United States Patent

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[54] **WIDE RANGE TUNABLE TRANSMITTING LOOP ANTENNA**
8 Claims, 9 Drawing Figs.

[52] U.S. Cl. **343/856,** 343/867, 343/741

[51] **Int. Cl.** **H01q 21/00,** H01q 7/00

[50] **Field of Search** 343/741, 742, 743, 744, 866, 867, 868, 870, 856, 895

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ABSTRACT: This specification discloses a loop antenna which employs a novel and unique feed scheme permitting a tuning range of up to 10:1 with a nearly constant input impedance and high efficiency. The antenna is useful for both receiving and high power transmitting applications and should find particular usefulness in the high frequency range of 2—30 MHz. The antenna consists of a single turn tuned primary fed by a small, single turn untuned secondary. By proper adjustment of the ratio between the diameters of the primary and secondary loops, an accurate match to a low impedance cable (50 ohms) may be achieved over the entire tuning range. Minimum efficiencies of 30 percent are attainable with practical designs having a diameter of only 5 feet for 3—15 megahertz coverage.

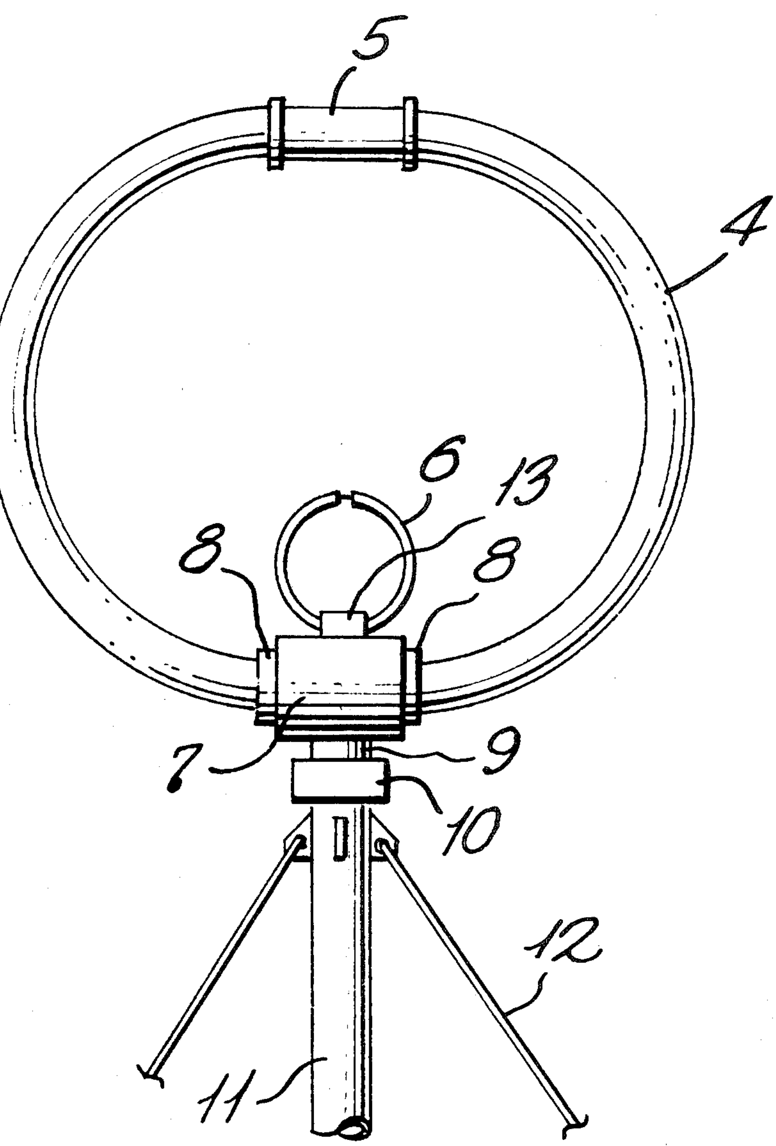

Fig. 1a.

