ALL ABOUT

VLF Active Antennas

An active receiving antenna can dramatically improve your receiver's performance, especially at very low frequencies. Here we will discuss some practical circuits for both wideband and narrowband operation.

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Part 2

IN THE FIRST ARTICLE of this series, we presented some of the fundamentals of active receiving antennas. That type of antenna has several advantages over wire antennnas, especially at very-low and low frequencies (VLF and LF). First, active antennas have a short physical length. The active antenna systems that we will discuss here are used with a one-meter long whip. That helps reduce the sensitivity to local noise from sources such as power lines. Because of the active antenna's high input-impedance and low output-impedance, it is more efficient than a simple wire antenna in converting a received signal at the antenna to a corresponding voltage level at the receiver's antenna terminals.

In general, the properties that we want our active receiving antenna to have are: high input-impedance, low input-capacitance, low output-impedance, and minimum distortion/high linearity.

Another objective is to keep the circuit as simple as possible. A single-stage JFET amplifier has the best combination of properties for active antenna preamplifier applications—and it allows the circuit to be kept relatively simple. (This is not to suggest that there might not be better, more complex circuits, using several semiconductors or IC's.)

Wide-band amplifier circuit

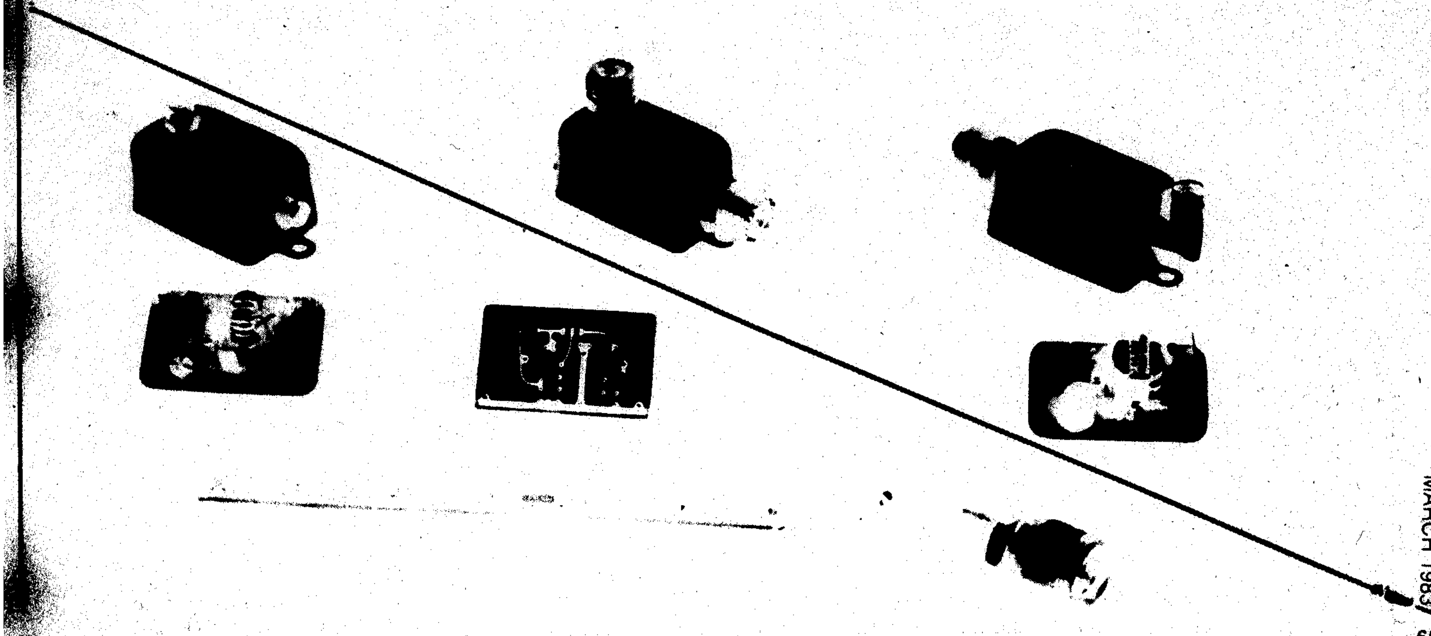
The JFET that we have chosen to use is the Siliconix J-310 (or U-310 in metal can). That JFET is often used as a grounded-gate transmission-line amplifier for TV and FM reception (at a 75-ohm input/output level). The J-310 will usually handle short-duration static surges up to 100 volts or so without damage, so a single low-capacitance neon bulb can provide input static-charge protection. That is of value since semiconductor diodes usually have a much higher junction-capacitance when used as protection devices and, if used, would increase the input capacitance of the preamplifier.

