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1530 Newton Avenue, Dayton, Ohio 45406
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[45] Patented Dec. 28, 1971

[54] ELECTRICALLY SMALL DOUBLE-LOOP ANTENNA WITH DISTRIBUTED LOADING AND IMPEDANCE MATCHING

8 Claims, 13 Drawing Figs.

[52] U.S. Cl. 343/701, 343/742, 343/744, 343/860, 325/373
[51] Int. Cl. H01q 11/12
[50] Field of Search 343/701, 742, 744, 860, 803, 804, 858, 856, 908; 325/373

[56] References Cited
UNITED STATES PATENTS
3,172,111 3/1965 Breetz 343/804
3,484,697 12/1969 Abend 325/373

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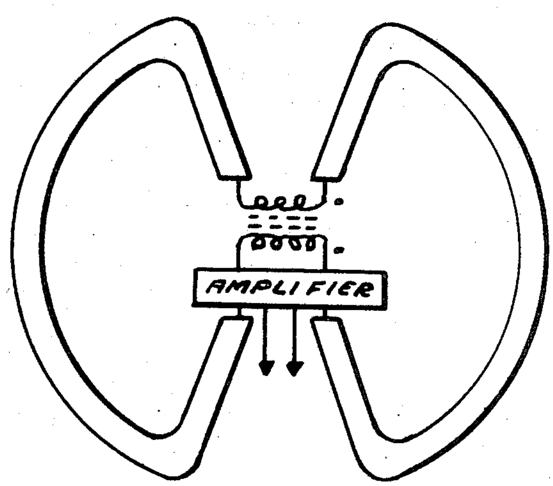
ABSTRACT: Relatively uniform impedance and broad bandwidth is obtained in a double-loop electrically small antenna by transformer coupling in phase opposition the ends of the loops. For receiving, amplification may be added within the loops to increase the effective electrical output of the antenna. The electrical output of the antenna may be remotely controlled at the receiver, to preclude overloading the receiver, by changing the potential supplied the amplifier over the conventional signal transmission line connecting the receiver to the antenna.



Patented Dec. 28, 1971 3,631,499

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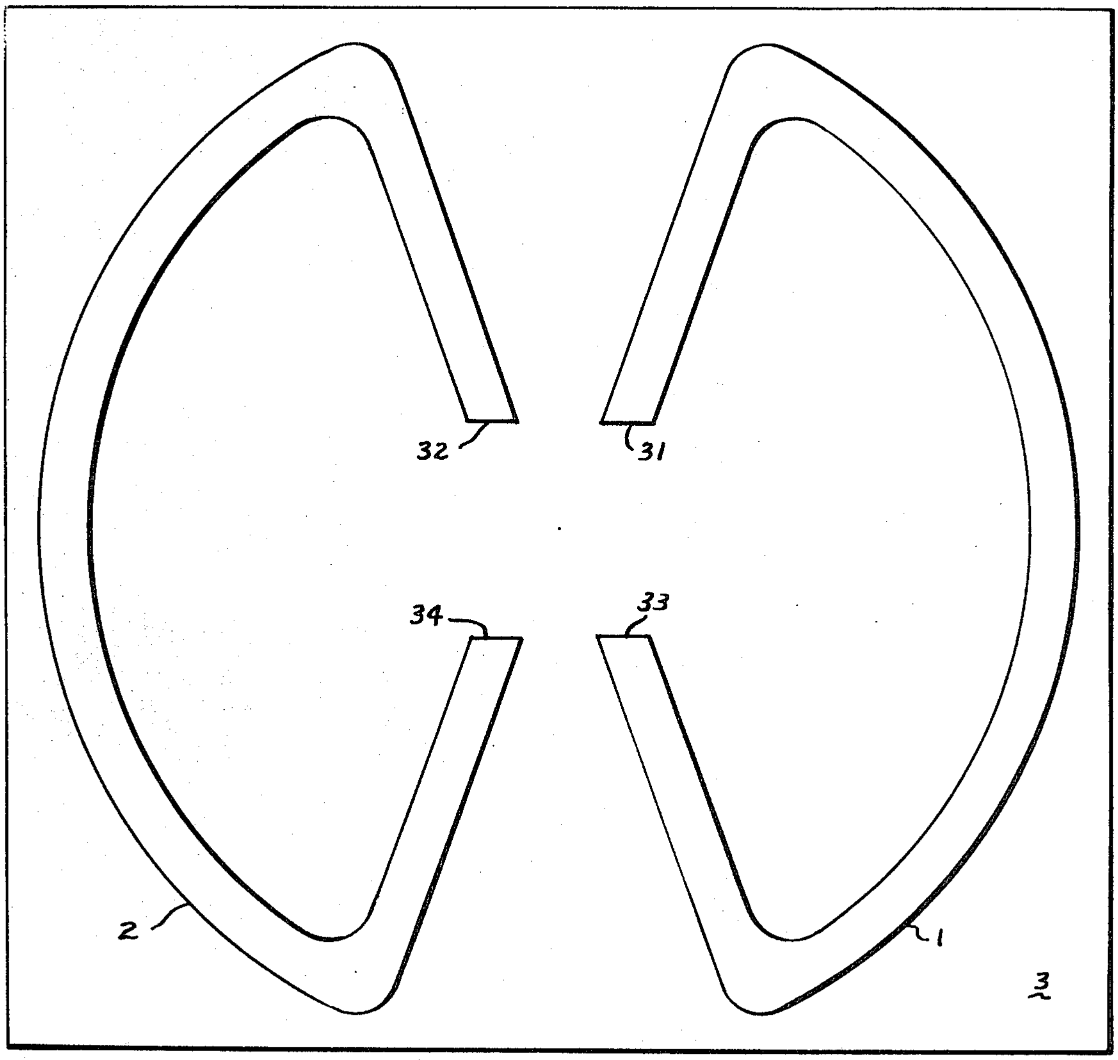

