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Down-to-earth Army antenna

Built low and compact for field radio operations, a vertical loop is easy to transport and set up. Early square-shaped models got high efficiency ratings, and an octagonal version is even better

By Kenneth H. Patterson

Army Limited War Laboratory, Aberdeen Proving Ground, Md.

Fight fans say a good big man will beat a good little man every time. But Army signalmen setting up radio sites in the jungles of Vietnam would much rather use a small radio antenna with adequate efficiency than a larger, more efficient one that has to be strung on high masts. Mobility and concealment are high-priority features in a guerrilla war.

For communications at medium and high frequencies, the Army normally uses various forms of long wires, dipoles, and rhombics. To be reasonably effective, the long wire should be a minimum of about 100 feet (plus a good ground), the dipole should be at least twice as long, and the better rhombics can exceed 600 feet. In addition, all of these antennas should be elevated to a minimum height of about 40 feet, with 80 feet being better. Such space and height requirements are invariably so difficult to meet that compromises are usually made in the field.

But a solution has been developed at the Army Limited War Laboratory at Aberdeen Proving Ground, Md. A vertical loop antenna (in the shape of an equilateral octagon, 5 feet to a side) has been built that doesn't have to be raised above the ground. Despite the inherently low radiation resistance of a loop, the new design usually does as good a job as a full-length dipole 40 feet above the ground, even though the length of the dipole is about 234 feet at 2 Mhz and 94 feet at 5 Mhz.

One can get an idea of the difference between the low-height performance of vertical loops and horizontal dipoles by visualizing their basic characteristics. The most significant consideration is the effect on the signal of reflection from the ground.

The theory of image antennas tells us that vertically polarized signals are reflected by the earth without a phase shift. Horizontally polarized signals, on the other hand, are phase inverted upon being reflected. The exact amount of inversion depends on orientation, but in most instances it can be expected to approximate the full 180°. It then follows that when the dipole antenna is used at heights lower than about $.12\lambda$, the reflected wave has a cancelling effect on the incident wave. In fact, zero height and a perfectly conducting earth are conditions that cause total cancellation and zero radiation.

Hit the dirt

Under the same circumstances, however, the reflected wave from a vertical loop combines with the incident wave under what is predominantly an in-phase condition. This quite naturally results in an increase in the amount of energy radiated in useful directions. With greater proximity to the earth, therefore, the radiation from the loop may actually improve. It cannot, of course, exceed a limit of twice its radiation in free space.

A close examination of the expressions for the radiation resistance values of the two antenna types, including the height-modifying terms, shows the loop approaching twice its free-space value as a function of decreasing height, while the horizontal antenna goes to zero.

If we wish to operate our antenna at a really low height, therefore, we must use vertical polarization. And if we cannot accept a null in our overhead

The author

Kenneth H. Patterson, who has been developing electronic communications equipment since 1923, designed the loop antenna described in his article. Before joining the Army Limited War Laboratory, he was chief of radio frequency development at the Ballistic Research Laboratories at Aberdeen. There he supervised work on a large portion of the instrumentation used to measure missile performance at the White Sands, N.M., range.

Will travel. Octagonal loop antenna with 5-foot sides is easily set up, dismantled, and transported. Efficiency near the earth matches that of conventional elevated antennas as long as several hundred feet.

pattern, we are restricted to a vertical loop. The problem is to improve the efficiency of the loop antenna.

Besides solving spatial and height problems, the antenna developed at Aberdeen:

- is operational from below 2.5 Mhz to above 5.5 Mhz—although tuning ranges as great as 10:1 are possible;
- offers a pattern factor well suited to both short- and long-range ionospheric propagation with no overhead nulls;
- has a predicted efficiency level of from 20% to 80% throughout the operational band. (Future models will do much better.);
- is self-supporting in use;
- can be transported by a small vehicle when packed;
- can be set up or dismantled by a crew of no more than three men in less than 30 minutes;
- doesn't require an artificial ground plane;
- has sufficient strength to withstand normal wind and rain storms.

The power rating, determined by the voltage breakdown and current ratings of the capacitors used in the matching network, is arbitrary. A 1-kilowatt version has been built.

The loop isn't being suggested as the best design for every antenna application. It won't, for instance, outperform the large rhombic in specific low-angle unidirectional tasks. But the loop can do the job at installations where real estate is limited and a complex of high antenna masts is impractical.

Field tested

Loop antennas, some shaped as squares and others as octagons, have undergone extensive field trials in the U.S. and Vietnam. The results in all cases have been excellent.

Before the loop was selected, other configurations were considered and rejected. Grounded verticals, or whips, were ruled out because of their height and their inherently restricted radiation pattern.

The horizontal series-fed antennas, including dipoles, long wires, V's, and rhombics, were also dismissed because of their height requirements. As noted before, the radiation resistance of these antennas approaches zero as height is reduced. (Radiation resistance is obtained by dividing the total radiated power of an antenna by the square of the effective antenna current measured at the point where power is supplied.)