In our application as an active VLF-HF preamplifier, the J-310 is used in a common-source common-drain configuration with inductive feedback (that improves the linearity and lowers the output impedance). Figure 1 shows our wideband circuit for the range of 10 kHz to 30 MHz. Note that the feedback from drain to source is large because of the low resistance of the transformer and its 1:1 turns ratio. (We will discuss how to wind that transformer in Part 3 of this series; that part will contain actual construction details.) For the circuit to operate properly, the transformer's output should be opposite in phase to its input (with respect to ground).

The amplifier circuit is intended to be used with a 1-meter vertical whip. The antenna and its mount capacitances serve as part of an input filter. The input capacitance of the JFET is quite low (about 7 pF). The 2.2-μH inductor at the gate of the JFET serves as a lowpass filter or trap, resonating with the junction and circuit (including antenna) capacitances at a frequency near 30 MHz. That input filter aids in reducing FM-VHF interference over a range of 50 to 500 MHz where the 1-meter whip acts like a resonant antenna.

Receiver coupler

The receiver coupler both provides power to the preamplifier and extracts the signal from the coaxial transmission line (from the preamp). A wideband receiver



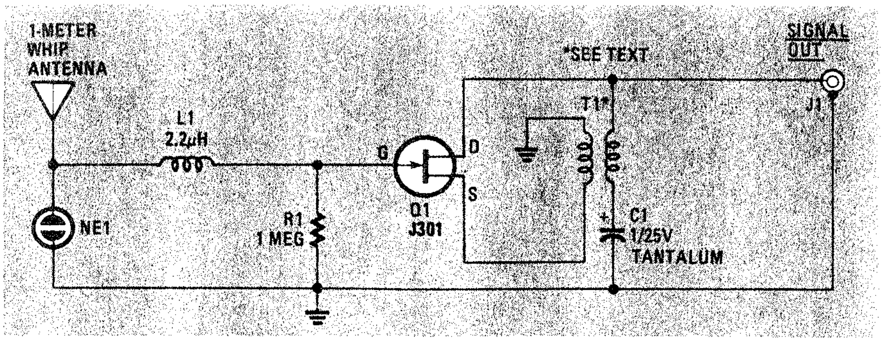


FIG. 1—THE WIDEBAND AMPLIFIER. The transformer should be connected so that the polarity of the output is opposite in phase to that of its input.

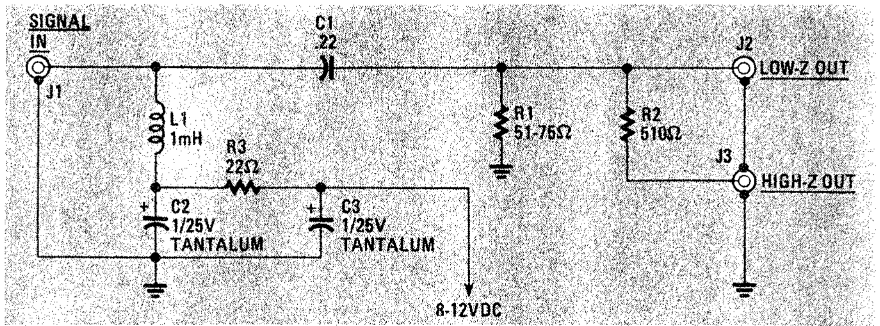


FIG. 2—THE RECEIVER COUPLER both provides power to, and extracts signals from, the amplifier, as well as acting as a highpass filter