Fig-1

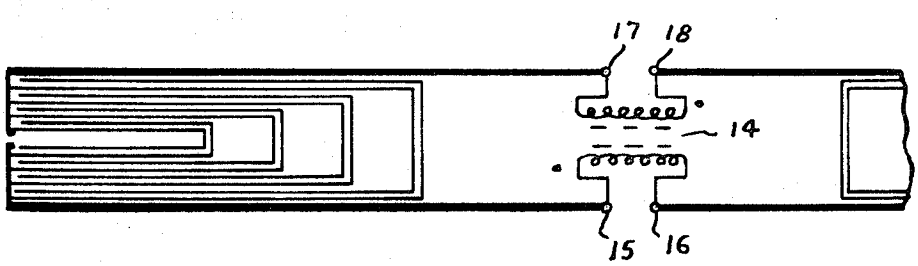

Fig-4

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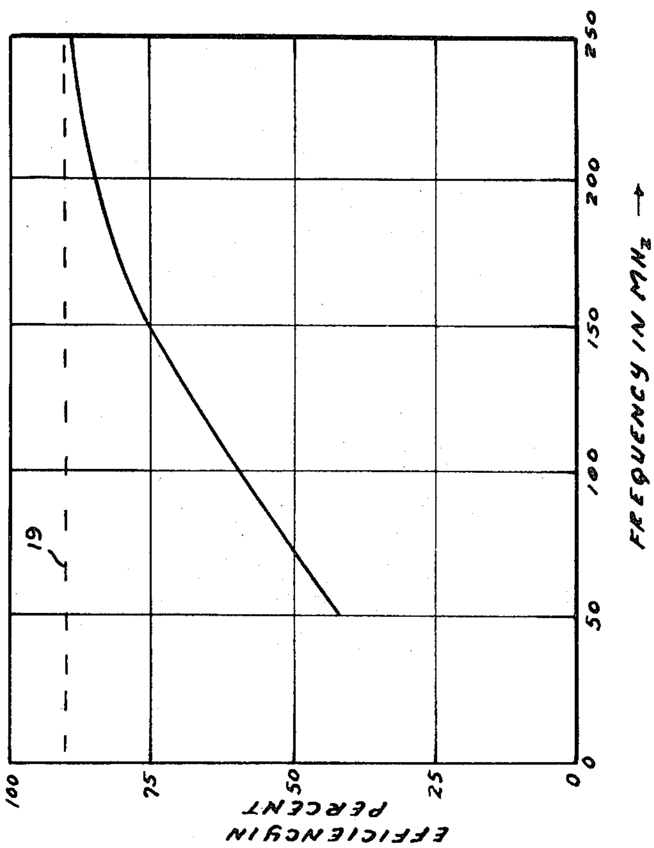