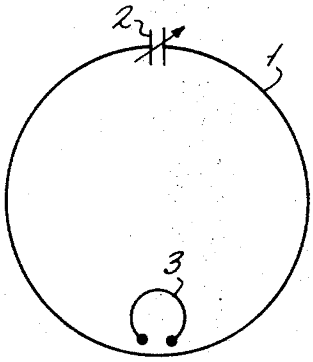

Fig. 1b.

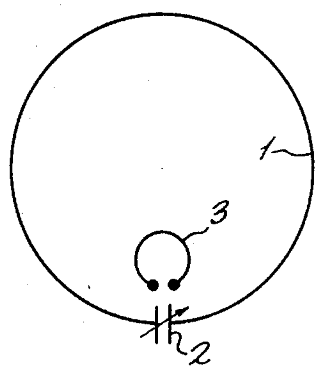

Fig. 1c.

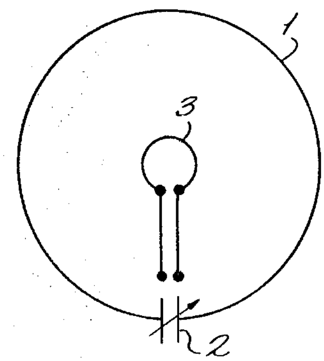

Fig. 2.

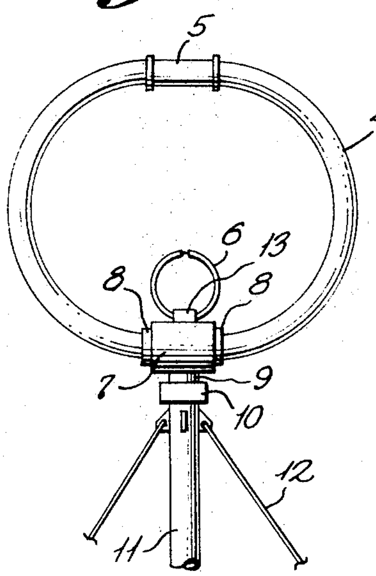

Fig. 4.

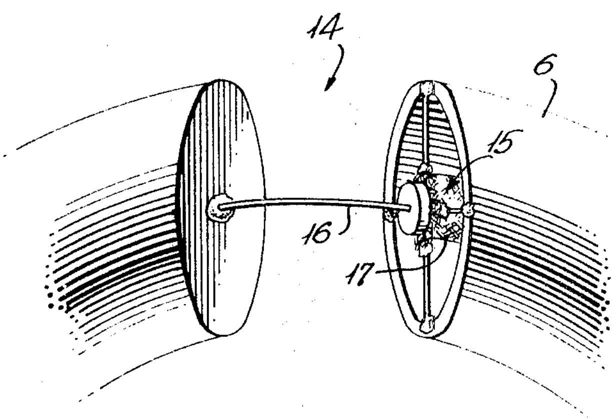

Fig. 3.

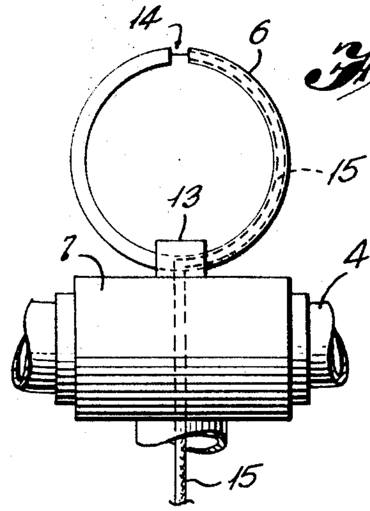

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Fig. 5.