coupler is shown in Fig. 2. Capacitor C1 and inductor L1 form a highpass L-section filter (with about a 10-kHz 3-dB rolloff). Resistor R1 is used to ensure that the preamplifier output sees a low-impedance load no matter what sort of receiver is connected. Resistor R2 is used for matching to a receiver with a higher input impedance. That resistor would cause a signal loss of 6 dB if the input impedance to the receiver were 500 ohms.

The coupler circuit provides DC power to the preamp through the coaxial cable. Power sources less than about +8 volts will reduce the dynamic range and linearity of the amplifier. The power dissipation of the JFET using a +8-volt supply will be about 200 mW. The rating of the J310 at 25°C is about 360 mW maximum. In practice, we have not burned one up even when operated with a +12 volt supply for an extended length of time.

The active antenna preamp is like a Class-A amplifier (where the output has low distortion, but the power furnished by the DC power supply is much greater than the power dissipated in the load). However, some distortion does ultimately appear in the output at high input-signal levels. That is due to the fact that a JFET biased in that way cannot be made perfectly linear over a wide dynamic swing of the output voltage. Other modes of operating the JFET with different biasing have been tried, but they have not resulted in any significantly better performance. So, in a sense, the circuits of Figs. 1 and 2 are of the "simpler is better" type.

Intermodulation distortion

A wideband active antenna covering from 10 kHz to 30 MHz has poor performance with regard to IMD (*I*nter*M*odulation *D*istortion) because little input filtering is provided. Interference will be noted especially if the observer is close to strong AM broadcast-band transmitters. The standard method for evaluating the intermodulation response of a receiver is to measure the 2nd and 3rd order intercepts.

Figure 3 shows a plot of the output power of the two fundamental signals (f_1, f_2) versus the output power of the second order and third order distortion products. (We discussed intermodulation distortion products in the first part of this series, which appeared in the February issue of **Radio-Electronics**). Those are shown as a function of the power of a two-tone input signal.

One thing we should mention first is that when the input signals are too large, the amplifier output will not follow the input linearly. That is called *gain compression* and can be seen in Fig. 3.

If the linear portions of the curves are extended, they will eventually cross each other. That is shown in Fig. 3, where the curves are extended by dotted lines and cross at an output level that cannot be reached by the amplifier. The point where they cross is called the *amplifier intercept*. The input and output coordinates where they cross give you the input and the output intercepts.

In general, the higher the intercept point is on the graph, the better the amplifier's capability. Those measurements are best made with a sensitive spectrum analyzer, but an approximate idea can be obtained by using a receiver and recording the S-meter readings with appropriate signal-generator sources. The relatively low number of only +10 dBm for the 3rd order intercept indicates that the active antenna should be used

