Feb. 21, 1939. A. ALFORD 2,147,806

DIRECTIONAL ANTENNA

Filed April 26, 1935

FIG. 1

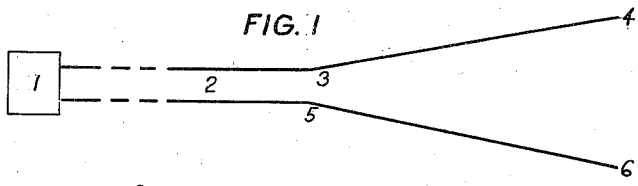


FIG. 1a

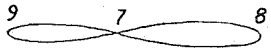


FIG. 2

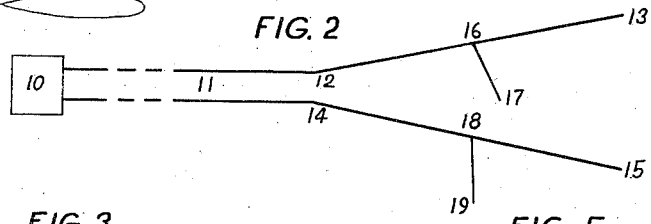


FIG. 3

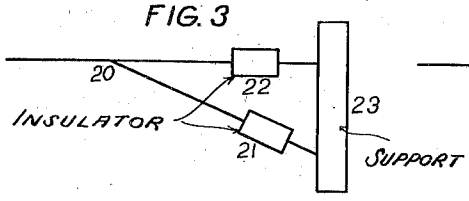
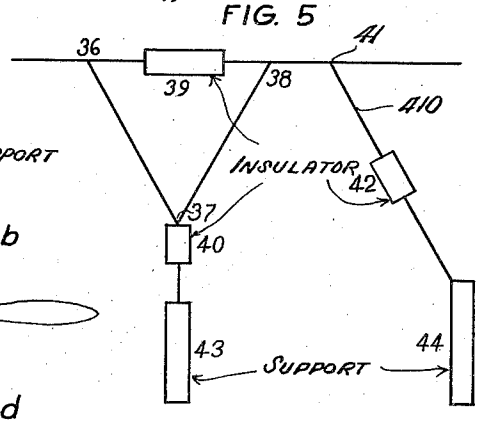


FIG. 5



2a

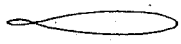


FIG. 2b

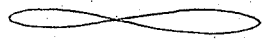


FIG. 2c

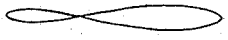


FIG. 2d

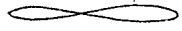


FIG. 4

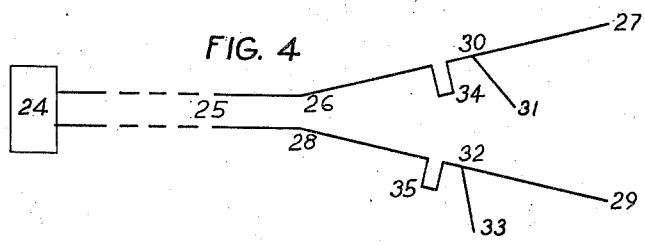
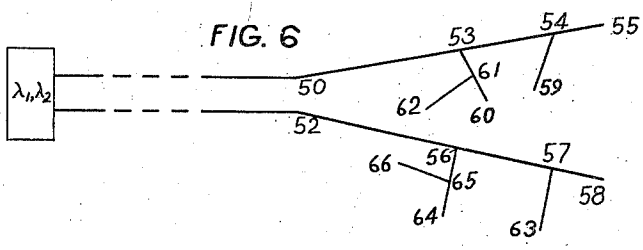


FIG. 6



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DIRECTIONAL ANTENNA

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Application April 26, 1935, Serial No. 18,369

20 Claims. (Cl. 250—33)

This invention relates to new and useful improvements in directional antennae.

According to the present invention an antenna which would normally radiate energy in or receive energy from two principal directions can be readily restricted to radiation in or from one principal direction without altering the existing installation, providing reflectors, terminations or any other expensive expedient heretofore practiced.

A bi-directional antenna of the customary type consists of two open ended radiators fed in phase opposition and forming a V. The length of each wire in wavelengths, i. e. the electrical length, the positioning of the V, the angle formed by the radiators, and the effect of ground determine the principal directions of received or transmitted radiation. Such an antenna of great electrical length (more than one wavelength), positioned horizontally or vertically more than a quarter wavelength above ground, and having each limb inclined with respect to the desired direction of transmission by that angle at which radiation is greatest for the particular length of wire, will radiate, or receive by standing waves principally in the two directions along the bisector of the V.

