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CONSTANT IMPEDANCE LOOP ANTENNA

Filed Sept. 20, 1968

4 Sheets-Sheet 1

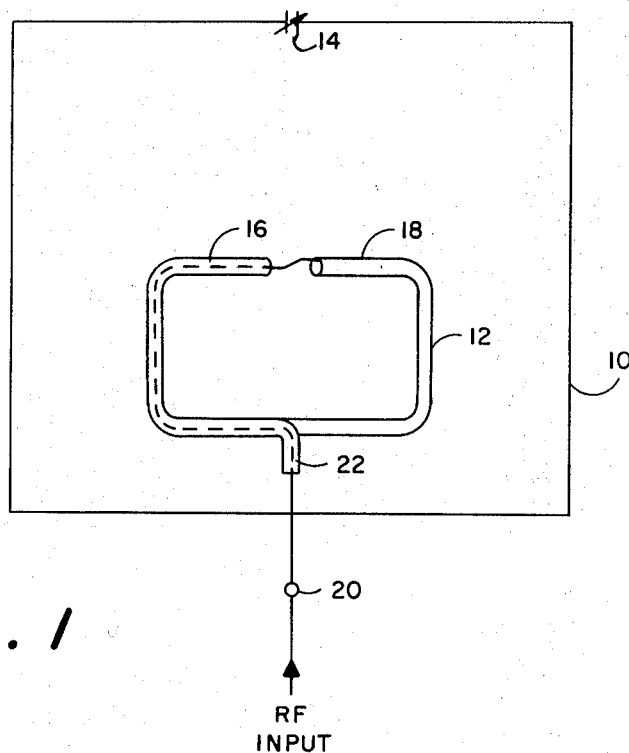


Fig. 1

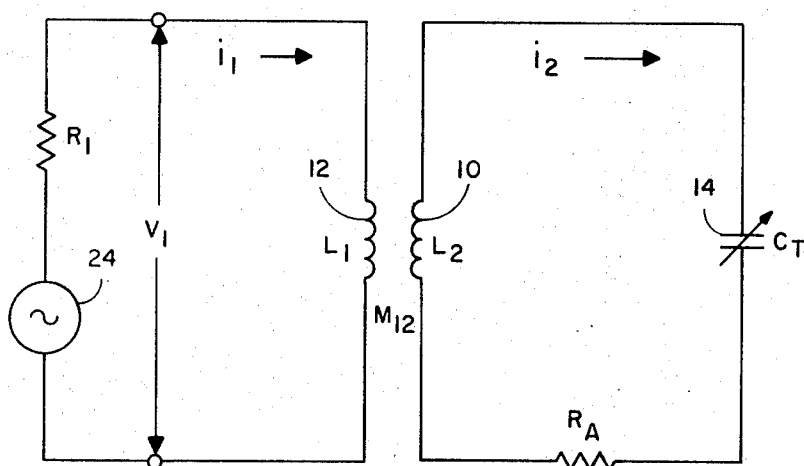


