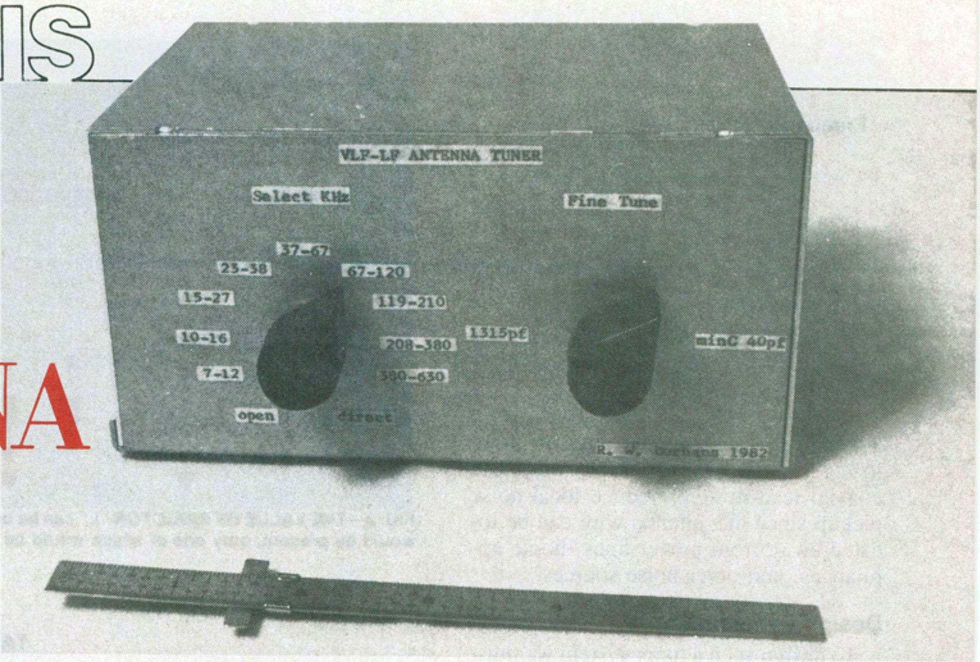

PASSIVE ANTENNA TUNER FOR VLF-LF

One way to improve the performance of VLF-LF antennas is through the use of a passive antenna tuner. Here's the theory, and some ideas on how to use it.

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Part 4

PREVIOUS ARTICLES IN this series have presented some details of short active antennas for frequencies covering the range from 10 kHz to 30 MHz. *Passive* antenna-tuners for random-length wires are another approach to the problem of good signal reception. Commercial models are available, but they are usually designed for the medium- and shortwave bands above 150 kHz; only one system claims to be effective all the way down to 10 kHz.

Since the greatest reception problems are encountered at low frequencies, let us discuss the design of selective antenna tuners covering the range of 10 kHz to 500 kHz.

Antenna lead-in

It is interesting to consider the idea of locating the antenna tuner at the receiver, with the antenna wire connected by a length of coaxial cable to the receiver and tuner as illustrated in Fig. 1. One problem at low frequencies is that the shunt cable-capacitance, C_c, in parallel with the antenna capacitance, C_a, reduces the sensitivity by the factor: $C_a/(C_a + C_c + C_t)$. By choosing a length of relatively high impedance, low-capacitance cable, it is possible to design a tuner that takes into account the cable capacitance as part of the tuner network, and that can operate with up to 50 feet (about 15 meters) of cable separating the antenna wire from the receiver and tuner. That antenna will be less effective than an active-antenna preamplifier system for the same length of antenna wire, but there will be fewer problems of intermodulation distortion because of the high selectivity, and no active preamplifier is involved. The