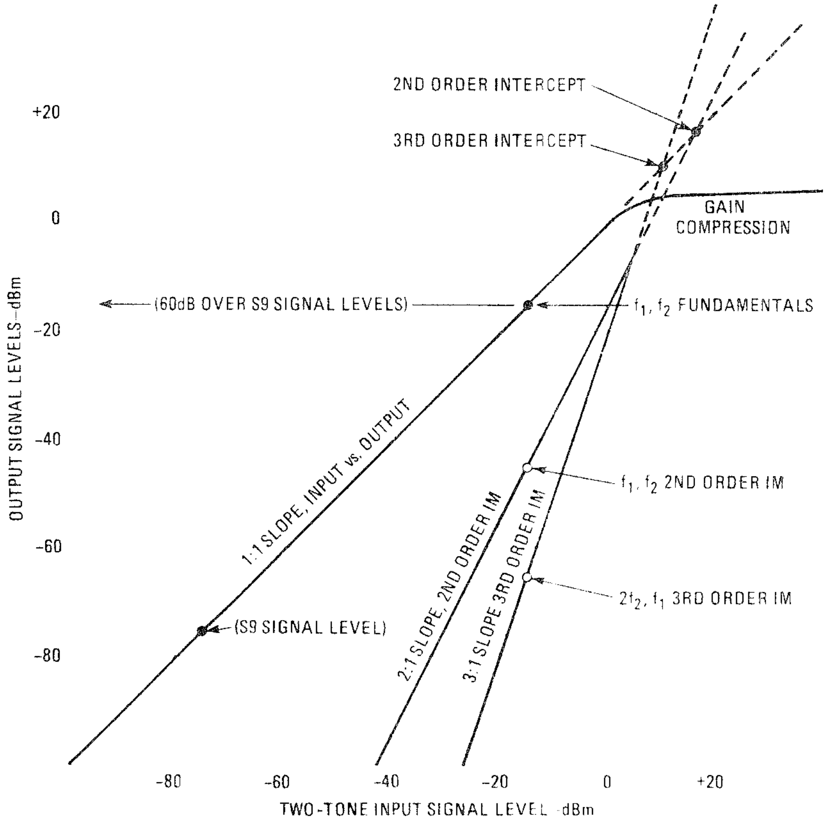


FIG. 3—THE HIGHER THE INTERCEPT POINTS, the better the amplifier's intermodulation rejection.

over a wide frequency range only where the local interference level is not severe. The antenna, of course, might be used in a high-signal area but the observer has to exercise some caution in making sure that the IM signals are not obscuring some desired signals on the same frequency.

For the wideband case of 10 kHz to 30 MHz, those intermodulation-distortion measurements suggest that only a short antenna of perhaps 1 meter or even less will provide the least amount of spurious responses—increasing the antenna length will only tend to increase the distortion level. Longer antennas should be used only when the active preamplifier is provided with some form of input and/or output filtering to reduce the out-of-band interference effects. With added input filtering, an active antenna with a 1-meter whip can provide less IMD because the input filter reduces the likely interfering signals before they have a chance to operate on the preamp input circuitry.

Although the wideband active antenna should not be used with anything longer than a 1-meter whip in areas of high adjacent-channel interference, longer antennas—perhaps up to 10 meters—can be tried in a "quiet" location for operating in the VLF-LF range. However, when using long antennas in the HF region there is an additional interference problem because the antenna is resonant at more than one frequency. One rule to follow here is to keep the length of the antenna less than 1/10 wavelength at the highest frequency used for a wideband system. Although that is short at the highest frequency, an antenna of that length used with the wideband preamp will perform almost as well as a 48-inch top-loaded vertical connected to a 50-ohm system (as in mobile CB radios at the 27-MHz region). A primary reason for using an active-antenna system is to provide good performance over a wide range with small physical size. Thus, if the antenna is to be used only for the CB range, it would be simpler to use an ordinary CB antenna and avoid all of the wideband problems.

