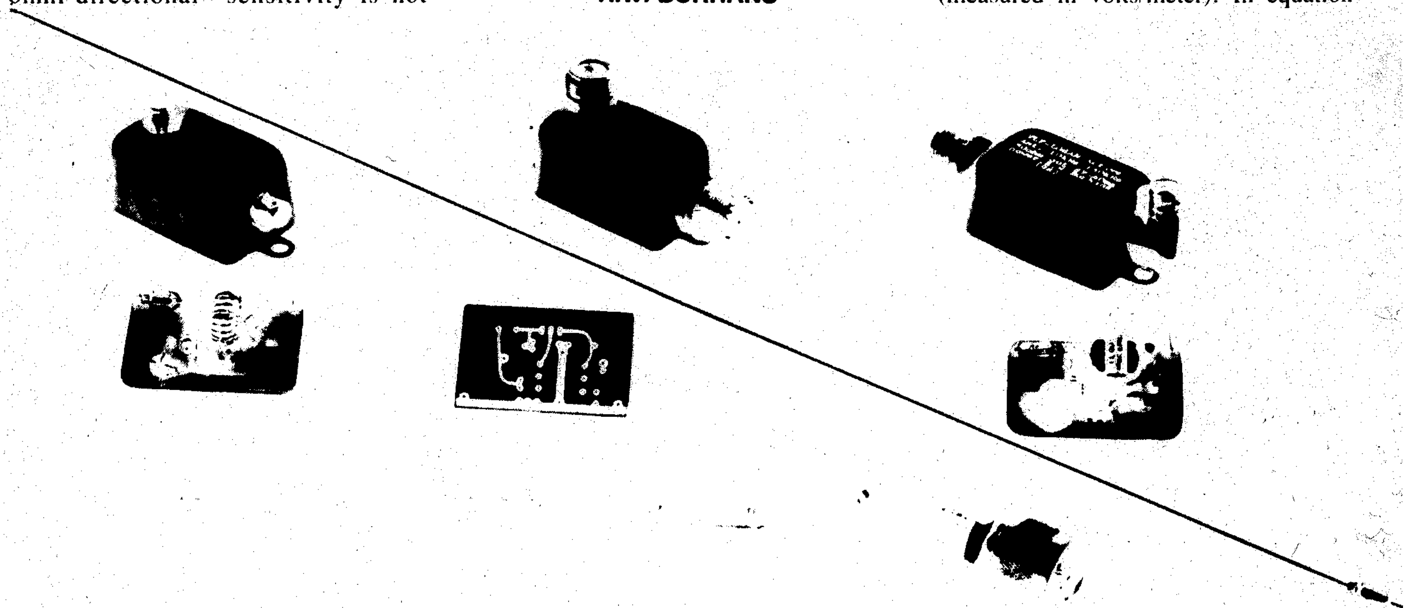
In this discussion, we will restrict ourselves to active systems using vertical whips. Loop antennas are very useful but tuning, coil changing, and an entirely different type of circuitry are needed for that type of active antenna system. Short whips are usually easier to make and operate, but have the disadvantage of being more sensitive to local noise (power-line noise, for example). Loop antennas are directional—they have to be oriented with respect to the signal for best sensitivity. On the other hand, vertical whips are omni-directional—sensitivity is not affected by the antenna's orientation.

Typical active antenna preamplifiers operate primarily as impedance converters or current amplifiers—they convert a small input-signal voltage at a high-impedance input to nearly the same voltage at a low-impedance output. A coaxial cable is connected from the output to the receiver's low-impedance antenna input (typically 50 to 500 ohms). As is common in many TV antenna-mounted preamplifiers, the power for operating the active preamplifier uses that same coaxial cable. There are, however, basic differences between the VLF-HF systems and the TV-type active preamps. For example, the VLF-HF active antenna must have a higher input impedance and more attention must be paid to the details of the amplifier's dynamic range and distortion. Another difference is that the frequency range covered by the VLF-HF preamplifier is a couple of orders of magnitude greater than that covered by the TV-FM units.

Active antenna preamplifiers mounted at the base of a short whip antenna are most often used at low frequencies (10 kHz to 100 kHz). There, the antenna length is much less than .001 wavelength. The general rule in airborne or marine VLF communications, or Omega and Loran-C navigation systems is to use a short active-antenna system .