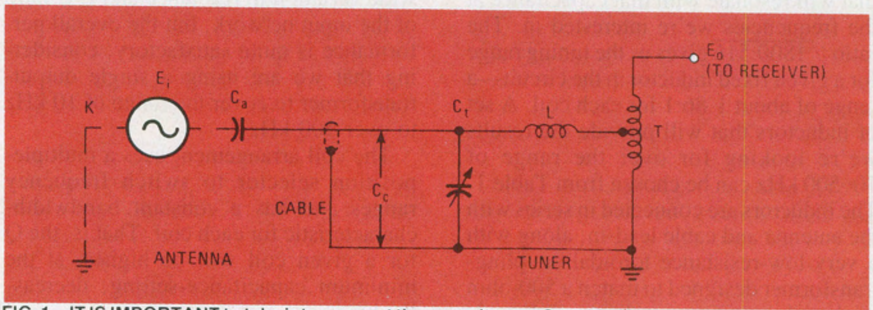

FIG. 1—IT IS IMPORTANT to take into account the capacitance, C_c, added by the coaxial cable between the antenna and tuner.

TABLE 1

Frequency range (kHz)	Inductance (mH)
10-16	150
15-27	68
23-38	33
37-67	10
67-120	3
119-210	1
208-380	0.3
380-630	0.1

advantage of having the antenna tuner located at the receiver is obvious. The coaxial lead-in helps reduce local-noise pickup since the antenna wire can be located away from power lines, home appliances, and other noise sources.

Design considerations

To design such a tuner system we must first measure or estimate the total minimum capacitance, including the antenna, cable, and minimum tuning capacitance. A relatively-high-value tuning capacitor is required, having a value several times greater than the total minimum capacitance. We chose a 3-gang variable capacitor, each section having a range of about 12 to 440 pF, like those found in older-style AM radios (commonly referred to as 360-pF units). They are still available new at rather high prices, but similar devices can often be found at surplus-electronics-parts stores.

Taking all the components together, the total minimum capacitance is:

Antenna capacitance	120 pF
Cable capacitance	360 pF
Minimum tuning capacitance	36 pF
Total minimum capacitance	516 pF

The total maximum capacitance (with the tuning capacitor fully meshed) is:

Antenna capacitance	120 pF
Cable capacitance	360 pF
Maximum tuning capacitance	1320 pF
Total maximum capacitance	1800 pF

Tuner circuit

Now that we have estimated a capacitance range for the tuning circuit of 516–1800 pF, a set of inductors is needed that will resonate with that capacitance at the frequencies we're interested in. The ratio $\sqrt{1800:516}$ gives us the tuning range for a given fixed inductor in the circuit—a range of about 1.86:1 for each coil. A set of inductors that will provide the results we're looking for over the range of 10–500 kHz can be chosen from Table 1. The inductors are connected in series with the antenna and cable lead-in, along with a very-low-resistance toroidal coupling-transformer designed to match a 500-ohm load at the receiver as shown in Fig. 2. The inductors are selected so that each frequency range will overlap the next slightly; that means an inductance change of less than $(1.86/1)^2$ between each set of coils selected for this example.

The wideband-output coupling-transformer takes the place of an additional set of parallel inductors to match the receiver's input impedance. In addition to the capacitive-divider loss at the antenna input, the transformer in series with a high reactance coil adds an insertion loss at the low-frequency end. That is, in part, compensated for by a higher Q. That selectivity decreases at higher frequencies, but gain increases. When connected to the 500-ohm receiver input-terminals, the low-impedance-input tap point of the output transformer looks like a 30-ohm load to all the coils. That is about the best that can be achieved because of the very wide variation in reactance and L/C ratio of the input network, but the overall performance is quite satisfactory, considering that we are using a single output-transformer to cover the range of 10 kHz to over 500 kHz.

The coil arrangement uses a multiple-position selector to switch frequency ranges and has a constant bandwidth-characteristic for each coil. That is, the Q for a given coil will be highest at the minimum capacitance-setting, decreasing by an amount equal to about the tuning ratio at maximum capacitance. The results obtained using low cost RF-choke-type inductors with the 120-pF antenna are shown in Table 2. The antenna used was a 10-meter-high, four-meter flat-top.