Fig. 2

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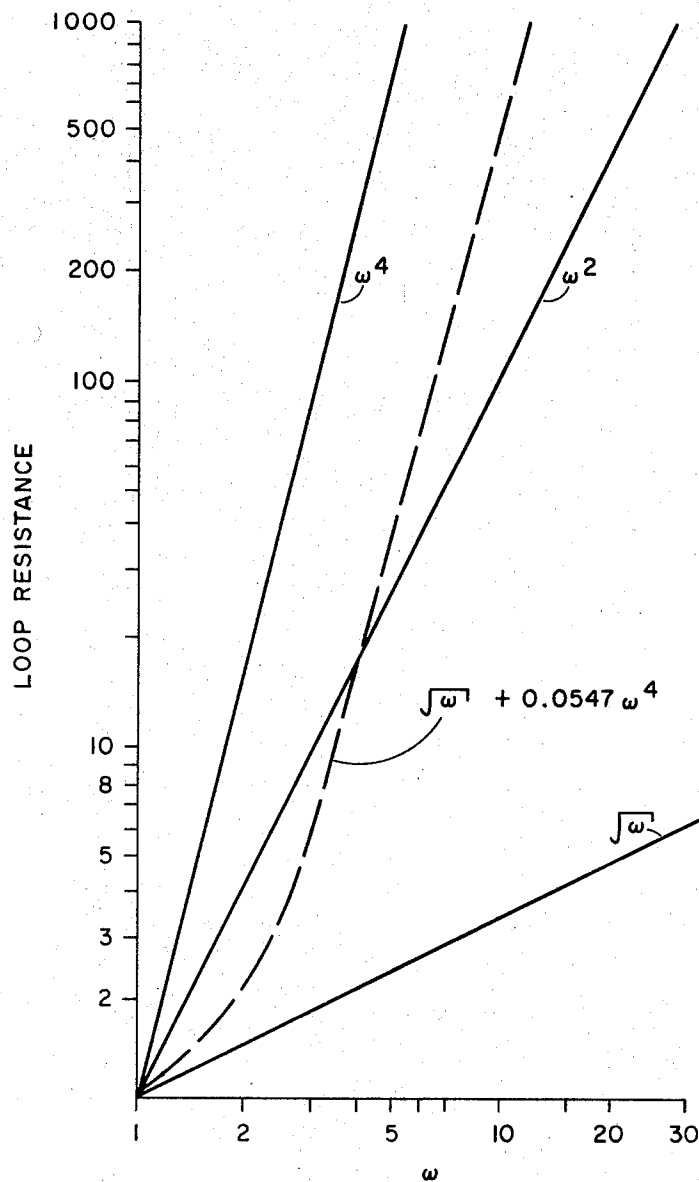


Fig. 3

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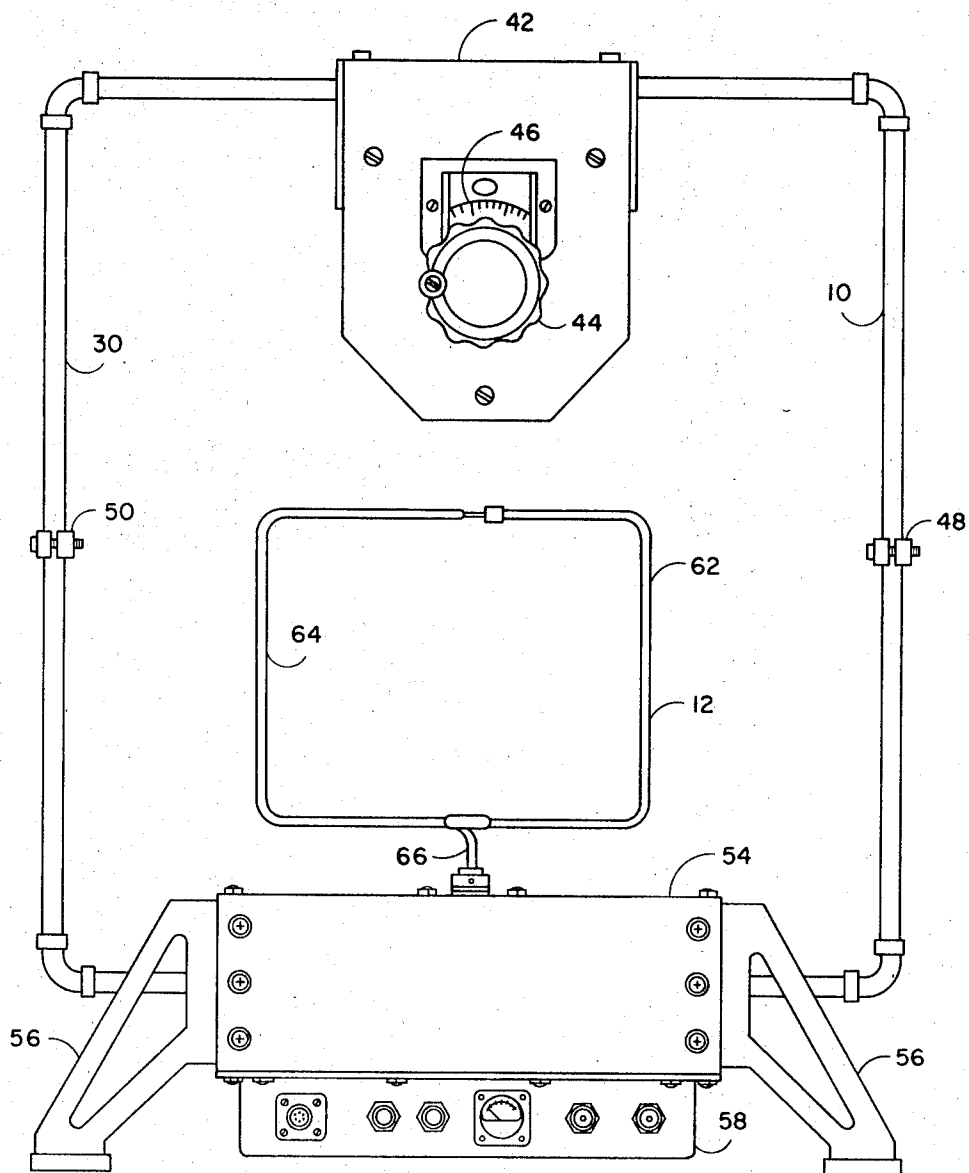