Radiation in one of the two directions may be prevented by means of suitably phased and spaced reflectors. However, the installation of reflectors is expensive and, on account of limitations of space, not always feasible. Whether the reflectors are fed or parasitic, their theoretical efficiency is rarely appreciated.

Another expedient for eliminating radiation in one direction is to ground the open ends through a suitable impedance and thus radiate or receive by travelling waves. Such installations are relatively expensive and do not lend themselves to alterations of existing antenna structures.

In accordance with the present invention, a bi-directional open ended antenna operating by standing waves is transformed into a uni-directional antenna by connecting a certain length of ordinary antenna wire thereto at a predetermined point from the open end. The length of this wire and its point of connection are so selected that net radiation from the antenna as a whole occurs entirely in the forward direction, i. e., opposite to the direction in which the V points. The result achieved is the same as with a corresponding travelling wave antenna but unlike the travelling wave antenna, the antenna of my invention utilizes standing waves as well as travelling waves.

The invention may best be understood both as to the underlying theory and the manner of practicing the same by referring to the following description which should be read in conjunction with the accompanying drawing in which:

Figs. 1 and 1*a* show diagrams which are useful in explaining the fundamental problem for which my invention is the solution;

Fig. 2 illustrates in diagrammatic form one embodiment;

Figs. 2*a*, 2*b*, 2*c* and 2*d* show a number of radiation patterns applicable to Fig. 2;

Fig. 3 shows one way of constructing Fig. 2;

Fig. 4 illustrates diagrammatically another embodiment;

Fig. 5 shows one way of constructing Fig. 4; and

Fig. 6 shows diagrammatically an antenna operable on more than one wavelength.

For convenience, the following description is given in terms of a radio transmission system, but it will be evident, owing to the obvious reciprocal relations involved, that it applies equally well to a radio receiving system.

Referring to Fig. 1, a source of modulated radio frequency energy **1** is coupled in any well-known manner to the transmission line **2**, which may be of the usual construction, and which in turn is connected to the apex of a V antenna composed of the electrically long open ended linear conductors **3**, **4** and **5**, **6**, the latter being fed effectively in phase opposition and having produced thereon standing waves of current and voltage. Such an arrangement is known to be directional, the two sides of the V being arranged at an angle with respect to each other which is determined by the electrical length of the sides, the elevation above the ground and the angle with respect to the plane of the sides at which it is desired to transmit most efficiently. The antenna system operates on a predetermined wavelength and, to insure efficient transfer of power to the antenna wires, the surge impedance of the line **2** is matched by suitable devices to the antenna load at or near the points **3**, **5**. The direction of most efficient radiation will then be in the vertical plane passed through the bisector of the angle formed by the sides.

Fig. 1*a* is a polar diagram showing the horizontal directivity of a standing wave type of V antenna. There are two principal lobes, **7**, **8** and **7**, **9**, the minor lobes being omitted from all diagrams for the sake of clearness. The arrangement is, therefore, bi-laterally directive, forward in the direction **7**, **8** and backward in the direction **7**, **9**. Radiation in the forward direction is somewhat greater than in the backward direction. This may be explained by reflecting on how the standing waves are produced on the wires. They result from the superposition of waves from the source travelling outward in the direction **3**, **5** to **4**, **6** and earlier waves reflected from the open ends, **4**, **6** and hence traveling in the direction **4**, **6** to **3**, **5**. The outward travelling waves are radiated in the direction **7**, **8** of Fig. 1*a* and

the reflected waves are radiated in the direction 7, 9. Since the outward waves are fresh from the source and the reflected waves have had energy extracted in the form of radiation before reflection, the radiation in the direction 7, 8 is somewhat greater than in direction 7, 9 as previously stated. This difference in forward and backward radiation is greater the longer the sides of the V because more energy is extracted by radiation before the outward travelling waves reach the outer ends and become reflected waves.

The desirability of reducing the backward lobes, i. e., 7, 9, is too well known to require detailed discussion. The backward lobe is in general of no practical utility and may be a harmful source of interference.