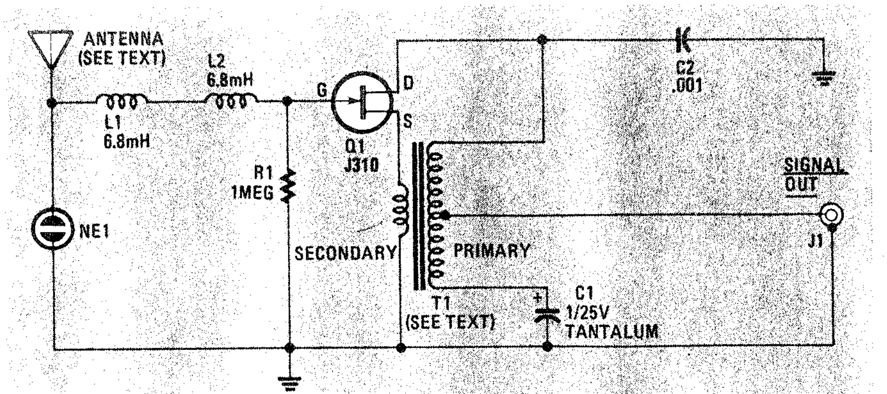


FIG. 4—THE INPUT INDUCTORS and circuit capacitance form a lowpass filter that makes this an amplifier for restricted use in the VLF-LF range.

Amplifier circuit—VLF and LF

At frequencies below about 500 kHz, the amplifier circuit is modified to provide input filtering and higher voltage-gain. Figure 4 shows the modified circuit. Two input inductors and the circuit capacitances form a lowpass filter with a cutoff frequency near 450 kHz (see Fig. 5-a). The choice of those inductors is somewhat critical because the preamp's operation depends partly on the resonant frequency of the coils, the distributed capacitance, and the capacitance of the windings to the shield housing. To reduce mutual coupling, the coils are connected in series with their windings opposing each other. Therefore, they still can be mounted close together on a small circuit board with no interstage shield. That arrangement provides at least another 30 dB of attenuation for broadcast-band signals directly at the input to the preamplifier where the problem of intermodulation starts. A single inductor can be used, but it will not provide quite as sharp a cutoff for interference from the AM broadcast band.

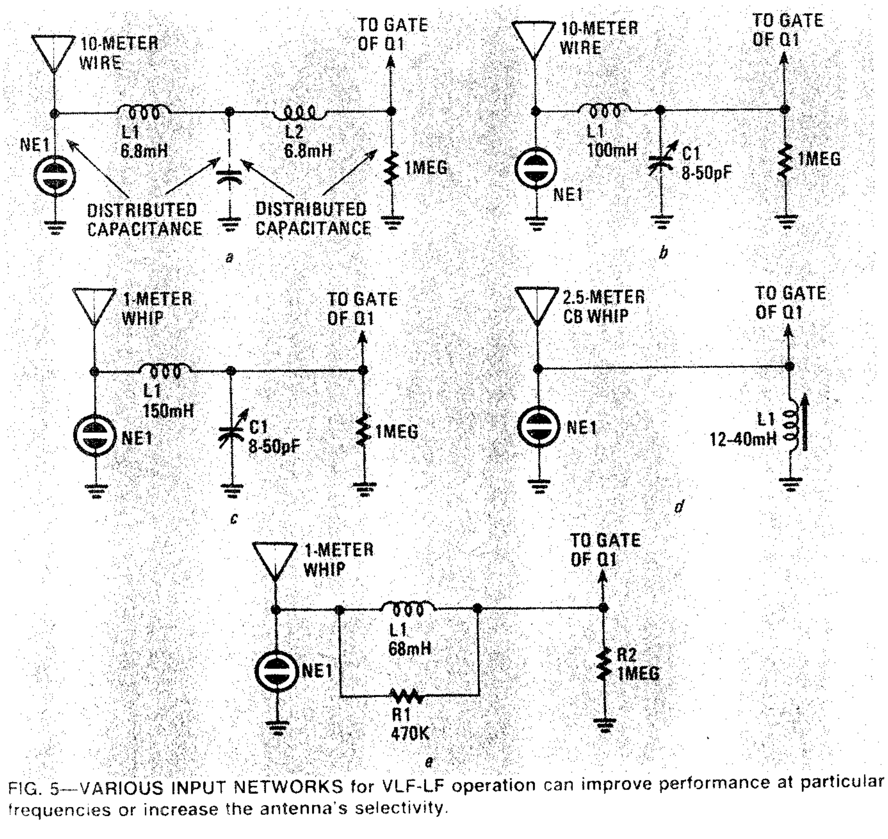


FIG. 5—VARIOUS INPUT NETWORKS for VLF-LF operation can improve performance at particular frequencies or increase the antenna's selectivity.