Fig. 4

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4 Sheets-Sheet 4

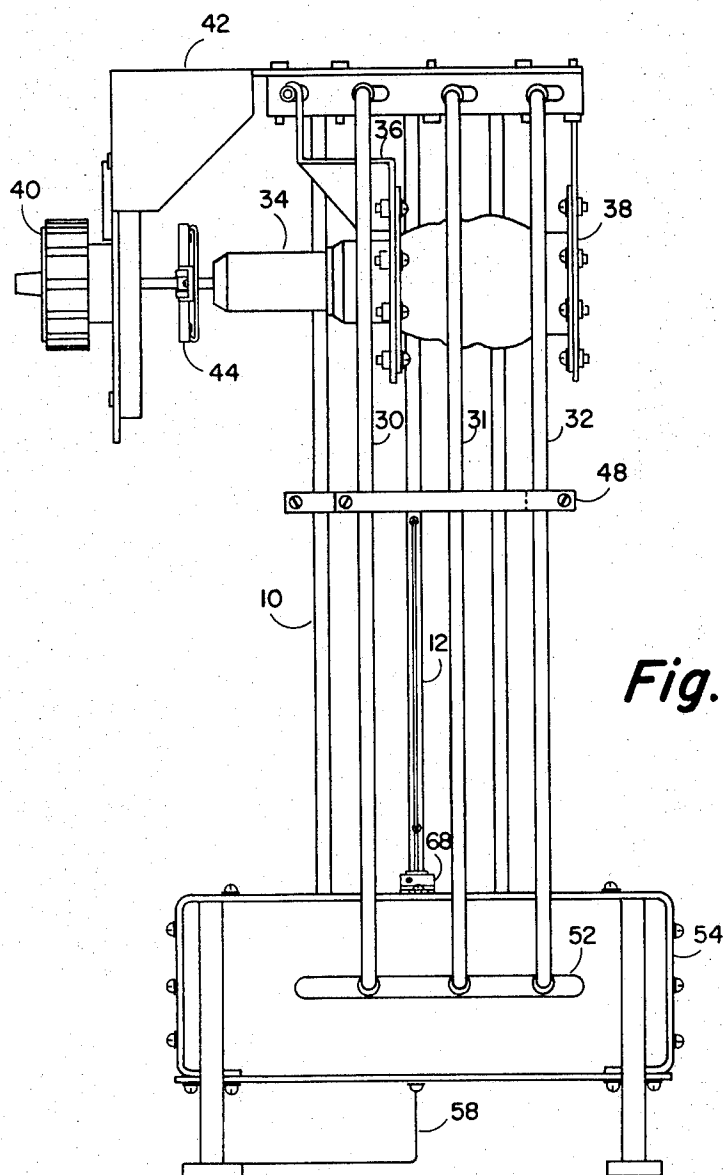


Fig. 5

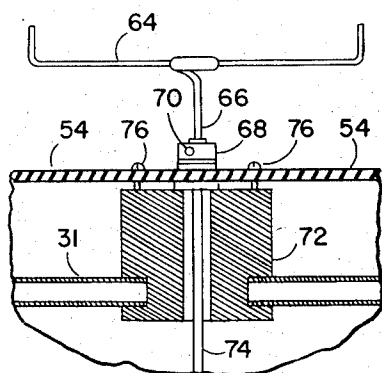


Fig. 6

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CONSTANT IMPEDANCE LOOP ANTENNA

