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SMALL DIRECTIONAL ANTENNA SYSTEM

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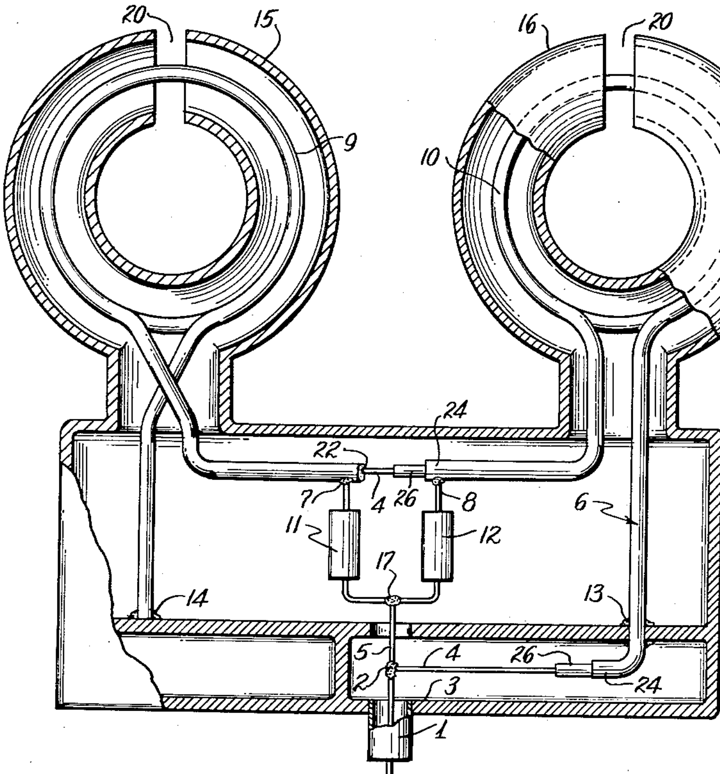

Fig. 1.

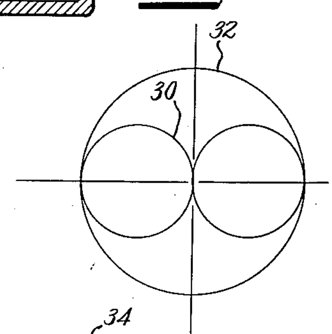

Fig. 3.

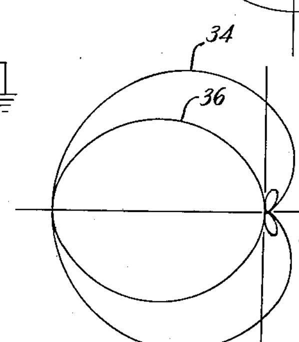

Fig. 4.

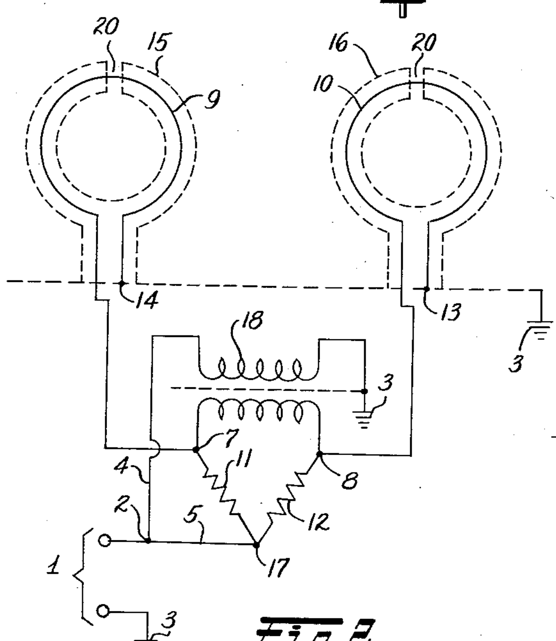

Fig. 2.

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SMALL DIRECTIONAL ANTENNA SYSTEM

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8 Claims. (Cl. 343—742)

This invention relates to directional antennas which are small compared to the wave length of the energy passing therethrough, and more specifically to a system for feeding a pair of spaced coplanar loops in a manner to produce a stable unidirectional radiation pattern.

While the system is described with reference to radio waves, the system can be equally well applied to sonic waves, in which case the loops are replaced with sonic transducers.