It has been suggested in order to accomplish this result, to lengthen the wires forming the sides of the V to such an extent that the backward radiation is negligible in comparison with the forward radiation. In other words, the wires should be so long that practically all of the energy is radiated on the outward journey and, therefore, little energy is left to be reflected from the open ends. This suggestion is open to very grave disadvantages not the least of which is the enormous length of the sides before the effect becomes appreciable. For example, when the sides are each 7¾ wavelengths long the backward radiation is approximately 2½ decibels less than the forward radiation. In this example, even though the sides are already quite long, the discrimination between forward and backward radiation is much too small to be useful. Even when the sides are made 16 wavelengths long the discrimination is not even 5 decibels, which again is much too small to be useful. It will be appreciated then that to increase the discrimination by lengthening the sides of the V would necessitate a large plot of ground and very expensive construction because of the great length required for the sides of the V. Another serious objection to this suggestion is the excessive concentration of the radiation as the sides of the V are made very long. A certain amount of concentration is desirable but when it becomes excessive, as it does when the sides of the V are more than about 8 wavelengths long, the vagaries of nature in the region between the radio transmitting station and the station at which the radio signals are to be received make the maintenance of reliable communication extremely difficult.

Another suggestion for the cancellation of the backward radiation is the use of a second V with sides equal and parallel to the main V and so spaced in the direction along the bisector and fed in such phase relation to the main V that substantial cancellation of the backward radiation takes place. This again is expensive since it requires the construction of a second V, thus practically doubling the cost of the antenna system. Another objection to reflectors such as are used in double V's is that when once installed to send or receive on a certain wavelength, the antenna must be practically rebuilt to operate on a different wavelength, and the same antenna can never be operated at uniformly high efficiency on more than one wavelength. Furthermore, there may be cases where land is not available for the installation of the second V.

Still another way in which cancellation of the backward radiation may be effectively accomplished is by terminating the outer end of each side of the V in a resistance equal in value to the surge impedance of the wire. The effect of such a termination is to absorb all the energy that remains of the outward travelling waves when they reach the outer end so that none is reflected. Considering the large amount of power which is normally used in radio transmission the resistance terminations are called upon to dissipate a correspondingly large amount of power and their construction is, therefore, expensive. Another factor contributing to the expense is the necessity for providing weatherproof housing for the terminations. Still another factor of expense is the provision of ground connections of steady and high conductivity, which are often used in "terminated" antennae.

I have dwelt on the methods practiced in the art for obtaining uni-lateral directivity partly to indicate the importance and desirability of the result and also, by contrast, to show the simplicity of my invention. This will be clearer upon consideration of some of the embodiments of the same.

Fig. 2 shows one such embodiment and to a large extent it resembles Fig. 1. That is, 10, 11, 12, 13, 14 and 15 of Fig. 2 correspond to 1, 2, 3, 4, 5 and 6 of Fig. 1, respectivey. Fig. 2 differs from Fig. 1 in that at point 16 intermediate the ends of conductor 12, 13, one end of a relatively short straight wire 16, 17 or other conductor is connected, the other end 17 being free or insulated. Similarly, another relatively short straight wire 18, 19 is connected to point 18 of the conductor 14, 15 the end 19 being free or insulated. Without the wires 16, 17 and 18, 19, Fig. 2 is the same as Fig. 1, a V type standing wave antenna bi-laterally directive. Merely by the addition of said wires, when properly proportioned as to length and point of connection to the sides of the V, the antenna of Fig. 1 is converted to the uni-laterally directive antenna of Fig. 2. The distance 16, 13 and the length of the wire 16, 17 depend on the wavelength as well as on the radiation resistance of the system consisting of 16, 13, 17. This must be so adjusted as to suppress substantially reflection of the outward travelling waves at 16, the combination effectively transforming the radiation resistance of the section 16, 13 so that it will be approximately equal to the surge impedance of the much longer remaining portion 12, 16. The distances 18, 15 and 18, 19 are made equal to the distances 16, 13 and 16, 17, respectively. If the radiation attenuation along the path from 16 to 13 and back to 16 is such that a fraction S^2 of the wave returns to 16, that is S^2 is the ratio of the amplitudes of the reflected to the forward wave in the outer section at the beginning thereof, then the above stated conditions are satisfied when the total back wave along 16, 12 is equal to zero, or in other words, of

$$\rho+\frac{S^2(1-\rho)^2 e^{-j\frac{4\pi l}{\lambda}}}{1-\rho S^2 e^{-j\frac{4\pi l}{\lambda}}}=0$$