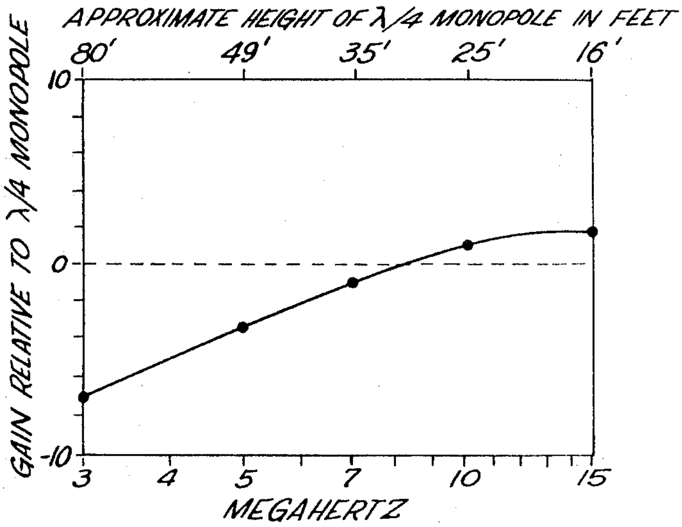


Fig. 6.

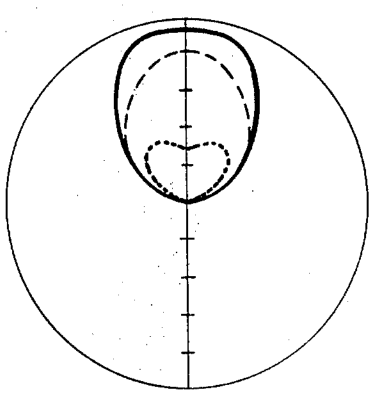
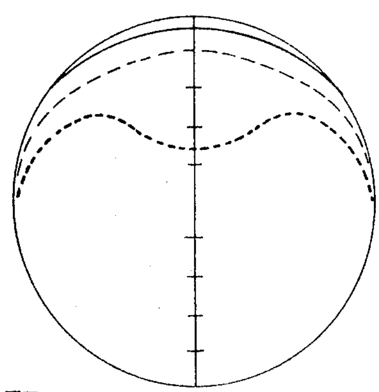


Fig. 7.



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WIDE RANGE TUNABLE TRANSMITTING LOOP ANTENNA

BACKGROUND OF THE INVENTION

This invention relates to loop antennas and more particularly to a very small loop antenna with a novel coupling system which permits efficient operation for transmitting applications and further which provides simple tuning over a frequency band several octaves wide with a nearly constant feed impedance.

The use of small tuned loop antennas dates back to the earliest days of radio. From their humble beginning to the present day, loop antennas of various types, configurations, and shapes have evolved from the ever advancing state-of-the-art and have served many useful purposes. Most significant among these has been the use of the loop antenna for direction finding applications. It is interesting to note that until the invention described herein, tuned loop antennas, having dimensions small with respect to a wavelength, have been used almost exclusively for receiving purposes. The reasons for such restricted use fall into two categories. First, certain types of loop antennas offer a considerable improvement in overall signal-to-noise ratio compared to other common antenna types for reception in the presence of man-made noise. Secondly, a practical feed arrangement has not been available which provides adequate efficiency, simple tuning over a wide frequency range, and accurate impedance matching for most transmitting applications.

The effectiveness of certain types of loop antennas for receiving applications in the high frequency range and below has long been a recognized fact. Its popularity for this purpose stems from the simple fact that a small, one turn loop, or a small tuned loop with several turns but which is shielded, exhibits the characteristic of being responsive almost entirely to the magnetic field component of a wave while being virtually insensitive to the electric field of the same wave. In a normal radiation field (radio wave), the magnitude of the electric vector is 120π greater than the magnitude of the magnetic vector, the difference being due to the intrinsic impedance of space. However, the induction fields associated with manmade noise have electric field components many times greater than those of a normal radiation field. Thus, a one turn (or a shielded multiturn), tuned loop antenna, being essentially sensitive only to the magnetic field, offers a high degree of rejection to the reception of such noise relative to an antenna such as a dipole which is sensitive to both electric and magnetic field components of a wave. At frequencies lower than about 10 MHz., improvements in signal-to-noise ratios greater than 20 db. relative to a simple dipole are not uncommon when the receiving environment is contaminated by severe manmade noise sources.