It is an object of this invention to provide, in a structure small compared with the wave length, a radiation pattern which is essentially single-lobed, and which remains so over a band of frequencies.

An embodiment includes two identical radiating elements, spaced a small distance apart, and a feeding circuit which provides, simultaneously, two symmetrical modes of current excitation to the radiating elements. In the first mode, the element currents are equal and directed so that the radiation fields at a distance tend to aid each other. In the second mode, the element currents again are equal, but are oppositely directed so that the radiation fields at a distance tend to buck each other. Considering one of the bucking mode currents as a reference, the feeding circuit provides aiding mode currents whose phase angle is substantially 90 degrees relative to the bucking mode currents, and whose amplitude is substantially directly proportional to frequency.

Fig. 1 is a sectional view of a form of device which embodies this invention;

Fig. 2 is a schematic circuit diagram of a device which embodies this invention;

Fig. 3 is a polar graph showing amplitude plots of aiding and bucking array factors; and

Fig. 4 is another polar graph showing two amplitude plots, one being of the combined array factor, and the other being of the combined array factor multiplied by the element pattern.

In the form of the invention shown in Fig. 1, numeral **3** designates a conductive housing having an input terminal portion **1** for connection to a signal supplying circuit. The housing **3** is formed to define a pair of spaced torus-shaped shielding portions **15** and **16** having air gaps **20** therein. A first loop antenna element **9**, formed of solid wire or rod, is housed in shielding portion **15** and is electrically connected, at one of its ends, to housing **3** at a junction **14**. The other end of element **9** is electrically connected, at **22**, to one end of inner conductor **4** of a coaxial transmission line **6**. The line **6** comprises the inner conductor **4** and an outer conductor **24** separated by a layer of insulation **26**. The line **6** is conformed to define a second loop antenna element **10** in shielding portion **16**. The other end of inner conductor **4** is electrically connected to a conductor **5** at junction **2**. The outer conductor **24** is electrically connected, at one end, to the housing **3**, at junction **13**.

An impedance device **11** is connected to element **9** adjacent junction **22** and an impedance device **12** is connected to outer conductor **24** at the end thereof adjacent junction **22** and forms therewith a junction **8**. Both impedance devices **11** and **12** have their other ends connected to conductor **5** at junction **17**.

The impedance devices **11** and **12**, while shown as fixed resistors, may in fact be any type of impedance elements but are constructed or adjusted so that their impedance values are equal at the desired frequency. The particular impedance value of each of the devices **11** and **12** determines the frequency range within which the desired results are produced, as will be described, and those values may obviously be made adjustable, in any well-known manner.

While it is to be understood that the system can be used either for transmitting or receiving, the explanation here is from the transmitting viewpoint. Radio frequency power applied to input terminal **1** results in an R.F. voltage V_{23} between junction **2** and housing **3**. Current flows from junction **2** into conductors **4** and **5**. Conductor **4** is associated with the bucking mode, while conductor **5** is associated with the aiding mode.

Considering first the bucking mode, R.F. power carried between conductor **4** and housing **3** enters the inner conductor **4** of coaxial transmission line **6**, emerging to produce a voltage V_{78} between junctions **7** and **8**. If the length of transmission line **6** is small in comparison with the wave length, voltage V_{78} is substantially equal to voltage V_{23}. The voltage V_{78} causes currents to flow in the symmetrical structure which comprises loops **9** and **10**, and equal impedances **11** and **12**. Loop **10** is the outside surface of transmission line **6**, and is connected to the housing at point **13**. Loop **9** does not contain an inner conductor and may therefore be fabricated with solid rod. It is otherwise similar to loop **10**, and is connected to the housing **3** at point **14**. Loops **9** and **10** are enclosed in electrostatic shields **15** and **16**, respectively. By virtue of the symmetry of the structure, the total impedance between junction **7** and the housing is the same as the total impedance between junction **8** and the housing; the currents and voltage drops which exist in the various parts of one half of the structure are all respectively equal and opposite to the currents and voltage drops which exist in the corresponding parts of the other half. This means that junction **17**, between equal impedances **11** and **12**, must be at zero potential with respect to the housing. Insofar as the bucking mode is concerned, junction **17** could just as well be grounded to the housing; no component of bucking mode current flows in conductor **5**.