Antenna sensitivity

Let's now introduce the concept of *effective length* (l_e). (In low-frequency usage, that is sometimes referred to as effective height). The effective length of an antenna is equal to the ratio of the voltage at the antenna output terminals to the field strength of the input signal (measured in volts/meter). In equation



form that is stated as:

$$\frac{V_{OUT}}{E_i} = l_e$$

The ratio of the effective length to the physical length (l) is a measure of the antenna efficiency. For example, an antenna with a physical length of 100 cm could have an effective length of 20 cm. The resulting output signal strength E_o would then be only one fifth that of the input.

The effective-length-per-unit-length of an active antenna can be estimated by determining the input capacitance of the system. That input capacitance includes the antenna-mount capacitance, C_m; the input-wiring capacitance, C_g, and the antenna-whip capacitance, C_a. (See Fig. 2-b.) The relationship is:

$$\frac{l_e}{l} = \frac{C_a}{C_a + C_m + C_g} \quad (1)$$

A typical one-meter long whip antenna might have a measured C_a of about 10 pF over a flat ground plane. Also, an antenna mount might have a fixed capacitance of C_m = 5 pF and the input wiring and active circuit capacitance might be C_g = 8 pf. The efficiency for a system with those values would be:

$$\frac{10}{10 + 5 + 8} K = \frac{10}{23} K = 0.434\ K \quad (2)$$

The factor K (which was assumed to be equal to 1 in equation 1) is a measure of the nearby shielding or coupling effect of the local ground plane (trees, structures, buildings, etc.). In practice, K is always less than one. A value of 0.75 might be obtained with a top-hat capacitive-loaded vertical antenna mounted on a pole or structure such that the local ground plane slopes away from the antenna on all sides. Values of K as low as 0.1 might be possible for a low horizontal wire with trees or buildings close to and higher than it. For example, let's presume that the K of equation 2 was equal to 0.5. The effective length would then be 0.434 × 0.5 = 0.217 meters. That is typical of what is actually observed with a medium-quality active antenna with a length of 1 meter. Another way of thinking about that antenna is to say that its efficiency, in terms of converting the input field strength to a corresponding level at the output terminal, is about 21.7%.

Because of the coupling factor, an active antenna mounted up in the clear will generally outperform an antenna mounted near obstructions. At VLF frequencies, a hill or mountain 0.5 km away from the antenna can reduce the antenna's sensitivity. Precision measurements of the phase and amplitude of 100-kHz Loran-C signals, made while flying over hilly terrain at low altitudes, can yield information about the variations of ground conductivity and terrain contours, which are related to K.

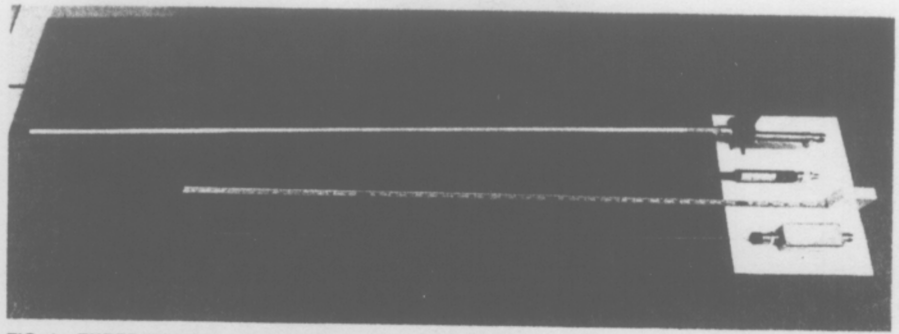


FIG. 1—EXPERIMENTAL WIDE-BAND ACTIVE ANTENNAS. The ones shown here are approximately one meter (39.47 inches) long. The tape measure is pulled out to 41 inches.

Input impedance

Active antenna receiving preamplifiers at frequencies of about 10 kHz have a high input impedance (greater than 1 megohm). That is because of the low antenna capacitance (C_a). Thus, the whip antenna can be considered to be a voltage source with a high internal impedance when coupled to the preamplifier input terminal (see Fig. 2). That internal impedance becomes lower as the frequency of operation is raised—reaching a value around 10,000 ohms at the AM broadcast band (1-MHz region).