The output transformer is an ultra-miniature audio-output transformer with a 200-ohm center-tapped primary and an 8-ohm center-tapped secondary. (We will talk more about that transformer when the series continues.) The output transformer has good response to at least 400 kHz, even though it was originally intended for audio-frequency use. The smaller amount of feedback applied from drain-to-source results in higher voltage gain of about + 6 dB at the expense of slightly less power gain, or a higher output impedance when compared to the 1:1 wideband toroid. However, we use the iron core transformer because of its low cost as well as the lowpass output filtering provided.

When used with a 1-meter whip, the VLF-LF version of the active antenna—with an input lowpass filter with about a 450 KHz rolloff—provides higher intercept points with respect to broadcast-band interference (although it is about the same for interference from other frequencies). If you are located in a region free from high-power broadcast-band transmitters, then you can use the preamplifier of Fig. 4 with longer antennas. However, a point is reached with any active system where merely increasing the antenna size does not improve the overall signal-to-noise ratio because the atmospheric noise level increases at the same rate as the signal.

Resonant input circuit

Figure 5 illustrates various high-impedance input networks for restricted use in the VLF-LF region (such as Loran-C only, or WWVB, or for the 160 kHz-190 kHz experimenters' license-free band). A series inductor with a small input tuning capacitor can be used to further reduce interference and increase the antenna performance. A miniature trimmer-capacitor with a tuning range of 8 to 50 pf placed from the gate to ground, directly across the 1 megohm input resistor (see Figs. 5-b and 5-c) provides a means of tuning the series inductor for a peak at the desired frequency range. The result is a sharp, high-frequency cutoff with a more gradual low-frequency rolloff. The inductor was chosen to be self-resonant (remember, real inductors also have capacitance) at a somewhat higher frequency than the top of the desired tuning range. That technique will work for some pot-core or slug-wound inductors but will usually not work well with large toroids, as they have too much distributed capacitance at VLF. It is also possible to shunt a slug-tuned inductor from the gate to ground (as in Fig. 5-c) but the preamp will then require a larger housing. For that parallel-tuned case, the 1-megohm resistor can be removed because the inductor provides the ground return for the gate. The antenna is then connected directly to the gate terminal with the inductor chosen to resonate with the antenna, input-circuit, and antenna-mount capacitances. The minimum of external tuning capacitance provides the highest Q (most selective) antenna in this application. For DX hunting in the low-frequency experimenters' band (at 180 kHz), a narrowband antenna with a Q of more than 50 can be achieved with a parallel-tuned circuit.

One problem with using a tuned circuit is that it restricts the remote applications of the active antenna. That is because the antenna must be located conveniently so that it can be retuned. However, for covering some fixed frequency (such as the experimenters' band) the antenna system can be aligned on the bench and then mounted for unattended operation. When tuning those systems, it is advisable to temporarily mount the preamplifier assembly in a fairly clear area (preferably where it will be permanently located) to avoid nearby capacitive coupling, which might detune a very selective system.

One technique for broadbanding a tuned circuit is to place a resistor in parallel with the inductor (See Fig. 5-d). Resistor values in the range of 50K to 500K ohms can help broaden Loran-C systems where a wide bandwidth is necessary.

Traps

Series-connected transmission-line traps tuned to local broadcast-band stations and placed just ahead of the receiver coupler can improve the IMD somewhat and reduce overload or gain-compression problems (see Fig. 6). The tuning capacitors must be isolated from ground and the inductor must be chosen so as to have a reactance greater than 50 ohms at the desired notch frequency. Dual traps are possible. For example, Fig. 6 shows a trap for 970 kHz and another for 1340 kHz connected in series. The combination of input lowpass filters at the antenna and traps at the preamp output can usually provide sufficient attenuation for cases of severe interference in the VLF-LF band from stations in the broadcast band.