where

$$\rho=\frac{Z_0+Z-ZZ_0}{Z_0+Z+ZZ_0}$$

Z_0 being the surge impedance of the antenna wire 12, 13 and Z the impedance looking in 16, 17 at point 16; e is the base of natural logarithms; and l the length 16, 13. Equation (1) being in general a vector equation is equivalent to two scalar equations. When Z is a pure imag-

inary these two equations will give a finite number of pairs of solutions for l and Z which will provide an impedance match at **16**. When Z has a real part the value of which may be assumed in advance from an estimate of radiation resistance, then the two scalar equations again provide a finite number of pairs of solutions for l and the imaginary part of Z. When no restrictions are placed on Z there is an infinite number of solutions of the two scalar equations for l and Z, only some of which may be used in practice. In practice it is desirable to make Z as nearly imaginary as possible by coiling wire **16**, **17** into a gradual spiral, solving the problem on this basis, and then correcting the solution to take into account the small amount of resistance present.

The above applies, of course, to the second branch of the V also.

The simplicity of construction is made evident upon consideration of Fig. 3 in which **20** corresponds to the point **16** or **18** in Fig. 2, **22** is an insulator to support the free end **13** or **15** of the side of the V which in turn is supported by the pole **23**. **21** is another insulator supporting the free end **17** or **19** of the relatively short straight or gradually coiled wire which in turn is supported by the same pole **23** at a point near the ground. The relatively short wires may be the same as those employed in the conductors of the V.

In the arrangement of Fig. 2, as previously explained, the portions **16**, **13** and **18**, **15** are very short relative to the length of the conductors **12**, **13** and **14**, **15**. The energy remaining in the outward travelling waves upon reaching points **16** and **18** is dissipated largely by radiation in the sections **16**, **13** and **18**, **15**. Said radiation is not very concentrated. Hence, it is quite harmless as far as interference is concerned. In some instances, however, the points **16** and **18** may be taken so as to divide the conductors **12**, **13** and **14**, **15** into two approximately equal parts. It is instructive in connection with my second embodiment, to examine qualitatively under these conditions the radiation patterns of the inner and outer sections, the inner section being **12**, **16** and the outer **16**, **13** and likewise for conductor **14**, **15**. Thus, Fig. 2*a* shows the radiation pattern for the inner section and Fig. 2*b* for the outer section when the addition of **16**, **17** is such as to cause practically no reflection of the outward travelling waves at **16**. The radiation from the inner section shown in Fig. 2*a* is nearly all to the right, i. e., in the forward direction, that to the left being very small by comparison. The outer section, on the other hand, radiates like an ordinary V with standing waves having a radiation pattern as shown in Fig. 2*b* where the radiation in the forward direction (to the right) is somewhat greater than in the backward direction substantially as explained in connection with Fig. 1.

When the length and positioning of **16**, **17** is varied so as to cause progressively more and more reflection of the outward travelling waves at the point **16**, the backward radiation from the inner section increases and the forward radiation remains substantially the same as shown in Fig. 2*c*. At the same time the radiation from the outer section diminishes uniformly in all directions as shown in Fig. 2*d*. By proper adjustment, the backward radiation from the inner section may be made equal to the backward radiation from the outer section. Obviously, if the backward radiation from the inner section is made equal in magnitude and in addition opposite in phase to the backward radiation from the outer section, the result will be complete cancellation of backward radiation from the antenna system as a whole. This, in effect, is what is accomplished in the embodiment shown in Fig. 4.

Fig. 4 resembles Fig. 2 in that **10**, **11**, **12**, **13**, **14**, **15**, **16**, **17**, **18** and **19** of Fig. 2 correspond to **24**, **25**, **26**, **27**, **28**, **29**, **30**, **31**, **32** and **33**, respectively, of Fig. 4. Wires **30**, **31** and **32**, **33**, of course, are arranged to bring about substantially equal backward radiation from sections **26**, **30**; **30**, **27**; **28**, **32**; and **32**, **29**. The phase delay device **34** in the form of a wire loop inductance is introduced adjacent to the point **30** and a similar device **35** just ahead of **32**. The function of the phase delay devices is to bring about phase opposition in the backward radiation from the inner and outer sections and, therefore, cancellation. Any desired phase delay may be achieved by adjusting the length of the non-radiating loops **34** and **35**, and since the backward radiation from the inner section traverses the loops twice and the backward radiation from the outer section only once, it becomes a simple matter of adjustment to make their relative phase result in cancellation.