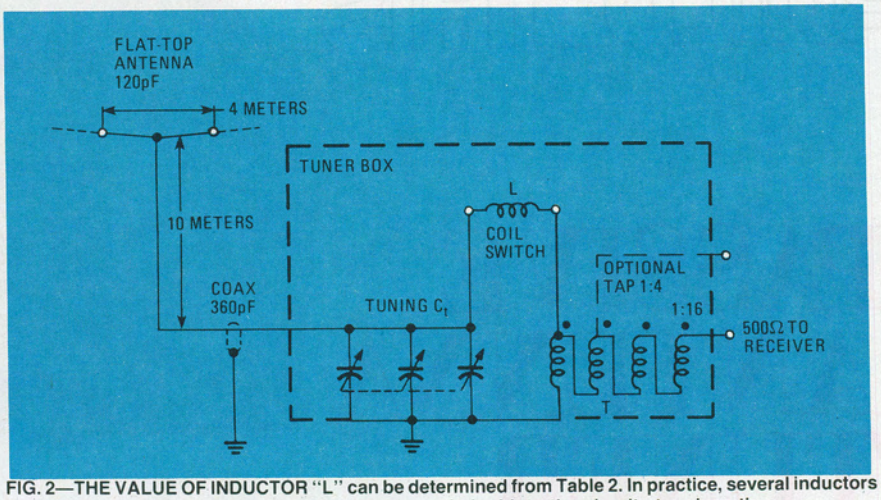

FIG. 2—THE VALUE OF INDUCTOR "L" can be determined from Table 2. In practice, several inductors would be present, only one of which would be switched into the circuit at a given time.

TABLE 2

Midband frequency (kHz)	Loss (db)	Q	Bandwidth (kHz)	Inductance (mH)	Inductor part number
13.9	−24	47	0.3	150	Mouser 43LJ415
20.1	−17	92	0.22	68	Mouser 43LJ368
30.1	−15	56	0.54	33	Mouser 43LJ333
52.7	−10	53	1.0	10	Mouser 43LH310
93.6	−9	36	2.6	3	Mouser 43LH233
168	−8	22	7.7	1	Mouser 43LH210
298	−9	12	24.	0.3	Mouser 43LR334
518	−9	12	42.	0.1	Mouser 43LR104

Input-capacitance variations

If you use an antenna wire or cable with more or less capacitance than the one we did, the inductance ratios will have to be computed for a different set of coils. The cable we used was surplus marked "FT&R Corp. Type K 109," and measured only 8 pF/ft. Thus, 45 feet of cable had a capacitance of 45 × 8 = 360 pF. For other high-impedance cable such as RG62, with a capacitance of 13.5 pF/ft., 360/13.5, or 27 feet, would be used with the same variable capacitor and coil-set. You may be able to find some high-impedance, low capacitance cable of the type used in automobile-radio installations. Each different system will involve a session of L-C calculations to match inductances and capacitances to the frequency range desired.

The following two formulas will help in those calculations:

$$f = \frac{10^6}{2\pi\sqrt{LC}}$$

$$L = \frac{10^{12}}{(2\pi f)^2}$$

TABLE 3

Frequency	10 kHz	400 kHz
Capacitive loss factor $C_a/(C_a+C_c+C_t) = C$	−23dB	−12dB
Ground loss factor estimate = K	−26dB	−14dB
Measured network loss with antenna & cable capacitance = N	−24dB	−9dB
Antenna-to-receiver Z loss-factor, direct, no cable $500/X_{Ca}$ = A	−49dB	−17dB
Antenna sensitivity without tuner or cable = K + A	−75dB	−31dB
Antenna sensitivity with tuner and cable = K + N	−50dB	−23dB
Net improvement in sensitivity (K + N) − (K + A)	+25dB	+8dB