FIG. 6

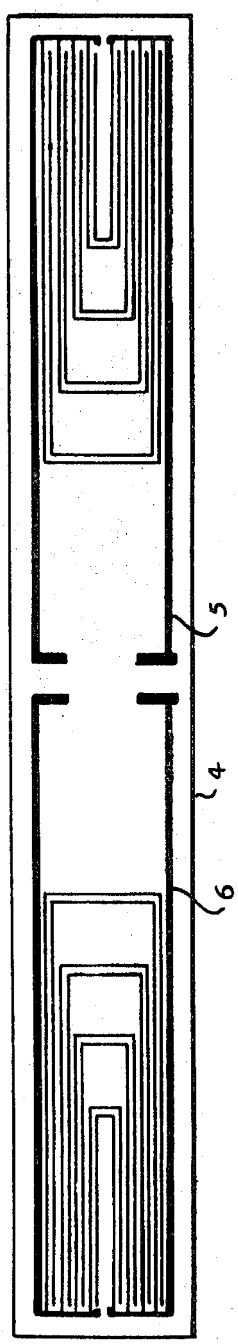

FIG. 2

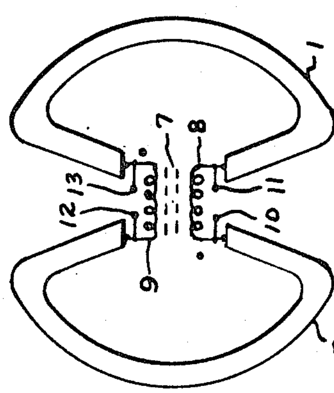

FIG. 3

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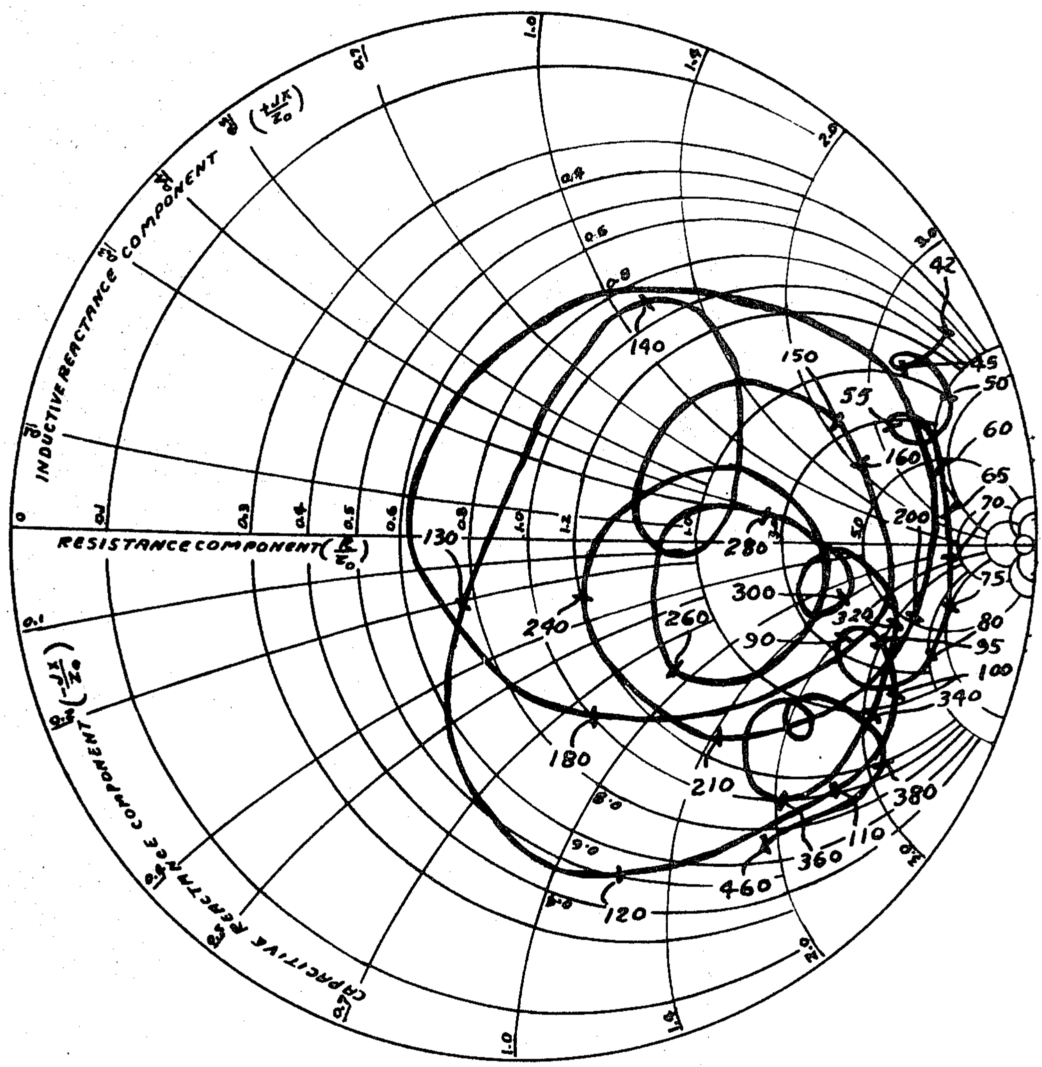

Fig-5

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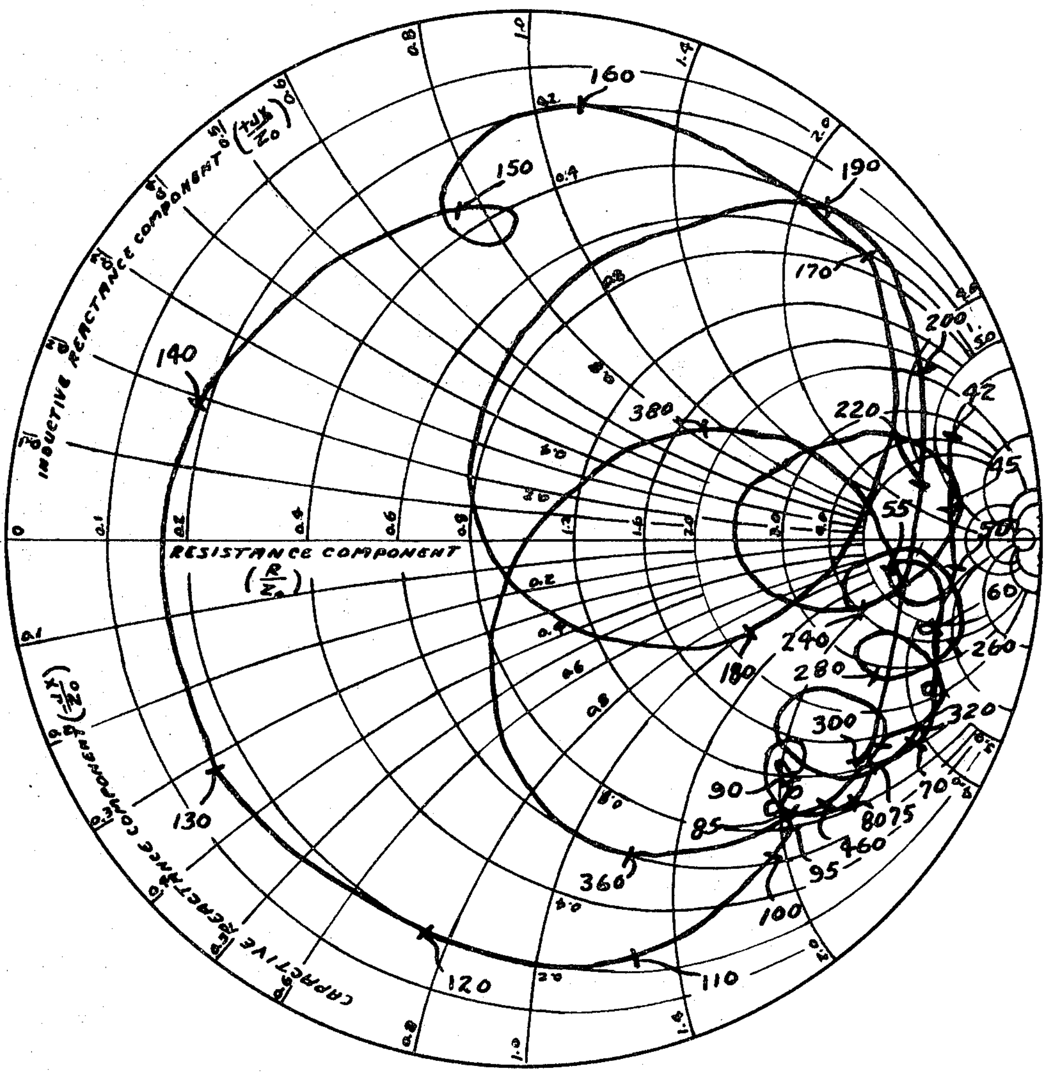