The vertical loop, being compact and vertically polarized, and having no overhead null in its pattern, got the nod almost by default. The superior low-height performance of a loop antenna was suggested to the Proving Ground by David Sunstein of the General Atronics Corp., Philadelphia.

To improve the loop's efficiency, two problems had to be solved: radiation resistance (R_R) had to be increased, and the sum of all other losses (R_L) had to be reduced. To assess the problems and the expected efficiency (E), the standard efficiency equation was used—efficiency equals radiation resistance divided by the sum of radiation resistance and R_L.

Cutting losses

The two principal sources of loss in a loop antenna are the inherent resistance in the conductor used to form the loop and the resistance in the antenna-matching network.

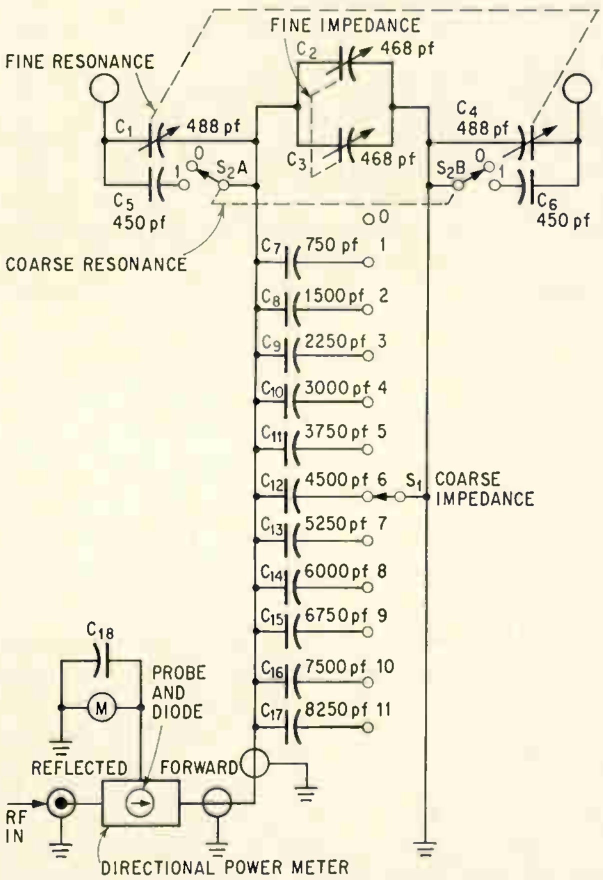
In considering the losses in the matching network, it was decided the antenna would be driven from a 50-ohm or 70-ohm coaxial line, thus requiring the input portion of the matching network to handle the comparatively high currents characteristic of low impedance levels. Particular care was taken in the design of the input part of the network to reduce the normal resistive power losses to a practical minimum.

To do this, the customary taps or links, with their inherent resistive losses, were discarded in favor of variable air-dielectric and fixed mica capacitors, both of which have low loss characteristics. The schematic diagram of this matching network on page 113 is conventional except that the low-value, high-impedance capacitor is divided into two equal sections to provide a close—though not precise—balance with respect to ground, and to permit higher voltages. For low-power applications where the emphasis is on portability, the second tuning capacitor is omitted.

In either balanced or unbalanced form, the capacitative matching network is practical, versatile, and efficient. Matching losses can be cut to the point where they can be ignored in many instances. If a loop with a high ratio of inductance to capacitance (L/C ratio) is attempted, however, a significant portion of the circulating current flows through the stray (shunt) capacitance and a poor match and an inefficient coupling condition results. This could occur, for example, if the operating frequency is raised to a level closely approaching the self-resonant frequency formed by the loop inductor and the stray shunting capacitance.

In using the matching network, the transmitter is turned on. With the arrow on the pick-up probe in the "REFL" direction the meter reads the reverse power level. The controls are adjusted to the deepest null until the meter reads zero, indicating a perfect match. The transmitter power can then be advanced to a maximum level and the pick-up probe rotated to "FOR" to read the forward power level.

The method selected to reduce loss in the loop



Indicator. The arrow on the front of the probe assembly indicates whether forward or reflected power is being provided by the pickup link. The link applies this energy to an r-f rectifier whose d-c output drives the power meter movement.

itself is a straightforward brute-force technique using conductors with an exceptionally large surface area. In the majority of the models built to date, the loop conductors are composed of 1½-inch tubing. With such large conductors, the r-f losses due primarily to skin effect are sharply pared.

Radiation resistance

The next step in improving efficiency is to obtain the greatest practical radiation resistance. This involves another classic equation:

$$R_R = 3.12 \times 10^4 [NA^2/\lambda^2]^2$$

where R_R = the approximate radiation resistance of a small loop.

N = the number of turns in the loop.

A = the area enclosed.

λ = the wavelength of the frequency being used.

The dimensional terms are expressed in the same units, squared or lineal.

The equation shows that two parameters, N and A, may be controlled to possible advantage. In the case of N, imagine a small loop antenna composed of a single turn shaped to form a square 3 feet on a side. Further assume that in all cases a very short drive cable is used, a low-to-moderate L/C ratio is employed, and losses in the capacitative matching network are negligible. In other words, essentially all the losses in this antenna stem from resistance in the wire conductor. Under these circumstances, the losses (R_L) are, to a great extent, directly proportional to the total length of the conductor.