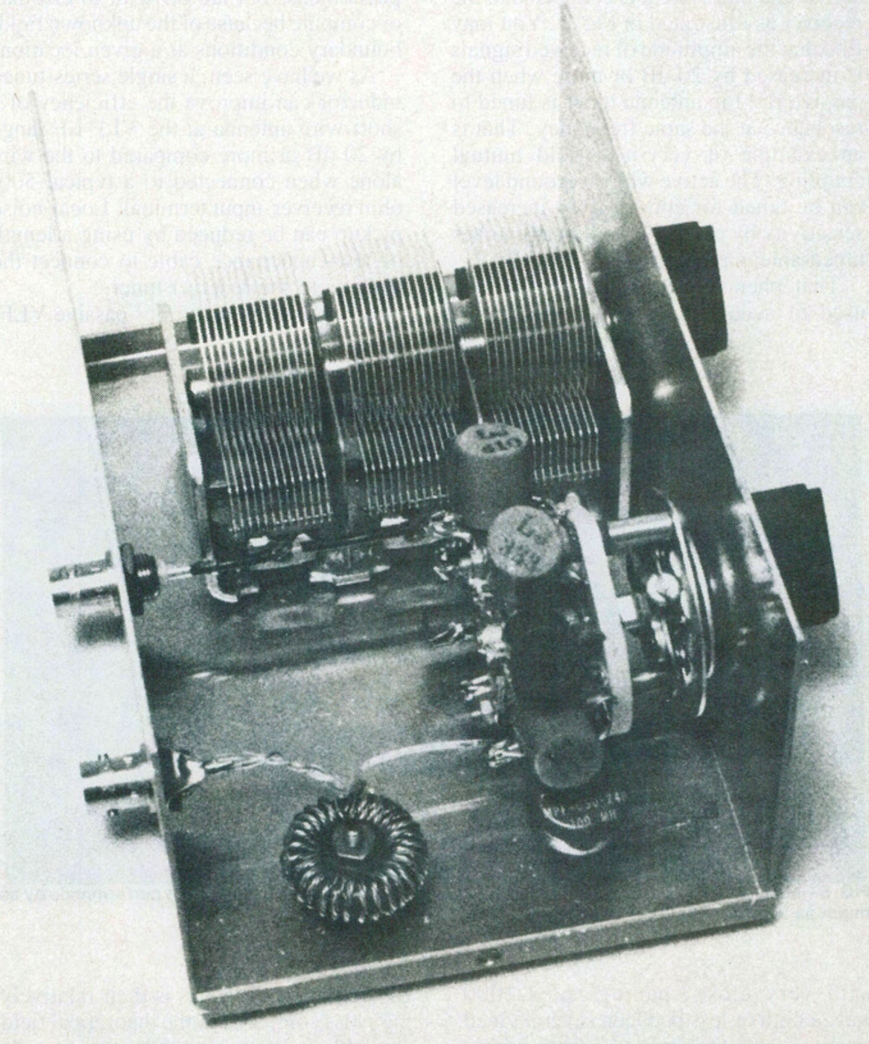

FIG. 3—INTERIOR OF THE AUTHOR'S prototype tuner. Note inductors mounted on rotary switch.

where f is the frequency measured in kHz, L is the inductance measured in μH (1000 μH = 1mH), and C is the capacitance in pF.

Performance data

Table 2 illustrates well the Q and mid-band loss of the tuning network with the antenna and cable connected; the figures were determined on the bench using a signal generator. Actual antenna performance will be somewhat worse than indicated by the loss factor because it will also be affected by the ground coupling K factor. (See Part 1, in the February 1983 issue of **Radio-Electronics.**) In our tests, K varied from .05 (an additional −26 dB) at 10 kHz to about 0.2 (−14 dB) at 400 kHz.

An estimate of overall efficiency made by comparing the wire antenna connected directly to the 500-ohm input of the receiver with the same antenna connected through the coaxial cable and tuner to the receiver, is illustrated in Table 3. From that table you can see that there is an overall improvement of 25 dB at the bottom of the VLF band (10 kHz), which decreases to only 8 dB at the high end of the LF band (400 kHz).

The high antenna-loss factors shown are typical of what happens when a random wire is connected directly to a 500-ohm receiver-input. The tuner provides an obvious improvement that is roughly proportional to the Q of the tuned circuit. In addition to increased sensitivity, the antenna tuner also provides high selectivity with practically none of the preamplifier or receiver IM problems noted with active antennas. On the other hand, active-antenna systems have better sensitivity.