Fig 6

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Patented Dec. 28, 1971

3,631,499

7 Sheets-Sheet 5

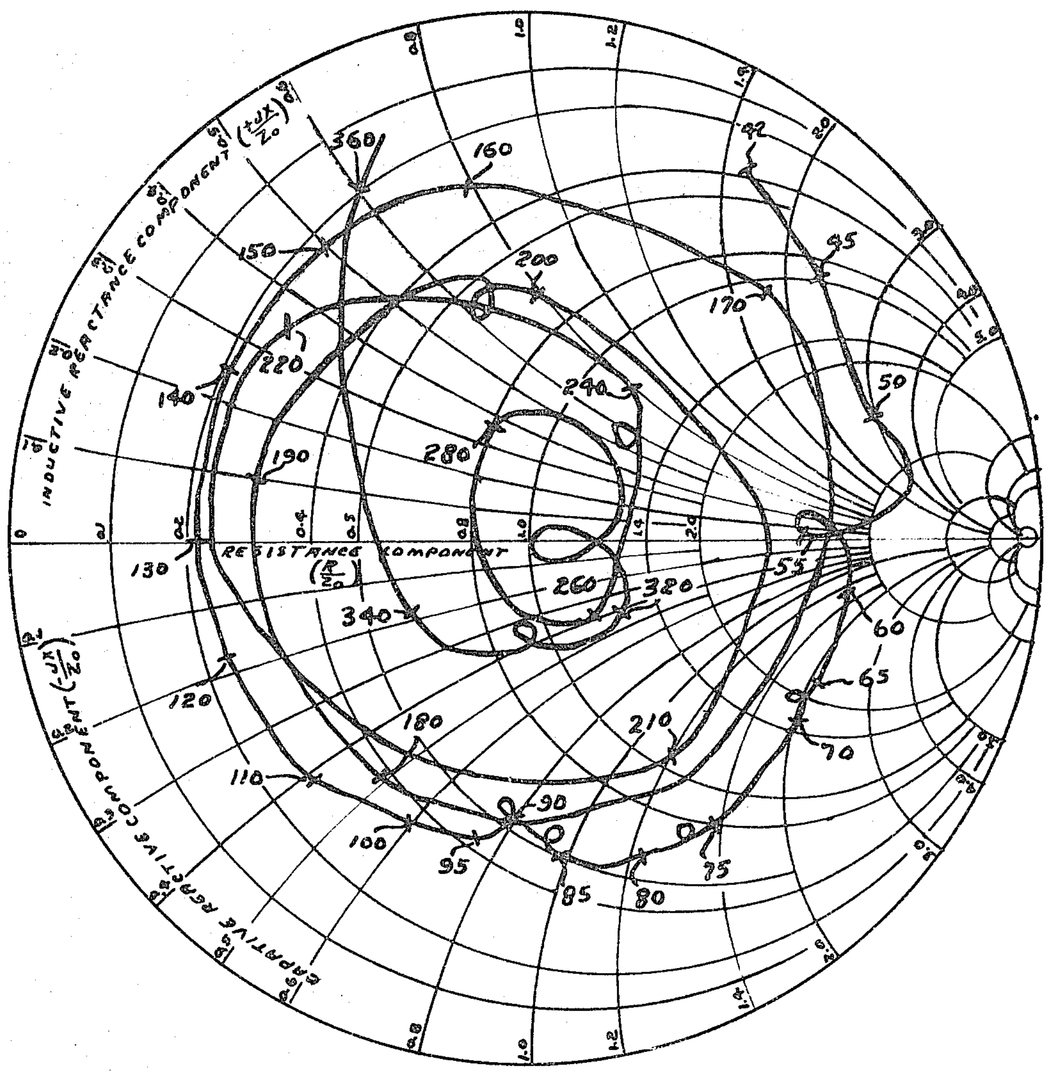

Fig 7

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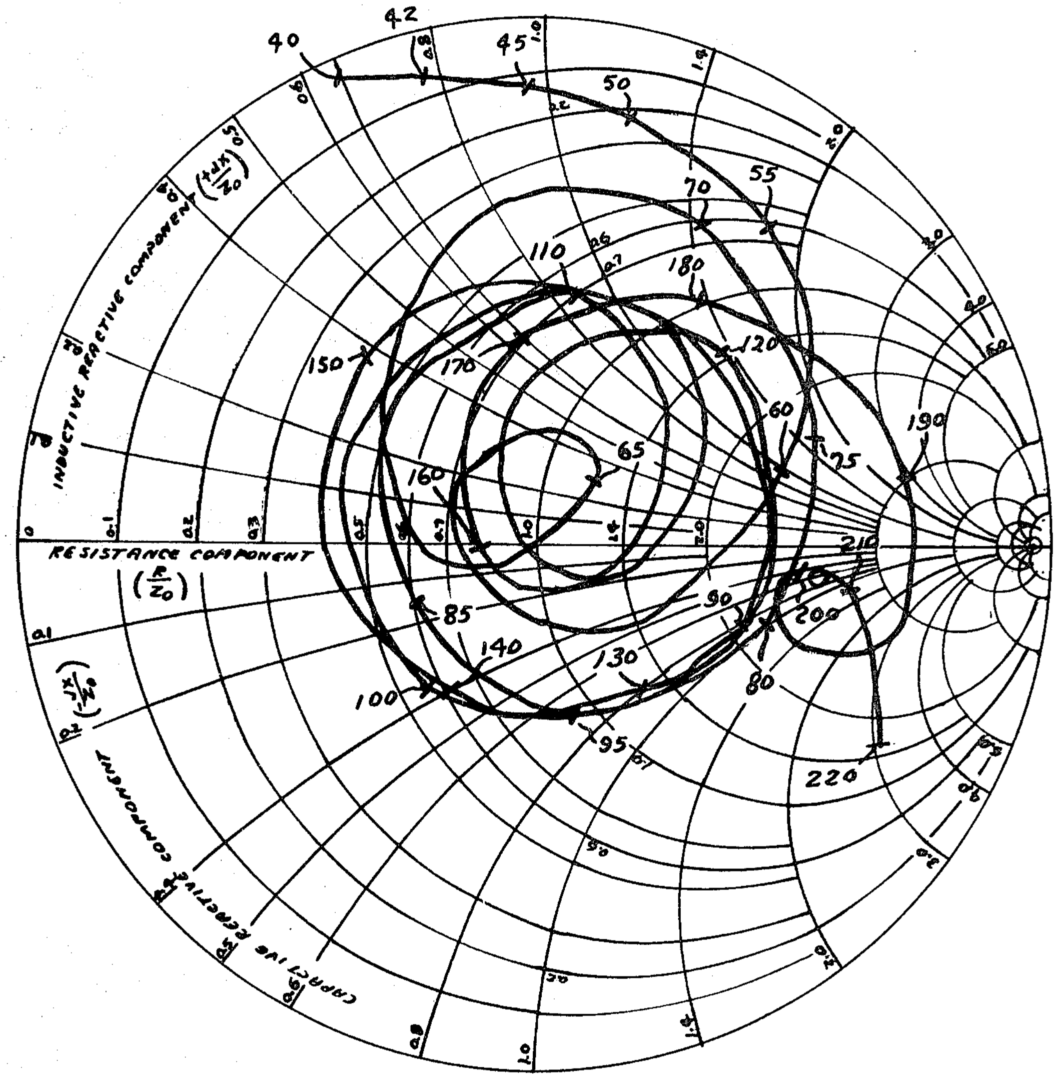

Fig 8

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Patented Dec. 28, 1971

3,631,499

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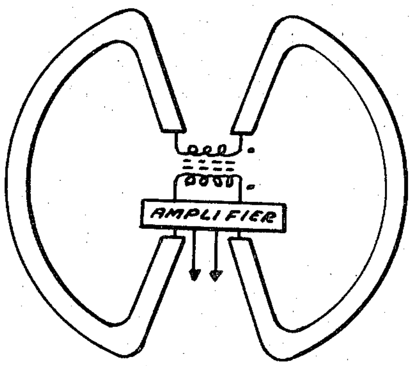

Fig-10