A summary of some measurements made with different antennas at 60 kHz for WWVB reception is shown in Table 1. It should be noted that a 2-meter vertical whip is about equivalent in sensitivity to the much larger flat-top antenna. However, the flat top is much more susceptible to noise and interference, even when it is operated with a lowpass filter at the preamp input. The effective-height estimate may not be the same over the entire frequency range. For example, the flat top appears to have an effective height of about 2 meters at 200 kHz but less than 0.9 meters at 60 kHz. That is because of K—the shielding effect and conductivity of the local ground terrain, which includes all the trees, power lines, and building structures. However, we are still able to operate the antenna even down to the 10.2 kHz Omega frequency with reasonable success and it is used routinely to check GBR on 16 kHz for VLF propagation conditions. (GBR is a high-power military VLF station from Great Britain.) In practice, it is always wise to check for IM effects at the specific frequency range that you plan to use the antenna. Sometimes they are severe but only at relatively narrow frequency ranges usually not in the VLF range.

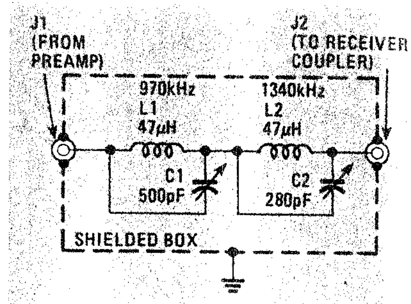


FIG. 6—TRAPS CAN BE USED to reduce interference from broadcast band stations—in this case from stations at 970 and 1340 kHz.

TABLE 1

Parameter		Whip 1	Whip 2	Flat Top
Physical Height	(h_m)	1m	2m	10m
Antenna Capacitance	(C_a)	10pF	20pF	118pF
Fixed Capacitance	($C_m + C_g$)	15pF	15pF	15pF
Voltage Gain at Preamp	(A_v)	1 (0dB)	1 (0dB)	2 (+6dB)
Estimated Ground Coupling Effect	(K)	0.7	0.7	0.05
Effective Height	(h_e)	0.28m	0.80m	0.88m
WWVB Reading on YAESU FRG-7700		S6	S9	S9+
Estimated E-field for WWVB (from NBS chart)	(E_i)	150 µV-per-m	150 µV-per-m	150 µV-per-m
Output S+N for 60kHz WWVB at Preamp	($E_o = E_i \times h_e$)	42 µV	120 µV	132 µV
Estimated (S+N)/N during 60 Hz "quiet hours"		+10dB	+20dB	+20dB
Overall Noise Rating		good	fair	poor
IM Distortion Rating		fair	poor	very poor

For general wideband surveillance, the 1-meter whip with an effective height of about 30 cm is the best antenna of all, because it has fewer IM interference effects and less local noise from the power lines.

A general conclusion from all of the experiments is that the local environment and the ground-conductivity effects of nearby structures are the most important factors in determining antenna sensitivity. Small changes in antenna location can produce remarkable differences in the antenna's performance.

Another observation is that the best location for a short whip is invariably up high in the clear. (That can especially be seen in aircraft applications where a very short vertical whip is used with remarkably good performance.)

Low-frequency experimental radio station operators have reported good results in mobile operation with reception of 160 to 190 kHz signals using 2.5-meter CB whips and parallel-tuned input networks. We have conducted similar experiments with Omega and Loran-C receivers in mobile vehicles where the only problems were those of shielding from buildings or when driving under bridges or near power lines. An additional problem in mobile operations is harmonic radiation from the vehicle's AC alternators.

When we continue this series, we will discuss construction details and include printed-circuit board layouts for the active antenna preamplifier and receiver coupler. We will also discuss how to bench test the preamp, and how to mount the system. R-E