Considering next the aiding mode, R.F. power carried between conductor **5** and housing **3** produces a voltage at junction **17** with respect to the housing which is the same as V_{23} if conductor **5** is short. Currents flow out of junction **17** into equal impedances **11** and **12**. Again making use of the symmetry, the total impedance in each half of the structure is the same. The currents flowing in equal impedances **11** and **12** are therefore equal to each other as are also the voltage drops across them. Thus junctions **7** and **8** each have the same potential with respect to the housing. The equal currents which flow in loops **9** and **10** are polarized in the same direction. Since there is no potential difference between junctions **7** and **8**, these points could just as well be joined by a conductor insofar as the aiding mode is concerned; thus no component of aiding mode power enters transmission line **6**; no component of aiding mode current flows in conductor **4**.

The two modes, bucking and aiding, can exist simultaneously in the structure of Fig. 1 independently and without coupling to each other except at the common junction **2**. Here they are each excited with currents which have values inversely proportional to the respective impedances presented to junction **2** through conductors **4** and **5**.

Fig. 2 is a schematic of an electric circuit which is essentially equivalent to the structure shown in Fig. 1. With a single exception, the foregoing description given for the structure in Fig. 1 can be read with respect to the circuit in Fig. 2; the exception is that the coaxial transmission line **6** in Fig. 1 is replaced by an ideal one-to-one transformer **18** in Fig. 2. The inner conductor **4** and outer conductor of transmission line **6** can, however, be considered as a one-to-one transformer itself.

It should be recognized that an alternate physical structure can be designed which is based on the circuit of Fig. 2 and which employs transformer **18** as shown. In this case, loop **10**, as well as loop **9**, would be fabricated with solid rod. In Fig. 2, reference numerals the same as those of Fig. 1 are used to indicate corresponding junctions and/or elements.

In order to calculate the radiation patterns of the antenna structure, it is desirable to know the loop currents for each mode in terms of the common junction voltage V_{23}. If the loops **9** and **10** are small in comparison with the wave length, their impedance is almost purely inductive. For the purpose here of calculating loop currents their resistive component will be therefore neglected. It is assumed, for the sake of further simplification, that the equal impedances **11** and **12** each have the purely resistive value R, which is made large in comparison with the loop reactances. If L is the total inductance of the two loops **9** and **10** in series, then the bucking mode loop currents I_b are given to a first approximation by

$$I_b=\frac{V_{23}}{j\omega L} \tag{1}$$

in which

$$j=\sqrt{-1}$$

$$\frac{\omega}{2\pi}=\text{frequency}$$

In the aiding mode, the loop currents I_a are given to a first approximation by

$$I_a=\frac{V_{23}}{R} \tag{2}$$

Considering next the radiation fields, it is well known that two elements carrying currents that are equal but opposite have an array factor F_b given by

$$F_b=j2I_b \sin\left(\frac{\pi s}{\lambda}\sin\phi\right) \tag{3}$$

whereas two elements carrying currents that are equal and in the same direction have an array factor F_a given by

$$F_a=2I_a \cos\left(\frac{\pi s}{\lambda}\sin\phi\right) \tag{4}$$

in which:

s=element separation
λ=wave length
ϕ=azimuth coordinate measured from a normal to the line joining the elements.

Applying the restriction $s<<\lambda$, the angle

$$\left(\frac{\pi s}{\lambda}\sin\phi\right)$$

is never larger than a small fraction of a radian, so that the sine of the angle is essentially equal to the angle, while the cosine does not differ much from unity. Thus Equations 3 and 4 can be written as more simple approximations:

$$F_b=j2I_b\frac{\pi s}{\lambda}\sin\phi \tag{5}$$

$$F_a=2I_a$$

The shapes of these array factors are as shown plotted in Fig. 3, curves **30** and **32**, respectively.