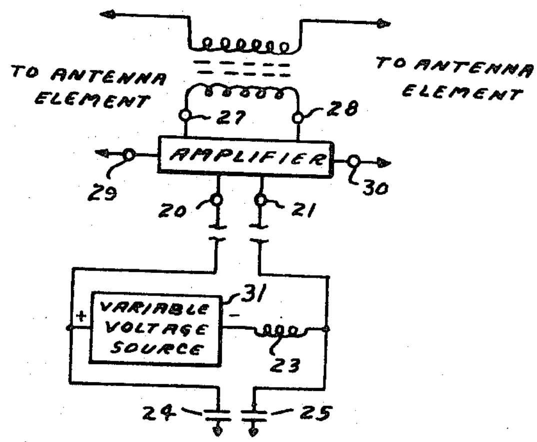

Fig-13

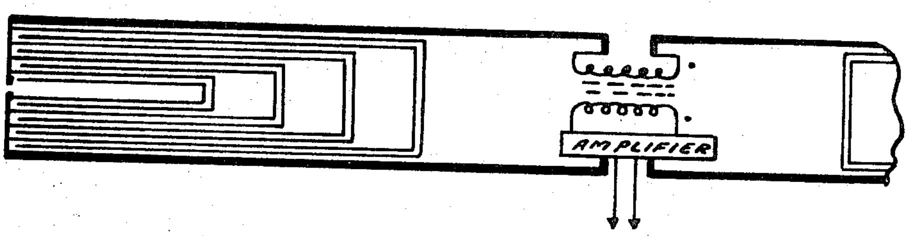

Fig-11

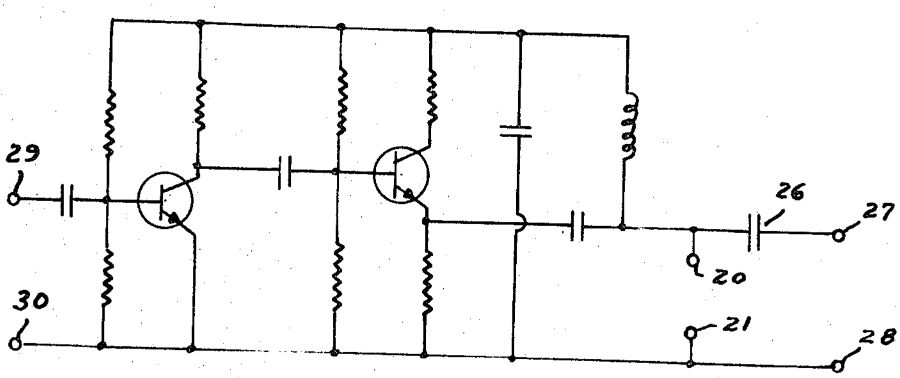

Fig-12

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ELECTRICALLY SMALL DOUBLE-LOOP ANTENNA WITH DISTRIBUTED LOADING AND IMPEDANCE MATCHING

BACKGROUND OF THE INVENTION

The field of the invention is in the electromagnetic antenna art and particularly in the art of antennas that are electrically small.