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Int. Cl. H01q 11/12

U.S. Cl. 343—744

11 Claims

ABSTRACT OF THE DISCLOSURE

A loop antenna is described which is operative over the high frequency band and which presents a substantially constant input impedance over wide ranges of this band without readjustment. The antenna includes a three turn loop made up of conductors having a relatively large cross-sectional area. The loop is closed by a tuning capacitor. As so constructed, the loop has a high Q and presents an effective radiation resistance which varies approximately in accordance with the square of the frequency of the signal carried by the loop so as to provide the effectively constant input impedance at an input terminal of a coupling loop fabricated from a single turn of coaxial cable.

The present invention relates to loop antennas and particularly to loop antennas which are operative either in a transmitting or receiving mode over a wide range of frequency.

The invention is especially suitable for use in a small antenna which is operative over the high frequency band which extends from approximately 2 mHz. to 30 mHz.

Loop antennas of various types have been suggested in the past. These usually have a loop of conductive material and a connection to the loop or a coil magnetically coupled to the loop which carries signals into or out of the loop. The loop itself must be carefully balanced, both physically and electrically, with respect to its input coupling means and also with respect to the surrounding structures in order to provide an effective radiation pattern. Thus, complex support structures and mechanisms have been provided in order to maintain the properly balanced relationship of the loop with respect to its coupling means, as well as to isolate the antenna from surrounding structures which could adversely affect its desired radiation pattern.

Another serious drawback of conventional loop antennas, particularly when they are used in the transmitting mode, is their large variation in input impedance with frequency. Thus, conventional loop antennas must be carefully tuned by complex matching networks if efficient power transfer is to be achieved. Generally, readjustment of the impedance matching network is required, even for minor adjustments in frequency. Both the phase and total impedance presented by the loop must be adjusted. This generally requires two controls, the adjustments of which are inter-related. Thus, changing frequency can be a complex time consuming operation with a loop antenna.

It is an object of the present invention to provide a loop antenna which is well balanced with respect to surrounding structures, such as ground (i.e. is effectively ground independent) and may be simply and quickly matched to a load, such as a source of signals to be transmitted or a receiver input and does not require retuning for operation over a wide frequency band, say of the order of several mHz.

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More specific objects of the invention are to provide a loop antenna

- (a) operative both in transmit and receive modes which is small in size,
- (b) which presents a substantially constant input impedance over a wide range of frequencies, and
- (c) which can be tuned to adjacent bands easily and with a single control.

Briefly described, an antenna embodying the invention includes a radiation translating loop which can either receive or transmit signals and a coupling loop; the translating loop and coupling loop being magnetically coupled with each other. The translating loop may be a closed loop having a series capacitor for tuning the loop to any frequency in the range of frequencies over which the antenna is selected to operate. The translating loop itself is made of one or more turns of conductive material, such that the resistance that it presents to signals varies approximately as the square of the frequency of such signals over the operating range. Accordingly, at the input of the antenna which may be a connection to the coupling loop, the antenna presents a substantially constant impedance, when tuned to resonance. Frequent tuning is therefore not required. The coupling loop itself may be a single turn of coaxial cable having a low inductive reactance over the frequency range of the antenna. The loop may be movable with respect to the translating loop so as to achieve fine control over the tuning of the antenna.

The invention itself, both as to its organization and method of operation, as well as additional objects and advantages thereof will become more readily apparent from a reading of the following description in connection with the accompanying drawings in which:

FIG. 1 is a simplified diagram of a loop antenna embodying the invention;

FIG. 2 is a schematic diagram of the equivalent circuit of the antenna shown in FIG. 1;

FIG. 3 is a family of curves showing the effective resistance of the translating loop of the antenna as it varies with angular frequency;

FIG. 4 is an elevational view of a loop antenna in accordance with the invention, including a transmit-receive switching directional coupler unit for tuning indication;

FIG. 5 is a side view of the antenna shown in FIG. 4; and

FIG. 6 is a fragmentary sectional view of the antenna taken along the line 6—6 in FIG. 5.