Another important feature of small tuned loop antennas which is an advantage over conventional vertical tuned whips or small tuned horizontal dipole antennas is its unique radiation pattern. If a loop antenna is oriented such that the plane of the loop is perpendicular to the earth and if it is placed at a height not greater than a small fraction of a wavelength above a ground having perfect conductivity, it will exhibit a nearly uniform response to radiation at all angles from the horizon to the zenith in the plane of the loop. The energy radiated by such a loop is vertically polarized on the horizon and horizontally polarized overhead (zenith angle). The pattern of this loop in the azimuth plane is that of a FIG. 8 at angles near the horizon. Thus, it may be seen that a small loop antenna has the distinctive property of offering radiation for transmission and response for reception over both long distances (by means of low angle vertically polarized propagation) or over short and medium distances (by means of horizontally polarized oblique incidence propagation). By comparison, a vertical tuned whip antenna is useful only for low angle, vertically polarized propagation since it exhibits a null overhead and poor response and radiation at elevation angles in excess of about 45°. Such a whip is thus useful only for extremely short range communication by ground wave propagation or relatively long distance communication by means of low angle sky wave propagation. A horizontal dipole antenna at a height above ground equivalent to a small fraction of a wavelength exhibits maximum response overhead with zero radiation near the horizon. It is thus useful only for relatively short range communication in that portion of the high frequency spectrum in which oblique incidence propagation is possible. From this, it can be seen that a properly designed small vertical tuned loop antenna would find considerable usefulness as a general purpose antenna system particularly for transportable or shipboard applications requiring an antenna of small dimensions which may be used for short, medium and long range communications.

A further advantage of the small tuned loop antenna for certain applications is the high Q characteristic which it exhibits. A small loop antenna designed for practical values of efficiency as a transmitting antenna will exhibit an equivalent Q as high as 1000 or 2000. Such a high Q would often times be useful for receiving applications in an environment in which strong signals from nearby high power transmitters, radiating on slightly different frequencies than that being received, would render reception impossible. However, the high Q or narrow bandwidth of such a loop would provide excellent rejection of such unwanted signals and would allow practical reception under normally impossible conditions. An example of such an application would be aboard naval ships wherein simultaneous transmission and reception is required at several frequencies within the high frequency band. This same narrow bandwidth characteristic also provides an improvement in signal-to-noise ratio with respect to wide band, short duration, impulse noise of large amplitude which might otherwise overload the input stage of a typical communication receiver. Such circuitry tends to be broadly tuned and thus particularly susceptible to overload in the presence of high amplitude impulse noise.

In the past, loop antenna designs have generally employed a high impedance feed in which the output is taken across the tuning capacitor. Although this technique works well in receiving wherein the first RF stage is placed adjacent to the feed terminals of the loop, it is nonetheless awkward and provides a difficult design problem for transmitting purposes. It is awkward because a loop antenna, to be effective for receiving purposes, must be balanced with respect to ground. This would require either a push-pull, high impedance, RF input stage or a well balanced low loss impedance transformer to be successful. Since the resistive component of the feed impedance, referenced to the terminals of the tuning capacitor, varies substantially as a function of the frequency to which the loop is tuned, a good impedance match is nearly impossible to obtain over a wide range of frequencies. Techniques have been devised which utilize numerous clever schemes to provide an effective impedance match at a particular frequency but which require separate adjustment to maintain the match as the frequency is varied. An example of such a method is that wherein the tuning capacitor is comprised of three separate capacitors in series across the gap of the loop. The outer two capacitors are mechanically ganged and form the tuning portion of the arrangement. The center capacitor has a value of capacitance which is generally much larger than that of the other two capacitors. A low impedance feed line is connected across the terminals of the center capacitor. By adjusting the ratio between the capacitance of the outer capacitors and the center capacitor, an effective match may be obtained. However, tuning the loop to a frequency removed by more than several percent of the original frequency will require readjustment of the center capacitor in order to retain a good match. Thus, although this scheme represents a reasonably practical solution to feeding a tuned loop for transmitting purposes, it represents a double adjustment procedure which is both clumsy, expensive, and unnecessary. Other feed schemes tend to employ the use of transformers which are generally complex and not practical for transmitting applications. Such transformers also require an additional adjustment to provide an effective match over a wide band of frequencies.