A longstanding and continuing goal in the antenna art has been, and is, to provide effective antennas that require the least amount of physical space. For many years it has been common practice to add a loading coil to a wire or rod antenna to achieve radiation and reception at frequencies that would normally require a much longer radiating element. That is, the antenna is electrically small for the frequencies at which it is utilized. Such antennas have a relatively narrow bandwidth, and to achieve broadband operation many elements are required and serious discontinuities occur between the tuned elements.

A small single antenna that will operate effectively over a relative broadband of frequencies is highly desirable with any variable frequency or tunable transmitter or receiver system. For instance, it is very beneficial to military vehicles whether they be airplanes, tanks, or submarines to have the smallest number and smallest size antennas that are feasible to maintain effective communication. Commercially, the television antenna is a typical example of the desirability and need of an effective small, mechanically simple, and broadband antenna.

While admittedly the antenna of this invention, when it is used alone without internal amplification, is not as efficient as a tuned dipole antenna at the particular frequency to which the dipole is tuned, the antenna of this invention does provide a bandwidth that would require a vast multitude of tuned dipoles; and it provides this bandwidth without discontinuities in the operating characteristics that a plurality of individual tuned elements inherently possess. Typical examples of prior art broadband antennas are contained in U.S. Pat. No. 3,241,148, "End Loaded Planar Spiral Antenna," issued to L. W. Lechtrack and U.S. Pat. No. 3,167,775, "Multi-Band Antenna Formed of Closely Spaced Folded Dipoles of Increasing Length," issued to R. Guertler.

SUMMARY OF THE INVENTION

The invention provides an electrically small broadband antenna that has relatively uniform impedance and broad directional characteristics. The antenna has two nominal output impedances such as 300 ohms and 70 ohms for matching to conventional high-impedance and low-impedance transmission lines. Amplification within the electrical circuit of the antenna provides a greatly increased electrical output from the antenna for receiving usage. To prevent overloading of the receiver input circuit, the gain of the amplifier, internal the electrical circuitry of the antenna, may be controlled from the receiver over the conventional signal transmission line.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a pictorial view of the electromagnetic radiating and receiving elements of an embodiment of the invention employing distributed loading;

FIG. 2 is a pictorial view of the electromagnetic radiating and receiving elements of an embodiment of the invention employing lumped loading;

FIG. 3 is a schematic diagram of a passive embodiment of the invention using the structure shown in FIG. 1;

FIG. 4 is a schematic diagram of a passive embodiment of the invention using the structure shown in FIG. 2;

FIG. 5 is a Smith Chart plot showing the changes in impedance of the system shown in FIG. 3 with changes in operating frequency when measured from the lower terminals;

FIG. 6 is a Smith Chart plot showing the changes in impedance with changes in operating frequency when the transformer shown in FIG. 3 is incorrectly poled;

FIG. 7 is a Smith Chart plot showing the change in impedance of the system shown in FIG. 3 with changes in frequency as measured from the upper terminals;

FIG. 8 is a Smith Chart plot showing the change in impedance of the system shown in FIG. 4 with changes in operating frequency;

FIG. 9 is a typical efficiency vs. frequency plot of an embodiment of the invention shown in FIGS. 3 and 4;

FIG. 10 is a block-schematic diagram of an embodiment of the invention having distributed loading and internal amplification;

FIG. 11 is a block-schematic diagram of an embodiment of the invention having lumped loading and internal amplification;

FIG. 12 is a schematic diagram of a typical amplifier that may be used with the embodiments of the invention shown in FIGS. 10 and 11;

FIG. 13 is a block-schematic diagram showing the circuitry for the remote control of the gain of the amplifier shown in FIG. 12.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

For ease of description and understanding, the embodiments of the invention described in detail will refer to antennas for the frequency band of approximately 50 MegaHertz to approximately 225 MegaHertz. Obviously, for higher bands of frequency the antenna may be proportionally scaled down and for lower frequency increased in size proportionally. Thus an embodiment of the radiating and receiving elements of the antenna using distributed loading for operation over the foregoing enumerated frequency band is shown approximately to scale in FIG. 1.

The general configuration is that of a double open loop comprising a right-hand element 1 and a left-hand element 2. The elements are formed using conventional printed circuit techniques on dielectric board 3. One-sixteenth-inch dielectric board having 1 -mil copper conductor has been found to be very satisfactory. The dielectric board should be conventional high-frequency material such as the military-type G–10, or the commercially available Cinclad C Series Grade A made by the Cincinnati Milling Machine Company. The G–10 material, while more expensive, has been found to generally be preferable for outdoor installations. Each loop is approximately 13½ inches high and approximately 7 inches wide. The largest dimension across both elements of the antenna is approximately 15 inches, thus the total length of the antenna is considerably less than a half wavelength at the highest frequency of operation. The width of the copper elements 1 and 2 is approximately five-eighths inch and the spacing between the upper terminating ends 31 and 32 of each loop and the lower terminating ends 33 and 34 is approximately 3 inches. These dimensions are not critical but have been found to be optimum in conjunction with the further to be explained circuitry.