PARTS LIST—PASSIVE TUNER

C_t—three-gang tuning capacitor, 12–440 pF per gang (Allied 695-4200 or similar)
T—quadrifilar toroidal transformer, 28 turns of four No. 30 insulated wire, twisted four-turns-per-inch on Amidon FT82-75 (or similar) core
L—RF-chock-type inductor(s) (see Tables 1 and 2)
Miscellaneous: high-impedance low-capacitance coaxial cable, rotary switch, metal enclosure, connectors, etc.

The antenna tuner's narrow bandwidth requires that it be peaked whenever you shift frequency. That's easy to do if you have an S-meter, or you can listen for an increase in the signal- or background-noise level from the receiver as you adjust the tuner. For experimenters who wish to vary that method of antenna tuning, there are many factors to consider. The antenna's Q is limited by both the coils used and the series resistance of the network. That means that, even with the very best of inductors, the series resistance of the high-impedance cable and the output transformer, as well as the ground resistance, will ultimately affect performance. At the higher frequency-ranges, a lower Q is inherent in the system because of the lower coil reactance compared to the resistance in the system. Another variable is the turns ratio of the output transformer.

One possible improvement that could be made after inspecting the data in Table 2 would be to switch the tap on the output transformer for a 4:1 ratio for the frequencies below 50 kHz, where the coils' resistance and loss are much higher. The 16:1 tap could be used for the coils for 50 kHz to 500 kHz, where the loss is relatively constant at 9–10 dB. That change would result in a lower Q for the larger inductors, but a net improvement in power transformation to the receiver as suggested in the circuit shown in Figure 2.

Figure 3 shows the parts placement in the experimental version of the antenna tuner. The inductors are mounted radially around the switch, with the output-transformer toroid toward the rear of the housing near the receiver-output terminal. The prototype shown had an extra non-standard inductor at the lowest-frequency switch position for reception below 10 kHz.

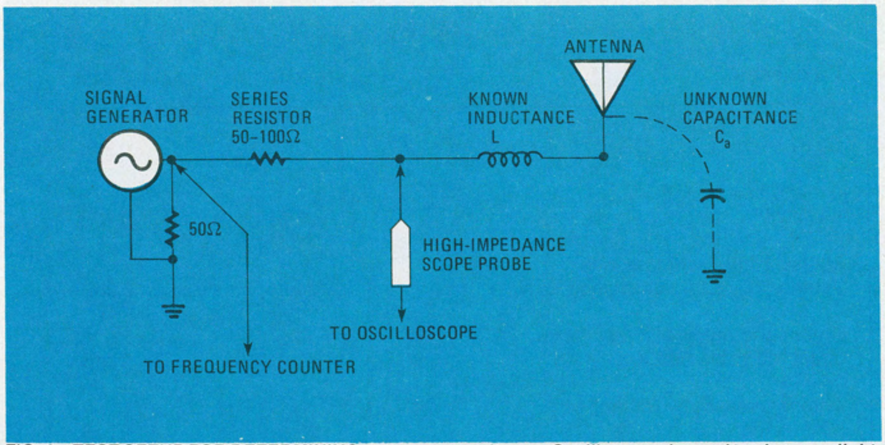

FIG. 4—TEST SETUP FOR DETERMINING antenna capacitance. Oscilloscope is used to observe slight dip in response at resonant frequency of system as frequency of signal generator is slowly varied.

Antenna-capacitance measurement

Most experimenters own a signal generator, oscilloscope, and frequency counter. They can be used to get a good estimate of the antenna's capacitance by following the method shown in Fig. 4. That is a simplified return-loss method where a small series-resistor takes the place of a 3-dB hybrid transformer. The resistor should have a value much lower than the reactance of the inductor at the frequency at which the measurement is made. Resistors in the range of 50 to 100 ohms, together with inductors having known values between 5 and 10 mH, can be used for antenna-capacitance measurements over the range of 10–500 pF for frequencies between 50–500 kHz. It is a good idea to make a preliminary estimate of the antenna capacitance by using the approximation of 10pF/meter of antenna length for wire antennas, and to use that figure as a rough guide to values for use in the initial test. After estimating the antenna's capacitance, the resonant frequency can be checked by substituting a capacitor of about the same value as that calculated for the antenna.