SUMMARY OF THE INVENTION

The present invention encompasses a new concept in the design of small loop antennas by virtue of a completely novel and unique feed scheme. Since a loop antenna both radiates and receives by virtue of the magnetic component of the field, it is possible to devise a feed scheme analogous to that of a simple transformer having a tuned primary and an untuned secondary. According to the invention, a small untuned feed loop is placed inside a tuned outer primary loop and in the plane of a primary loop. The feed loop is positioned along the inner edge of the primary loop conductor. The diameter of the feed loop is selected to provide an accurate impedance match to the outer primary loop, which impedance match will prevail over a greater frequency range than 10:1. This structure provides a significantly wider frequency tuning range with higher efficiency and a more nearly constant feed impedance than antenna loop structures of prior art.

Further advantages and objects of the present invention will become readily apparent as the following detailed description of the invention unfolds and when taken in conjunction with the drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. 1*a*, 1*b* and 1*c* schematically illustrate different embodiments of the antenna of the present invention;

FIG. 2 is a view in elevation of a preferred embodiment of the antenna of the present invention;

FIGS. 3 and 4 are enlarged views of portions of the antenna of FIG. 3 illustrating the interconnections to the feed loop;

FIG. 5 is a curve showing the efficiency of the antenna of FIG. 2 relative to a resonant quarter wave monopole; and

FIGS. 6 and 7 illustrate radiation patterns in the elevation plane produced by the antenna of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

In FIGS. 1*a* through 1*c*, the reference number 1 designates the primary loop of the antenna, which is tuned by variable capacitor 2. A feed or secondary loop 3 is positioned in the plane of the primary loop 1 and may be located at any of the positions shown in FIGS. 1*a*, 1*b* or 1*c*. The feed loop 3 connects to a low impedance feed line, which may have an impedance of 50 to 300 ohms selected to match the impedance of the feed loop. The impedance of the feed loop is determined by its diameter with respect to that of the primary loop.

Simple transformer action occurs between the primary loop and the feed loop due to the highly reactive field near the tuned primary loop. This highly reactive field serves to greatly concentrate magnetic flux lines which cut the small untuned feed loop. The degree of magnetic flux concentration is a function of the Q (Figure of merit) of the tuned primary. The Q of the tuned primary varies with frequency; the highest Q occurring at the lowest frequency of operation with the lowest Q exhibited at the highest frequency. This variation in Q results from the variation in the sum of the loss resistance and radiation resistance of the primary as a function of frequency. The effective feed impedance of the secondary feed loop is controlled by its diameter or area and by the number of flux lines cutting it. Thus, the feed impedance looking into the secondary loop will be essentially independent of frequency since when the feed loop is extremely small with respect to a wavelength at the lowest frequency of operation, the number of flux lines cutting it is large because of the high Q, whereas when the feed loop becomes a larger fraction of a wavelength as the frequency of resonance is increased, the concentration of flux lines is reduced due to the lower Q. Another explanation for the constant feed impedance behavior of the small secondary loop may be found in examining the relationship between the loss resistance and the radiation resistance of the primary loop which is, of course, reflected into the secondary feed loop by virtue of the previously discussed transformer action. In a practical wide-band design, the loss resistance at the lowest frequency of operation will generally be greater than the radiation resistance by some considerable factor. However, the radiation resistance of the primary loop increases rapidly with frequency and soon overtakes the loss resistance. If the design is such that the maximum radiation resistance, which occurs at the highest frequency of operation, is made no more than about three times the value of the loss resistance, a maximum impedance mismatch of only 2:1 will be exhibited looking into the feed loop terminals since the total possible impedance excursion is within a 4:1 ratio. Of course, the 2:1 maximum mismatch will prevail only if the feed impedance is referenced to the mean value of the 4:1 excursion.