Referring more particularly to FIG. 1, a loop antenna embodying the invention is there depicted as including a radiation translating loop 10 and a coupling loop 12. The translating loop 10 is a closed loop in which a series capacitor 14 is interposed. The capacitor 14 is a variable capacitor for tuning the loop. The translating loop 10 is so constructed, as will be explained more particularly hereinafter, as to have an effective resistance to signals which it receives or transmits which varies approximately as the square of the frequency of such signals.

The coupling loop 12 is made up of a coaxial cable. This coupling loop has two sections 16 and 18 which are approximately symmetrical. The center conductor of the section 16 is connected at one end of that section to the shield conductor of the section 18. The other end of the shield conductor is connected to the shield conductor at the opposite end of the section 16. An input terminal 20 may be connected to the inner conductor

of the section 16 by way of an extension 22 of that section 16.

In the case where the antenna is used as a transmitting antenna, a radio frequency input, as may be derived from the output of a transmitter is connected to the terminal 20. It will be observed that the extension 22 presents an unbalanced coaxial line to the input terminal 20 by virtue of the coupling of the translating loop 10 to the input terminal by way of the coupling loop, two important features inure. First, ground independent operation (viz. the antenna is essentially insensitive to ground structures in its vicinity). Secondly, impedance matching is highly efficient, since the impedance presented by the antenna at the terminal 20 is essentially constant over a wide range of frequencies. The latter feature, of course, simplifies and makes highly efficient impedance matching of the antenna to a source of signals to be transmitted. Retuning to different frequencies can readily be accomplished by means of the single control presented by the variable capacitor 14. The coupling loop, however, may be movable, as by being mounted in a rotating joint, so that it may turn about an axis perpendicular to the axis of the loop 10. This rotation varies the mutual inductance between the translating loop 10 and the coupling loop 12 and may be used for fine adjustment so as to obtain a perfect matching of the antenna to a source of input signals.

The operation of the antenna shown in FIG. 1 will be more apparent from the equivalent circuit thereof shown in FIG. 2. A source of signals shown as the generator 24 depicts the source of RF input signals for the antenna. The translating loop 10 presents an inductance L_2 which is resonated approximately or tuned by means of the tuning capacitor 14 which is indicated as having a capacitance C_T . Current from the source 24 indicated as i_1 circulates through the source internal resistance R_1 and through the coupling loop inductance L_1 . This current induces another current i_2 into the translating loop, which current is induced via the mutual coupling M_{12} between the loops 10 and 12. The inducer current i_2 dissipates power in the effective antenna resistance indicated as R_A . Neglecting the source internal impedance, the input voltage V_1 , which may be measured between the terminal 20 and the shield of the coaxial cable extension 22, may be expressed by the following equation:

$$V_1 = i_1(j\omega L_1) + i_2 j\omega M_{12} \quad (1)$$

The voltage around the loop through which the current i_2 may be expressed as:

$$0 = i_1 j\omega M_{12} + i_2 \left(R_A + j \left(\omega L_2 - \frac{1}{\omega C_T} \right) \right) \quad (2)$$

By solving these equations, the input impedance V_1/i_1 may be calculated as:

$$Z_{in} = \frac{V_1}{i_1} = \left[j\omega L_1 \frac{\omega^2 M_{12}^2}{R_A + j \left(\omega L_2 - \frac{1}{\omega C_T} \right)} \right] \quad (3)$$

When the translating loop 10 is tuned for resonance, the input impedance becomes:

$$Z_{in} = j\omega L_1 + \frac{\omega^2 M_{12}^2}{R_A} \quad (4)$$

The translating loop circuit consisting of L_2 , R_A and C_T desirably has a very high Q, say in excess of 200 over the high frequency band (1.5 mHz. to 30 mHz.). Accordingly, the mutual inductance M_{12} may be made very small, without sacrificing induced power. Now, if the inductive reactance of the coupling loop 12 is made small with respect to the mutual inductance, the input impedance of the antenna becomes:

$$Z_{in} \approx \frac{\omega^2 M_{12}^2}{R_A} \quad (5)$$

It can be seen from the last equation, that if the effective resistance R_A was variable with a frequency over