If a short whip were connected directly to a 500-ohm receiver input terminal, a LF signal would be greatly attenuated as a result of the mismatch. For example, let's look at what would happen to a 10 kHz signal. The reactance of C_a for a 1-meter whip would be about 1.6 megohms at 10 kHz. Without an active preamplifier, the attenuation would be about 500/(1.6×10^6 + 500) ohms, or roughly −72 dB! If, on the other hand, an active preamplifier were used, the same 1-meter whip would provide ample signal at 10 kHz, as the source would be much more closely matched to the load.

The effective capacitance of a wire antenna is approximately 10 pF/meter. Thus, at 10 kHz, a 30-meter wire antenna directly connected to a 500-ohm receiver-input terminal is a 50,000-ohm reactance. Another way of looking at that is to say that the antenna efficiency is 500/50,000 = .01, or 1%. At 10 kHz, our 21.7%, 1-meter active antenna looks much better than that 30-meter wire.

As we go higher in frequency, up to the 30-MHz region, the impedance of the 1-meter whip decreases to the point where it could be connected directly to a low-impedance receiver input. Hence, active, high-input-impedance antenna systems are most useful at the VLF-LF range (usually below 500 kHz); at those frequencies they can perform as well as a very-long-wire antenna that is connected directly to the receiver's low-impedance input.

Antenna noise levels

In airborne applications, for aerodynamic considerations and to minimize interference, it is desirable to use as small an antenna as possible in the VLF range. A recent FAA report suggests a minimum effective length of about 20 cm when operating at 100 kHz (Loran-C). An active antenna with a 20 cm l_e will provide an output signal level of 20 μV across a 50-ohm receiver input terminal when it is immersed in a 100 μV/meter electric field.

The antenna noise level found in a receiver is a function of the receiver bandwidth. A typical Loran-C reciever might have a noise level of perhaps 1000 μV/m. Thus, a weak Loran-C signal may be buried in noise to the 100 μV/1000 μV, or −20dB S/N level at the antenna input,

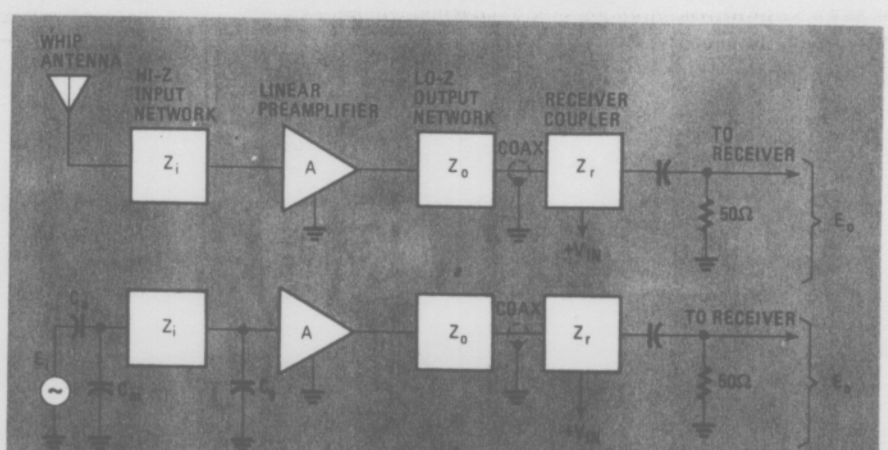


FIG. 2—BLOCK DIAGRAM OF AN ACTIVE ANTENNA is shown in *a*. The whip antenna is replaced by its equivalent circuit in *b*.

even though the total signal and noise level (S + N) is quite high at the preamp output. That is a general characteristic of most VLF-LF receiver systems. The antenna noise is much larger than the receiver-circuit noise levels by at least an order of magnitude.

Figure 3 is a chart that shows the magnitude of the atmospheric noise level (in the midwestern United States at 170 kHz) as a function of the receiver bandwidth. Summer afternoons are dominated by the noise of thundershower spherics. They produce a typical noise level of 100 μV/m (40 dB above 1 μV/m) in a receiver with a 400-Hz bandwidth. In the morning, summer noise levels are lower. Lower still are the winter noise levels, which are usually less than 1 μV/m. However, in the winter, the antenna becomes less sensitive despite the reduced noise level. That is due to the lower conductivity of ice and frozen ground. For example, propagation of VLF signals is very poor over a large ice mass like the Greenland ice cap. The action is similar to that of a carbon wedge inserted into a microwave waveguide.