In our case, the flat-top antenna was terminated on a back porch, where it was easy to connect various pieces of test apparatus—and even a receiver—directly to its base. Variations on the substitution method can be used to measure cable capacitance with known inductors, or for unknown inductors with known capacitors, or even for coil distributed-capacity, using difference methods with known capacitors in parallel.

Mutually-coupled antennas

An interesting effect occurs when a tuned wire antenna is placed very near a short wideband active-antenna whip. The vertical active-antenna system is mounted at ground level, directly underneath the flat-top antenna at a distance of 5 to 10 meters (about 15–30 feet). The flat-top is connected to the tuner, but the output of the tuner is terminated with a resistor instead of the receiver. The active-antenna system is connected to the receiver as illustrated in Fig. 5. You may find that the amplitude of received signals is increased by 20 dB or more when the passive flat-top antenna tuner is tuned to resonance at the same frequency. That is an example of very-near-field mutual coupling. The active whip at ground level can be tuned for considerably increased sensitivity by placing it very near another tuned-antenna system.

That phenomenon could possibly be used to make directive VLF-LF arrays with very close spacings of 1/1000 wavelength or less between several tuned antennas and the excited active probe. Such a system, though, would probably require good series-inductors, and would be difficult to tune—the relative phase-change between antennas would be very steep because of the high Q of the tuned circuits.

VLF observers report many unusual antenna-effects due to things like drain pipes, gutters, power lines, telephone cables, trees, etc. Most of those can probably be accounted for by mutual-coupling phenomena, but are difficult to estimate or compute because of the unknown field-boundary conditions at a given location.

As we have seen, a single series-tuned inductor can improve the efficiency of a short-wire antenna at the VLF-LF range by 20 dB or more compared to the wire alone when connected to a typical 500-ohm receiver-input terminal. Local-noise pickup can be reduced by using a length of low-capacitance cable to connect the antenna to the receiver/tuner.

A dominating feature of passive VLF-LF short-wire antennas is their relatively high loss compared to the theoretical field available in space above the antenna. To offset that, though, an antenna tuner provides a considerable reduction in interference, along with high selectivity and no intermodulation distortion at the receiver input. It also offers improved sensitivity, compared to the antenna without a tuner. **R-E**

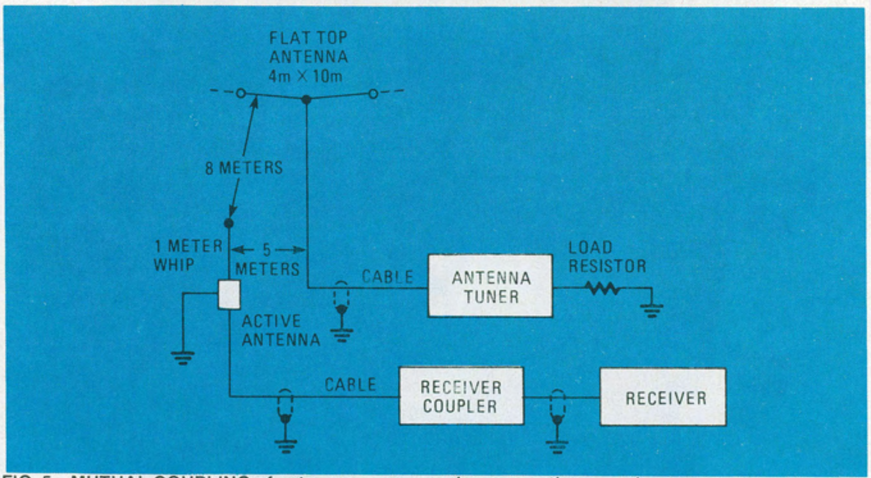

FIG. 5—MUTUAL COUPLING of antennas—one passive, one active—can improve performance by as much as 20 dB.