the frequency range of the antenna as the square of the frequency, then the input impedance at resonance would be substantially constant over that frequency range. The effective resistance is made up of three components, DC connection resistance (R_{DC}). This resistance does not vary with frequency; the skin effect resistance (R_{SK}); this skin resistance is proportional to the square root of frequency. The final factor or component is the radiation resistance (R_R). This resistance is proportional to the fourth power of frequency. Radiation resistance is also a function of the structural characteristics of the translating loop and may be expressed by the equation:

$$R_R = 31,200 \left(N \frac{A}{\lambda^2} \right)^2 \quad (6)$$

where

N is equal to the number of turns in the loop,
 A is equal to the area of the loop in meters, and
 λ is equal to the wave length of the signal in meters.

The radiation resistance R_R may be translated in terms of frequency and as translated may be expressed as follows:

$$\lambda^2 = \frac{36\pi^2 \times 10^{16}}{\omega^2} \text{ meters}^2 \quad (7)$$

Inasmuch as the coefficients of ω are all in variant with frequency, this equation may be expressed as:

$$R_R = K_A \omega^4 \quad (8)$$

Referring to FIG. 3, the variation of the effective resistance with frequency as a function of ω^4 which is related to the radiation resistance and the function of the square root of ω which, of course, is related to the skin resistance are depicted. Between these two curves, the desired variation of effective resistance ω^2 is also depicted. It can be observed, however, that if the coefficient of ω^4 is modified, a curve shown by the dash line is obtained which approximates ω^2 . This curve is the variation of effective resistance as a function of

$$\sqrt{\omega} + 0.547\omega^4 \quad (9)$$

It is apparent from FIG. 3 that the error between the curve shown in the dash line and the ω^2 curve is within 1.66 over a 7 to 1 range in frequency. This indicates that the voltage standing wave ratio (VSWR) will be within 1.66 over the 7 to 1 frequency range. Returning to Equation 5, it can be seen that perfect impedance matching and perfectly constant input impedance can be obtained by adjusting the value of mutual inductance M_{12} slightly. This can be accomplished by merely rotating the coupling loop 12 or moving the loop to alter the spacing between the coupling loop and the translating loop. The coefficient of ω^4 which provides the variation and effective resistance of the translating loop, shown in FIG. 3 (viz 0.0547) is obtained by configuring the translating loop so that the diameter or area presented by the loop conductor is a predetermined fraction of the area enclosed by the loop itself. A ratio of the conductor area to the loop area of approximately 1 to 900 has been found to produce the required coefficient. Of course, the number of turns in the loop may also be used to provide the requisite coefficient. For a specific example, it has been found that the requisite coefficient can be obtained by a translating loop of the configuration shown in FIGS. 4 and 5 of the drawings. This translating loop has three turns made of silver plated copper tubing having an outside diameter of $\frac{1}{2}$ inch. The area enclosed by the loop is approximately 0.171 meter squared. This loop also has very high Q which exceeds 300 over the range from 2 mHz. to 30 mHz.

It will also be observed from the fact that the radiation resistance is a small fraction (specifically $5\frac{1}{2}\%$) of the skin resistance. The antenna will have a relatively high efficiency. This efficiency is 5.2%. In the case of a small

loop antenna, this is very much desirable and permits the radiation of signals with high efficiency.