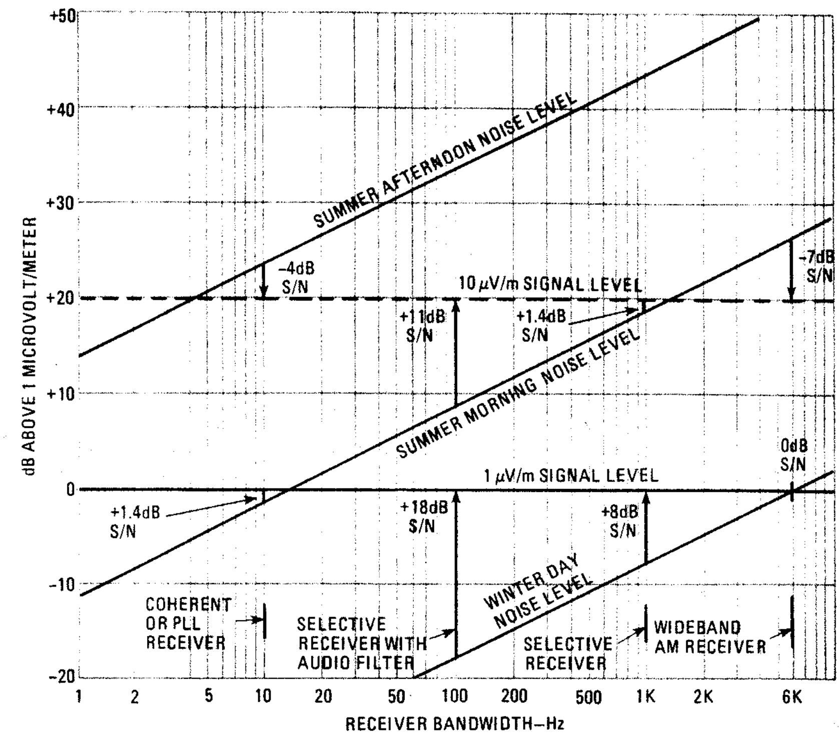


FIG. 3—ANTENNA NOISE LEVELS are a function of the receiver's bandwidth and differ from season to season as well as with the time of day.

Intermodulation distortion

We want an active-antenna system that will ensure that the signal heard on the receiver is not some spurious response of the preamplifier or the receiver itself. That may be rather difficult in some urban areas, where the general RF-"pollution" level is high over the entire VLF through HF spectrum. We do not want our antenna system to amplify strong signals that are in the passband of the active antenna but *not* on the frequency we are interested in receiving.

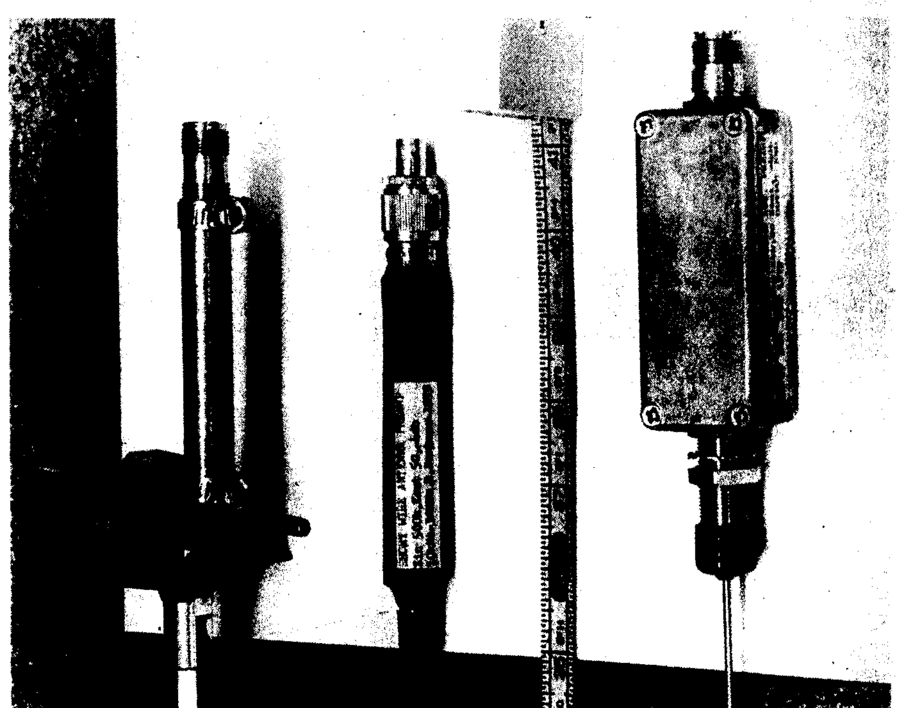
Achieving those goals is difficult in practical wide-range semiconductor preamplifier circuits. That's because they suffer from problems caused by second- and third-order intermodulation distortion products that are created by small non-linearities in the active preamp.