An alternative structure having flattened loops and using lumped loading within the loops is shown approximately to scale in FIG. 2. This configuration has the advantage of being more compact than that of FIG. 1 and thus for some space-limited applications is more suitable. Generally the structure shown in FIG. 1 is preferred due to its simplicity of construction, and generally preferable directional characteristics. The dielectric board 4 preferably is of the same material as mentioned previously and likewise conventional printed circuit techniques are used to form the loop elements 5 and 6 and the various length conductors forming the lumped inductance-capacitance loading elements. The preferred dimensions for the frequency band of approximately 50 to 225 MegaHertz are an overall length across both loops of approximately 24 inches and a width of approximately 3 inches. These dimensions are not critical nor are the dimensions of the folded loading elements. An 18-inch overall length with a 2-inch width is not quite as efficient at the lower end of the band, and a 30 by

4-inch overall size of the loops gives but a very minor improvement at the low frequencies, thus the 24 by 3-inch size is generally preferable.

FIG. 3 shows schematically a passive embodiment using the structure of FIG. 1. Transformer 7 is a conventional radiofrequency transformer operable over the enumerated band of frequencies having windings with nominal impedances of 300 ohms, and 70 ohms. FIG. 4 shows schematically a similar transformer connected to the structural embodiment shown in FIG. 2. It is to be remembered that while a conventional 300 ohm to 70 ohm coupling transformer is used in these embodiments of the invention, that an impedance of 300 ohms looking into one winding of such a transformer is only obtained when the other winding "sees" 70 ohms, and that the nominal impedance rating merely defines a turns ratio, that is,

$$Z_s/Z_p=(N_s/N_p)^2, \text{ or } N=\sqrt{Z_s/Z_p}$$

Where Z_s = Impedance connected to secondary winding,
Z_p = Impedance looking into primary winding,
N_s = Turns on secondary,
N_p = Turns on primary, and
N = Turns ratio, secondary to primary.

Thus, for these embodiments it has been found that a conventional high-frequency transformer having a turns ratio of approximately 2.1 to 1 connected as shown will provide a broadband antenna having two nominal output impedances suitable for connecting either to a conventional 300-ohm twin-lead transmission line or to conventional 70-ohm coaxial line. Referring to FIG. 3, by using a transformer 7 having a turns ratio of approximately 2 on the lower winding 8 to 1 on the upper winding 9, an output impedance suitable for connecting to a conventional 300-ohm line is provided at terminals 10 and 11; or, if it is desired to use a 70-ohm transmission line, connection is made to the upper terminals 12 and 13. Similarly, in FIG. 4 by using the same kind of transformer 14, a nominal output impedance of 300 ohms is provided at terminals 15 and 16, and a 70-ohm nominal output impedance is provided at terminals 17 and 18.

FIG. 5 is a Smith Chart showing a typical output impedance characteristic over the frequency range of 42 MegaHertz to 460 MegaHertz of the embodiment shown in FIG. 3 as measured at the 300-ohm connections. The chart is normalized at unity equal to 300.

The importance of correctly poling the transformer is shown by the chart of FIG. 6. In obtaining these data the connections from winding 8 to the loop elements 1 and 2 were reversed. As shown by the chart this produces an undesirable spread in the impedance characteristic. It also distorts the directional characteristics and greatly reduces the efficiency of the antenna. In FIG. 7, impedance characteristics, normalized to 70, of the antenna of FIG. 3 over the range of 42 MegaHertz to 300 MegaHertz, looking into the 70-ohm connection, is shown.

The Smith Chart of FIG. 8 is typical of the characteristic impedance normalized at 300 of the embodiment shown in FIG. 4 as measured at the 300-ohm output. Equally satisfactory operation is obtained at the 70-ohm output. As in the embodiment shown in FIG. 3, it is important that the transformer be correctly poled.

FIG. 9 is a representative plot showing the efficiencies of the passive structures shown in FIGS. 3 and 4 over their nominal operating range of frequencies. The typical efficiencies of an infinite number of half-wave dipoles each tuned to the particular operating frequency is indicated by the dashed line 19.

The directional characteristics of the embodiment shown in FIG. 3 is that of an ellipsoid having a major axis in the plane of the loop elements 1 and 2, centrally located between them, and having approximately equal minor axes. The directional characteristics of the embodiment shown in FIG. 4 is a lemniscate of revolution having its major axis in the plane of the antenna centrally located between the loops.

The passive antennas such as shown in FIGS. 3 and 4 may be used for both transmitting and receiving. When an embodiment of the antenna is used for transmitting, the transformer, obviously, must be capable of withstanding the particular radiofrequency power involved.

For receiving use the output of the antennas may be greatly increased by adding amplification within the circulating currents of the antennas as shown in FIGS. 10 and 11. It is to be observed that the amplification is "within" the antenna elements and not just an amplification of the output signal of the antenna before it passes into the transmission line as is conventionally done. A conventional broadband high-frequency amplifier covering the frequencies involved that has relatively low input and output impedances may be used. A typical amplifier is shown in FIG. 12. The amplifier may be electrically placed between the adjacent open ends of the loops and the transformer on either side of the transformer. It is connected so as to amplify the signal from the ends of the loops going to the transformer.

As those practicing this invention will understand, the input and output impedances of the amplifier should preferably be such as to essentially provide the desired output impedances at the high- and low-impedance antenna terminals; that is, conventionally, 300 ohms and 70 ohms. The phasing of the signals is critical as it is with the passive structures. The amplifier shown in FIG. 12 effects a phase reversal, thus the transformer must be poled opposite to the way it was connected for the passive embodiments. When using amplifiers that have their output in phase with their input, poling of the transformer as in the passive embodiments, is used.