From Equations 5 and 6 it will be noted that if the currents I_b and I_a were to be equal, then the array factors would be in quadrature phase relation, while their magnitude ratio would be inversely proportional to wave length. However, in the feed system described, I_b and I_a are not equal to each other, but have the values given by Equations 1 and 2, respectively. Substituting these values in Equations 5 and 6 yields:

$$F_b=j2\frac{V_{23}}{j\omega L}\frac{\pi s}{\lambda}\sin\phi$$

$$=V_{23}\frac{s}{Lc}\sin\phi \tag{7}$$

where

$$c=\frac{\omega\lambda}{2\pi}=\text{velocity of light (constant)}$$

$$F_a=V_{23}\frac{2}{R} \tag{8}$$

Note that the dependence on frequency has been eliminated, and the array factors are in phase. Now in order to have the array factors combine to produce optimum directivity, it is necessary that the amplitudes be equal, that is:

$$V_{23}\frac{2}{R}=V_{23}\frac{s}{Lc}$$

This defines a required value, R, for the equal impedances **11** and **12**:

$$R=2\frac{c}{s}L \tag{9}$$

Under the foregoing conditions, the bucking and aiding array factors superimpose to form a total array factor F_t:

$$F_t=K_1(\sin\phi+1) \tag{10}$$

which is the cardioid shape plotted in Fig. 4 as curve **34**.

To obtain the resultant pattern of the complete antenna system, one multiplies the total array factor by the individual loop characteristic F_l. The latter is a figure-of-eight:

$$F_l=K_2\sin\phi \tag{11}$$

Thus, the resultant pattern F_r of the antenna has the shape given by

$$F_r=K_3\sin\phi(\sin\phi+1) \tag{12}$$

and shown plotted in Fig. 4 as curve **36**. In Equations 10, 11 and 12, K_1, K_2, and K_3 are arbitrary constants. Within the limitations of the stated assumptions this pattern shape remains stable and independent of frequency.

While a single specific embodiment of the invention has been shown and described in detail, it is to be understood that other forms may be resorted to within the scope of the appended claims.

I claim:

1. A directional antenna system comprising; two identical antenna elements spaced apart less than one-tenth wave length, a feeding circuit for simultaneously feeding bucking and aiding modes of current to said elements, said aiding mode currents having a phase angle of substantially 90 degrees relative to said bucking mode currents and an amplitude relative to that of said bucking mode currents substantially proportional to frequency.

2. A directional antenna system comprising; two identical elements and a circuit for simultaneously feeding said elements bucking and aiding modes of symmetrical current excitation, said aiding mode currents having a phase angle of substantially 90 degrees relative to said bucking mode currents and an amplitude relative to said

bucking mode currents substantially proportional to frequency.

3. A directional antenna system comprising, two spaced radiating elements fed from opposite ends of the secondary winding of an isolation transformer, the primary winding of said isolation transformer being connected between ground an an input terminal for said elements, a pair of equal impedance devices connected between said input terminal and each of said opposite ends of said secondary winding.

4. A directional antenna system comprising; two similar spaced radiating elements, an isolation transformer, two equal impedance devices and an input terminal; said radiating elements being connected to opposite ends of the secondary of said isolation transformer, the primary winding of said isolation transformer being connected between said input terminal and ground, one of said equal impedance devices being connected between said input terminal and one end of said secondary winding, the other of said equal impedance devices being connected between said input terminal and other end of said secondary winding.

5. A directional antenna system comprising; two spaced radiating elements and a circuit for simultaneously feeding said elements bucking and aiding modes of symmetrical current components, said aiding mode components having a phase angle of substantially 90 degrees relative to said bucking mode currents and an amplitude relative to said bucking mode components substantially proportional to frequency, said aiding mode component amplitude being adjusted to produce a radiation pattern null in the direction of an extension of the line joining said radiating elements.

6. A unidirectional antenna comprising; two electrostatically shielded coplanar loops, one of said loops being wound of solid wire, the other of said loops being wound of coaxial transmission line, one end of each loop being grounded, the other end of each loop being connected through each of two equal impedance devices to a common input terminal, the inner conductor of said coaxial transmission line being connected at one end to said common input terminal and at the other end to the ungrounded end of said first loop.

7. A unidirectional antenna as defined in claim 6, each of said equal impedance devices having a resistance substantially equal to twice the inductance of the two loops, connected in series bucking, multiplied by the ratio of the velocity of light to the loop separation.

8. A unidirectional antenna comprising; two coplanar loops, an input terminal, balancing transformer means connecting said input terminal to said loops in bucking polarity, two equal impedance means connecting each of said loops to said input terminal in aiding polarity, each of said equal impedance means having a resistance substantially equal to twice the inductance of the two said loops, connected in series bucking polarity, multiplied by the ratio of the velocity of light to the separation distance of the two said loops.

No references cited.