Second order distortion

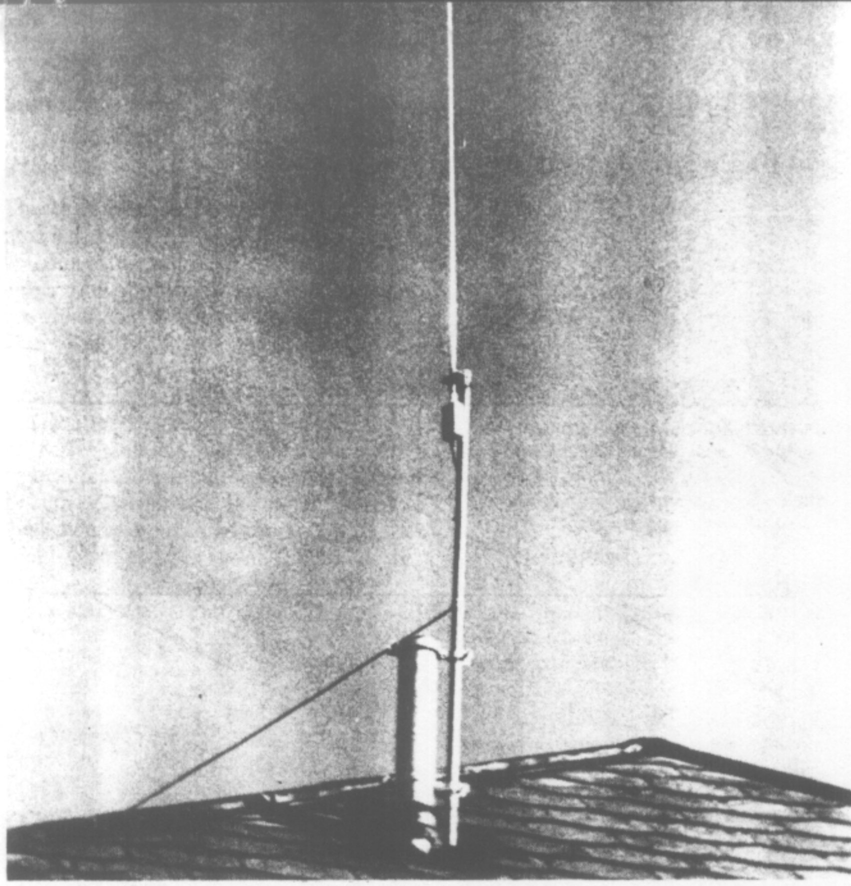
Suppose we have an active-antenna system connected to a receiver tuned to 370 kHz in the LF beacon band. Let's also suppose that there are local broadcast-band transmitters on 1340 kHz and 970 kHz that produce a difference frequency of 1340 − 970 = 370 kHz. If the active-antenna preamplifier is not perfectly linear—and it never is in practice—then at some high signal level, a mixture of the two broadcast-band AM signals will be superimposed on the desired 370-kHz beacon signals. If the listener is located close to the AM transmitters, the interference signal level might be quite high. It increases by 20 dB every time that the strength of the signals causing the interference increases by 10 dB. The problem can be reduced by using semiconductor circuitry that is more linear, or by using high-impedance traps and low-pass filters connected directly to the active-antenna input circuitry.

Third order distortion

Third order distortion can be a more severe problem. It occurs when a strong local AM broadcast-band signal mixes or multiplies with a weaker signal producing interference frequencies of $2f_1 - f_2$ or $2f_2 - f_1$. Suppose f_1 is a weaker signal on 700 kHz and f_2 is a strong local signal on 1340 kHz. Then $2f_1 - f_2 = 60$ kHz and $2f_2 - f_1 = 1980$ kHz. If we tune our receiver to each of those frequencies, signals will be heard faintly in the receiver. The one at 60 kHz is particularly troublesome, since it is right on top of a normal VLF time signal from WWVB and produces annoying fading that coincides with the signal variations from the broadcast stations.