The amplifier may have fixed gain and be completely self-contained in the antenna structure. Embodiments of this type have the advantage of the conventional dual output impedances of 70 ohms and 300 ohms readily available by connecting the transmission line directly across the respective transformer windings. They, however, have the disadvantage of providing unnecessary and perhaps excessive amplification of already strong signals with the resultant likelihood of overloading the input circuits of the receiver when it is tuned to the frequency of a strong signal. It has thus been found to be generally desirable to control the gain of the amplifier in the antenna from the receiver location. With conventional transistor amplifiers as shown in FIG. 12 this may readily be done by controlling the supply voltage on the amplifier as shown in FIG. 13. Referring to both FIGS. 12 and 13, the transmission line from the receiver is connected to the amplifier at terminals 20 and 21. The direct current supply voltage for the amplifier is also carried over the conventional transmission line from the remote control position at the receiver to the amplifier. Inductance 23 prevents the power source from shorting out the radiofrequency signals and capacitors 24 and 25 keep the direct current out of the receiver input. Blocking capacitor 26 prevents the direct current from flowing in the antenna transformer winding. Terminals 27 and 28 connect the amplifier output to the transformer and terminals 29 and 30 connect the signals at the adjacent ends of the loops to the input of the amplifier. Conventional variable-voltage transistor power supply 31 may thus be used to adjust the gain of the amplifier so that larger gains may be used with weak signals and the gain reduced for strong signals.

It has been found that generally the maximum amount of gain before oscillation takes place, is approximately 25 db. For embodiments using fixed-gain amplifiers, 20 db. of gain is the preferred amount of gain to reasonably preclude any oscillation taking place, In embodiments having remote control at the receiver the maximum amount of gain before oscillation takes place may be utilized for the reception of weak signals by using amplifiers having a maximum gain of approximately 30 db.

I claim:

1. An electrically small broadband antenna having output connections of a nominal high output impedance of 300 ohms and of a nominal low output impedance of 70 ohms for connecting to respective impedance transmission lines comprising:

a. a right-hand open-loop conductive element having an upper terminating end and a lower terminating end;
b. A left-hand open-loop conductive element having an upper terminating end and a lower terminating end;
c. a radiofrequency transformer having a high-impedance winding and a low-impedance winding with a turns ratio between the said winding of approximately 2.1 to 1;
d. means for connecting the high-impedance winding between the said lower terminating ends of the said right- and left-hand open loops and the low-impedance winding between the said upper terminating ends of the said right- and left-hand open loops;
e. means cooperating with the said high-impedance transformer winding for connecting a high-impedance transmission line; and
f. means cooperating with the said low-impedance transformer winding for connecting a low-impedance transmission line.

2. An electrically small antenna for operation over the frequency band of approximately 50 MegaHertz to approximately 225 MegaHertz having a nominal 300-ohm output impedance and a nominal 70-ohm output impedance comprising:
a. a dielectric printed circuit board having:
1. an approximately ⅝-inch-wide copper strip forming a right-hand open-loop conductive element having a height of approximately 13½ inches and a width of approximately 7 inches, and an upper terminating end and a lower terminating end, and
2. an approximately ⅝-inch-wide copper strip forming a left-hand open-loop conductive element having a height of approximately 13½ inches and a width of approximately 7 inches, and an upper terminating end and a lower terminating end, the upper and lower terminating ends being juxtapositioned the respective said upper and lower terminating ends of the said right-hand open loop;
b. a radiofrequency transformer suitable for operation over the frequency from approximately 50 MegaHertz to approximately 225 MegaHertz, having a first winding and a secondary winding with a turns ratio between the windings of approximately 2.1 to 1;
c. means for connecting the said first winding of the transformer between the said upper terminating ends of the said loops and the said second winding of the transformer between the said lower terminating ends of the said loops;
d. means connecting with the said first windings for providing an output; and
e. means connecting with the said second winding for providing an output.

3. An electrically small receiving antenna for operation over the frequency band of approximately 50 MegaHertz to approximately 225 MegaHertz and providing an output to a transmission line comprising:
a. a dielectric printed circuit board having,
1. a right-hand open-loop conductive element having an upper terminating end and a lower terminating end, and
2. a left-hand open-loop conductive element having an upper terminating end and a lower terminating end;
b. a radiofrequency transformer suitable for operation over the frequency from 50 MegaHertz to 225 MegaHertz, having a first winding and a second winding;
c. means for connecting the first winding of the said transformer between the upper terminating ends of the said right- and left-hand open-loop elements;
d. a radiofrequency amplifier having an input and an output and suitable for operation over at least the frequency range from 50 MegaHertz to 225 MegaHertz;
e. means for connecting the input of the said radiofrequency amplifier with the said lower terminating ends of the said right- and left-hand open-loop elements;
f. means for connecting the output of the said radiofrequency amplifier to the second winding of the said transformer; and
g. means cooperating with the said amplifier for providing an output to the said transmission line.

4. The antenna as claimed in claim 3 wherein the said right-hand open-loop element and the said left-hand open-loop element contain lumped loading.

5. The antenna as claimed in claim 3 wherein the said right-hand open-loop element and the said left-hand open-loop element contain distributed loading.

6. The antenna as claimed in claim 3 wherein the said right-hand open-loop element is approximately a ⅝-inch-wide copper strip having a height of approximately 13½ inches and a width of approximately 7 inches and the said left-hand open-loop element is approximately a ⅝-inch-wide copper strip having a height of approximately 13½ inches and a width of approximately 7 inches.

7. The antenna as claimed in claim 6 wherein the said transformer has a turns ratio of approximately 2.1 to 1.

8. The antenna as claimed in claim 7 wherein the said amplifier has a gain of less than 25 db.

* * * * *