In general, the design of a loop antenna embodying the principle of this invention will have a perimeter or circumference less than three-eighths of a wavelength at the highest frequency for which operation is intended. Beyond this size, a uniform current distribution around the loop conductor no longer exists and self-resonance of the tuned primary tends to occur which reduces its practical effectiveness as an antenna. The efficiency of a properly designed loop antenna may be made to exceed 20 or 30 percent at the lowest frequency of operation, wherein the overall frequency coverage from the highest to the lowest frequency is in a ratio greater than 5:1 or 6:1 with ratios as high as 10:1 being practical. The frequency range over which a practical design will tune is largely limited by the capacitance ratio of the tuning capacitor employed. The tuning range may be found with reasonable accuracy by taking the square root of the ration between the mean and maximum capacitance used for tuning. The actual tuning range will always be somewhat less than this value due to the distributed and leakage capacitance inherent within the tuned primary. The overall efficiency of a loop antenna, designed according to the invention, may be calculated if both the total loss resistance and the radiation resistance are known. The absolute efficiency is equal to the radiation resistance divided by the sum of the radiation resistance and the loss resistance. To obtain the efficiency in percent, this value must be multiplied by 100. The radiation resistance is approximately equal to

$$R_r = 31{,}000 \frac{A^2}{\lambda_2}$$

Where

R_r = Radiation resistance in ohms

A = the area enclosed by the tuned primary and

λ = the wavelength in meters.

Practical loop designs for use in the range of 2—30 megahertz will utilize copper or aluminum tubular conductors having a diameter of 3 inches to 5 inches. A typical design for 3 to 15 megahertz operation would be constructed as shown in FIG. 2 with a primary loop 4 having a diameter of about 5 feet and tuned by a high voltage vacuum capacitor 5 having a capacitance range of approximately 25 to 1,000 picofarads. The tuned primary loop should be made of aluminum or copper tubing having a diameter of approximately 4 inches—5 inches. The diameter of the feed loop, which is designated by the reference number 6, for 50 ohms impedance should be approximately 10 inches. The diameter of the tube used to construct the secondary feed loop is not critical since currents of large magnitude do not flow through its conductor. Typical sizes would fall in the range of 012 AWG wire up to tubing having a diameter of 1.5 inches for 3—15 megahertz operation.

The shape of the tuned primary loop envisioned by this invention is ideally circular but is slightly elliptical to facilitate its construction. It may also be in the form of any regular polygon with six or more sides. A square loop is to be avoided due to its significantly lower efficiency. A square loop design results in a higher ratio of loss resistance to radiation resistance since the area enclosed by the loop is small compared to the perimeter. Multiturn loops are to be avoided for two reasons:

1. They are not capable of being turned over a greater than approximately 3:1 frequency range, and

2. Unless shielded, they exhibit a poor rejection of local manmade noise.

Although the position of the feed loop with respect to the tuned primary discussed thus far and shown in FIG. 1*a* represents a preferred embodiment, in actual practice the feed loop may be placed at any point within the interior of the loop or adjacent to the outer edge of the primary loop conductor. For example, more uniform current distribution might be obtained by locating the feed loop concentric to the tuned primary as illustrated in FIG. 1*b*. For practical purposes, models might also be built wherein the feed loop is placed directly above but symmetrical to the tuning capacitor which would be located at the bottom rather than the top of the primary as shown in FIG. 1*c*.