ACTIVE ANTENNA PREAMPLIFIERS can be made very small.



An active-antenna system presents few mounting-problems.

TABLE 1	
Harmonic number	Frequency—kHz
1	15.734
2	31.468
3	47.203
4	62.937
5	78.671
6	94.406
7	110.140
8	125.874
9	141.608
10	157.343
11	173.077
12	188.811
13	204.545
14	220.279
15	236.014
16	251.748
17	267.482
18	283.217
19	298.951
20	314.685
21	330.419
22	346.154
23	361.888
24	377.622
25	393.357
26	409.091

That type of two-tone interference increases by 30 dB for every 10 dB increase in the level of the two interference signals. The large number of broadcast-band stations, and the thousands of LF beacons in the continental United States (as well as the world), means that there are many potential interference sources that could cause problems for VLF-LF receiving setups.

Harmonics and overload

Another common type of interference that plagues all types of reception setups is simple harmonic multiplication. In other words, a strong signal on 250 kHz can produce weaker harmonic signals at 500 kHz, 750 kHz, etc. At the VLF-LF range, that problem is usually not as much of a concern as those mentioned above, since the interference caused by second, third, etc. harmonics is usually not as severe as that caused by second or third order distortion. Also, the higher the harmonic number, the weaker the interference signal will be.

Input preamplifier overload can occur when a locally strong station is transmitting at a frequency that falls within the antenna's passband. That problem can sometimes be cured by using traps or input low-pass filters, or by shorting the whip to ground with a remote, weatherproof, low-capacitance relay. However, it is very difficult to get rid of a signal from a nearby amateur or CB transmitter if the active antenna is designed to operate in the same frequency band.

Other interference

Most TV receivers radiate some horizontal-oscillator signal (15.734 kHz); that problem is especially severe in modern solid state and IC sets. The harmonics from that source, up through 400 kHz, can often be heard in a VLF-LF receiver. A list of the TV-oscillator harmonic frequencies up to 409.091 kHz range is shown in Table 1. If your communications receiver lacks a precision digital readout, those interference signals can be used for frequency markers in the VLF-LF range. Sometimes, however, those signals can interfere with the reception of an important beacon. In the case of Loran-C, for instance, the interference from TV harmonics at 94.406 kHz and 110.140 kHz have been reported to disturb the operation of some marine Loran-C receivers near marinas in populated areas; in such situations, audio or notch filters can be used to reduce that problem.

Harmonics from 60-Hz power-line-operated systems can also cause interference. For instance, the 170th harmonic of 60 Hz is 10.200-kHz, which happens to be the Omega navigation-system frequency. That, as you might imagine, can cause problems, especially when an Omega receiver is poorly located with respect to power lines or faulty power-line ground systems. Rusty marine vessels that use 60-Hz power systems have reported problems with those harmonics when operating Omega receivers while at sea.

In some cases, better grounding of house-wiring systems can help reduce interference from power systems. Active antennas work best when some ground reference is provided at the antenna base. That's because any antenna that is very much shorter than one-quarter wavelength acts like an electric field probe that measures the potential difference between itself and its ground plane. Thus, good grounds are always a necessity and they can eliminate many reception problems. As to what type of ground system to use, a cold-water copper-pipe system or deep-driven copper rods and heavy conductors will do; but a large number of copper radial-wires laid out around even a short pole-mounted whip will provide marked improvement in VLF reception.

A wide variety of other types of interference are often heard throughout the VLF-HF region; their sources include garage-door openers, microwave ovens, motor controllers, personal computers, and TV-set remote tuners. The active circuitry contained in such devices often radiates signals at frequencies between 40 and 200 kHz. Many microcomputer systems radiate strong harmonic energy in the 1- to 30-MHz range. Some control systems are vibration-sensitive and can be frequency- and amplitude-modulated by room or household noises. Those signals cause interference that is independent of the type of active or passive antenna used on the receiver.

Active-antenna systems may not be the ultimate answer to a single small receiving antenna covering all frequency ranges, but they can provide very satisfactory performance with proper attention to the details that we've covered in this article. The next article in this series will present some practical circuit details of active-antenna systems for the experimenter, SWL or casual listener. **R-E**