As one would expect, the efficiency of this imaginary reference antenna is extremely low. In fact, if it were made of 18-gauge copper wire, the computed free-space efficiency at 3 Mhz would be a mere 0.0457%.

If the number of turns in a 3-foot-square loop were increased to three, the radiation resistance would be increased by a factor of nine. Unfortunately, the extra turns in this example also increase the loss resistance by a factor of three. Consequently, the efficiency improvement is reduced to a net factor of three; this is a reasonably significant improvement, but efficiency is still intolerably low.

The same conductor used for the three-turn loop can be reshaped to form a single-turn square loop with 9-foot sides, increasing its area by a factor of nine. Since R_R is proportional to A^2, the radiation resistance is now greater by a factor of 81. Here again, however, the losses are three times greater, resulting in a net efficiency improvement factor of 27. Using 18-gauge copper wire, the free-space calculated efficiency of this antenna is 1.23% at 3 Mhz and 13.1% at 6 Mhz.

Unless extremely severe restrictions are imposed on space, therefore, the largest practical single-turn loop is preferable to a smaller multiturn unit.

Shaping up

The final consideration is form. Efficiency has been shown to be highest when a fixed-length peri-

Precise tuning. Reflected power meter permits fine tuning and exact matching, and monitors forward output power level. The coarse adjustments make discrete, step-by-step changes, while the fine controls provide continuous variations overlapping the coarse steps.

meter encloses the greatest possible area. A circular configuration is best from a performance standpoint, but practical factors, such as the types of commercial tubing available, must be considered. This is especially true of developmental models, which are most economically built with straight tubing and "els."

Comparisons were made between a square, an equilateral octagon, and a circle, all of the same total perimeter. The octagon encloses 20% more space than the square, and the circle 29% more. Since radiation resistance is proportional to the square of the area, the radiation efficiency of the small octagon loop exceeds that of the square by about 45%, while the circular loop outperforms its square counterpart by about 65%. But because straight tubing packs more compactly, is more readily available, and is much cheaper than the circular kind, the octagon shape was chosen. The size—5 feet is the maximum length for any part—was held down so the antenna could be easily disassembled and carried in a small motor vehicle.

With the loss reduction achieved, the loop antennas that have been built provide a calculated free-space efficiency of about 22% at 2.5 Mhz and about 77% at 5 Mhz.

In the final analysis, however, an antenna's efficiency, or, perhaps more important, its effectiveness, must be proven in field tests.

As noted before, preliminary tests in the U.S. were followed by several hundred more conducted by the Army in Vietnam. Numerous frequencies and different ranges were used at various times of day in the later trials. Also, the tests were at all times confined to relatively low power levels, usually on the order of a few watts.

Nevertheless, all contacts attempted in Vietnam were not only 100% successful, but, with few exceptions, were rated "perfect." These few exceptions were never ranked lower than "good."

Competitive trials

The earlier U.S. tests, however, were perhaps more informative in providing direct comparisons between the loop and other antennas. As a matter of fact, the octagonal loop made of 1½-inch tubing is actually a second-generation model. For convenient construction, the earlier developmental models were constructed in a square shape and formed from ¾-inch tubing. Later tests have revealed a very significant 8-decibel superiority for the octagon version over the square.

Despite this, however, the square models showed themselves to be effective radiators in the early trials. In numerous ionospheric field tests conducted between Aberdeen Proving Ground and two widely separated mountain valleys in the Alleghenies, the square loop proved, in almost all instances, as effective as a full-sized dipole, and actually surpassed the dipole in most matchups. Several frequencies between 2.5 Mhz and 5.5 Mhz were used, and in each instance the dipole was cut to the optimum length. Furthermore, the dipole was strung in a cleared area at a height of 40 feet, while the bottom of the loop was only 4 feet above the ground.

In one field test to determine ground-wave propagation over a distance of two miles, a dipole supported at a height of 6 feet delivered a measured field strength of about 68 microvolts on a transmitter power of 6 watts. The square loop gave about 600 microvolts on the same power, and the octagon produced approximately 1,500 microvolts. The frequency used was 3.275 Mhz—not the best for the small loops.

It's true that the dipole's propagation in this particular test suffered from a less favorable polarization. But polarization characteristics are basically inherent and have to be considered in choosing antennas for operation at low heights.

Modifications

Though the octagon loop is a second-generation version, further improvements are being made. With the fiberglass mast used in some recent models, a single soldier can set up the antenna. For some applications, the diameter of the tubing can perhaps be advantageously increased from the present 1½ inches to 3, 4, or even to 6 inches. For other applications, the usual output tank circuit and matching network can be eliminated if the final amplifier is located close to the loop. The loop then can serve as both the radiation element and the final tank circuit, a technique especially useful where power is low and portability a prime requisite. Models of such long-range, highly portable antennas have been successfully tested at the Limited War Laboratory.