Referring to FIGS. 4 and 5, the loop antenna is shown as comprising three turns 30, 31 and 32 of tubular copper tubing, desirably silver plated, as mentioned above. A vacuum capacitor 34 has its plates connected respectively to the beginning of the first turn 30 and the end of the last turn 32 by way of brackets 36 and 38 respectively. The vacuum capacitor 34 may be a commercially available vacuum capacitor, such as a Jennings VCSL-1000-5, which is manufactured by Jennings Radio Company, of Oakland, Calif. A tuning control 40, which may be mounted at the top of the turns 30, 31 and 32 by means of a bracket 42, is connected to the capacitor 34 by way of a coupling 44. A scale 46 may be provided in the control 44. This scale may be calibrated in terms of frequency in order to adjust the antenna. Brackets of insulating material 48 and 50 on opposite sides of the turns 30, 31 and 32 may be used to hold the turns in position. The lower section of the turns extend through an opening 52 in an enclosure 54. Suitable insulating brackets in the enclosure 54 may be used to prevent the turns 30, 31 and 32 from shifting laterally. The enclosure 54 is held in position by means of legs 56. A transmit-receive and directional coupling unit 58 may be secured to the bottom of the enclosure 54. The output terminal of a transmitter is connected to an input of this unit and via the unit to the coupling loop 12. The loop itself is made up of sections of coaxial cable 62 and 64 and inter-connected to form a loop, as was described in connection with the loop 12 shown in FIG. 1. An extension 56 of the section 64 of the coupling loop passes through a rotating collar 68 of insulating material which may be secured to the section 66 by means of a set screw 70. The section 66 then extends downwardly through the top of the enclosure 54 through a block 72 of conductive material, such as copper, via an opening 74 therein and thence to the input terminal which may be at the output of the unit 58. The block 72 is fastened to the top of the enclosure 54 by means of screws 76. The center turn 31 of the translating loop 10 is split and extends into blind holes in the block 72. The block provides a conductive connection between these split ends of the loop 31. The block 72 therefore affords means of physical support for the entire loop and assists in preventing the translating loop from meandering. The coaxial cable of which the coupling loop 12 is constructed, is also sufficiently rigid, so that it is supported in position by means of the collar 68.

From the foregoing description, it will be apparent that there has been provided an improved loop antenna which may be fed from an unbalanced coaxial line and is both ground independent and highly efficient in operation. Because of the construction of the antenna, its input impedance remains essentially constant over a wide range of frequencies, thus, requiring little adjustment. Variations and modifications in the herein described antenna within the spirit and scope of the invention will undoubtedly, however, suggest themselves to those skilled in the art. Accordingly, the foregoing description should be taken merely as illustrative and not in any limiting sense.

What is claimed is:

1. A loop antenna which presents approximately constant impedance at the input thereof over a wide range of frequencies comprising

- (a) a closed radiation translating loop and a coupling loop which are magnetically coupled to each other, said translating loop being free floating electrically with respect to ground,
- (b) said translating loop having an effective resistance to signals translated thereby which varies approxi-

mately as to the square of the frequency of said signals over said range,

(c) said coupling loop having an inductive reactance which is small in relation to the inductive reactance presented by the mutual inductance between said coupling loop and said translating loop, and

(d) means for connecting said coupling loop to said input.

2. The invention as set forth in claim 1 wherein said translating loop has a capacitor interposed in series therein for tuning said translating loop to a frequency in the said range.

3. The invention as set forth in claim 2 wherein said translating loop has a high Q over said wide band of frequencies which Q exceeds 200.

4. The invention as set forth in claim 1 wherein said coupling loop is disposed within said translating loop.

5. The invention as set forth in claim 4 including means for rotating said coupling loop as to vary the mutual inductance between said loops.

6. The invention as set forth in claim 1 wherein said coupling loop is provided by a coaxial cable formed into two sections of equal peripheral length, the shields of said sections being connected to each other at one end thereof and the inner conductor of one of said sections being connected to the shield of the other of said sections at the opposite end thereof.

7. The invention as set forth in claim 6 wherein said means for connecting said coupling loop to said input comprises an extension of one of said sections.

8. A loop antenna which presents approximately constant impedance at the input thereof over a wide range of frequencies comprising

(a) a closed radiation translating loop and a coupling loop which are magnetically coupled to each other, said translating loop being free floating electrically with respect to ground,

(b) said translating loop having an effective resistance to signals translated thereby which varies in accordance with the following relationship,

$$\sqrt{\omega} + 0.0547\omega^4$$

where ω is the angular frequency of said signals in radians per second,

(c) said coupling loop having an inductive reactance which is small in relation to the inductive reactance presented by the mutual inductance between said coupling loop and said translating loop, and

(d) means for connecting said coupling loop to said input.

9. The invention as set forth in claim 8 wherein said relationship is satisfied by a translating loop defined by a conductor, the ratio of the area of said conductor to the area enclosed by said translating loop being of the order of 1 to 900.

10. The invention as set forth in claim 9 wherein said translating loop has a plurality of turns of tubular conductive material approximately 1/2 inch in diameter which encloses an area of approximately 0.171 square meter.

11. The invention as set forth in claim 10 wherein said translating loop has three turns.

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