The bottom portion of the primary loop 4 comprises a piece of straight conducting tubing 7, which is joined to the arcuate section of the primary loop by flanges 8 to permit disassembly of the loop to facilitate shipment of the antenna. A vertically oriented supporting mast 9 is frazed to tubing 7 and is rotatably supported by a rotator 10, by which the loop may be rotated. The rotator is supported on a lower mast 11, which is stabilized by guy wires 12.

As shown in FIG. 3, the feed loop is mounted on the tubing 7 by means of a bracket 13. The feed loop is formed with a gap 14 and a coaxial cable 15 extends from the gap down through one side of the tube forming the feed loop and passes out through the bottom of the feed loop down through the mast 9. As shown in FIG. 4, the inner and outer conductors 16 and 17 of the coaxial cable 15 are connected to the feed loop 6 at the gap 14. The outer conductor 17 is connected to the half of the feed loop tubing through which it extends and the inner conductor 16 is connected to the other half of the feed loop tubing, which is closed off at the gap. When the antenna is used for transmitting, the signal to be transmitted with be applied to the inner loop via the coaxial cable 15. And when the antenna is used to receive, the received signal will be taken from the feed loop by the coaxial cable 15. The particular manner in which coaxial cable is connected to the feed loop provides for balanced operation with respect to ground.

FIG. 5 illustrates the efficiency of the antenna shown in FIG 2 relative to a resonant quarter-wave monopole above a perfectly conducting ground. At the top of the chart is a scale which points out the approximate height required for quarter-wave monopole resonance at each frequency shown on the bottom scale. The small gain of the loop over the monopole above about 8 megahertz is due to the height gain factor resulting from the image of the loop below ground.

FIG. 6 shows the radiation pattern of a 5 foot diameter loop such as that shown in FIG. 2 in the elevation plane at right angles to the plane of the loop for horizontal polarization at 4, 10 and 20 megahertz. It can be seen that the response of the antenna to reception and radiation of horizontally polarized waves steadily decreases as the frequency is increased. Maximum response is always at or near the zenith.

FIG. 7 depicts the elevation plane response in the plane of the loop for vertical polarization. It can be seen that maximum energy is radiated on the horizon at all frequencies.

The above description is of a preferred embodiment of the invention and many modifications may be made thereto without departing from the spirit and scope of the invention, which is defined in the appended claims.

I claim:

1. A loop antenna comprising a one turn primary loop having a perimeter of less than three-eighths of a wavelength and formed by a conducting member interrupted along its length by a gap, a capacitor connected across said gap for tuning said primary loop to a desired frequency, said capacitor being variable to permit tuning of said antenna over a wide band of frequencies, a single turn secondary loop substantially smaller than said primary loop magnetically coupled to said primary loop with both said primary and secondary loops falling in the same plane, said secondary loop having a diameter selected to bear an optimum relationship to the diameter of said primary loop so that variation in feed impedance is minimized over the band of operation, and a low impedance transmission line connected to terminals of said secondary loop.

2. A loop antenna as recited in claim 1 wherein said secondary loop is positioned within said primary loop.

3. A loop antenna as recited in claim 1 wherein said secondary loop is positioned off center of said primary loop and adjacent to said primary loop.

4. A loop antenna as recited in claim 3 wherein said secondary loop is positioned adjacent to the opposite side of said primary loop from said capacitor.

5. A loop antenna as recited in claim 3 wherein said secondary loop is positioned adjacent to said capacitor.

6. A loop antenna as recited in claim 2 wherein said secondary loop is positioned in the center of said primary loop.

7. A loop antenna as recited in claim 1 wherein the area enclosed by said primary loop is about 6 times that enclosed by said secondary loop.

8. A loop antenna as recited in claim 1 wherein said primary loop is approximately circular in shape.