It should be pointed out that the angle between the wires forming the sides of the V in Fig. 4 should be determined on the assumption that the antenna is an ordinary V having sides only half as long. This determines the angle 2θ between the sides of Fig. 4. The length of each of the wires **30**, **31** and **32**, **33** is adjusted as previously explained so as to make the magnitude of the back radiation from the inner and outer sections equal. The same adjustment brings about a dependent phase difference between the reflected waves in the inner and outer sections which may in some instances effect the desired cancellation. In this event I may dispense entirely with the phase delay devices **34** and **35**. In any event for cancellation, said phase difference should be made equal to,

$$\frac{l}{2\lambda}(1-\cos\theta)360^\circ-180^\circ$$

where l is the length of one side of the V, λ the working wave-length and θ the angle each side makes with the direction of most efficient radiation. In general, it will be found also that this automatically brings about the proper phase difference between forward waves from the inner and outer sections for efficient addition to the desired direction. The latter phase difference required for in phase addition is equal to

$$\left[1-\frac{l}{2\lambda}(1-\cos\theta)\right]360^\circ$$

where l, λ and θ have the same meanings as in the previous formula.

If the inner sections **26**, **30** and **28**, **32** are of the same length as the outer sections **30**, **27** and **32**, **29**, respectively, then the outer sections may be mere extensions of the inner section, i. e., the outer section **30**, **27**, for example, may extend in the same direction as its inner section **26**, **30**. If, on the other hand, the inner sections are substantially different in length from the outer sections, the angle formed by the inner sections and the angle formed by the outer sections should be determined independently in accord-

ance with their respective lengths so as to obtain maximum radiation in substantially the same direction for both inner and outer sections. Thus, in case the outer sections are materially shorter than the inner sections, the outer sections should form a greater angle than the inner sections and vice versa.

The simplicity of the construction of this embodiment is apparent from Fig. 5 in which a phase delay loop is shown by **36**, **37** and **38**. **39** is an insulator to separate **36** and **38**, and **40** is an insulator to support the lower end of the loop **37**. The other side of insulator **40** is fastened to a suitable support **43** near the ground. The short straight wire **410** which is connected to a selected point on each side of the V is shown connected at **41**. The other end is tied to the insulator **42** which in turn is attached to a suitable support **44** near the ground.

It will be obvious to those skilled in the art that many variations and modifications may be effected without departing from the spirit of the invention. The positioning of the V antennae with respect to ground may be varied, the V may be replaced by other shapes, one-half of the antenna may be replaced by its ground image, etc. Moreover, the above described structures which are adjusted for radiating at a particular frequency and its harmonics may be readily modified to operate on a different frequency by varying the points of connection of wires like **16**, **17** and the length of these wires.

The antenna may also be arranged to operate on a plurality of different frequencies. Such arrangement is shown in Fig. 6.

This antenna differs from the one shown in Fig. 2 in that the wires **16**, **17** and **18**, **19** have been replaced by networks **56**, **64**, **66** and **53**, **60**, **62**. Each of these two networks contains one more parameter, i. e., **62**, **61**, in one network, and **66**, **65** in the other network, so that these networks may be proposed in such a manner that they would have prescribed impedances not only at one frequency, but at two frequencies, and will, therefore, be able to function in the same manner as **16**, **17** and **18**, **19** in Fig. 2, whether the transmitter indicated in this figure is transmitting on wavelength λ_1 or wavelength λ_2. Inasmuch as the lengths **53**, **55** and **56**, **58** of the outer parts of the antenna can be given the correct values to satisfy the conditions only at one frequency, wires **54**, **59**, **57** and **63** have been added near the ends of these wires in order that the effective length of the outer parts of the antenna may be made to satisfy the necessary conditions outlined above at both wavelengths. It is quite obvious that by adding more parameters to the networks which produce refractions on one hand and to the networks at the ends of the outer wires on the other hand, it is possible to satisfy the required conditions not only on two frequencies, but on three or more frequencies as well.

What is claimed is:

1. In a unidirectional antenna, two open ended diverging antenna wires, an impedance device connected to each wire intermediate the ends thereof so as to divide each wire into two sections with the impedance device effectively in electrical shunt to one of the sections, and a phase delay device connected in series with the other section of each wire at a point adjacent the impedance device.

2. In a unidirectional radio transmitting antenna, two open ended antenna wires diverging in the direction of radiation, means for feeding said wires in phase opposition, and an impedance device insulated from ground connected to each wire at a single point intermediate its ends to divide the wire into two sections with said device in direct shunt to one section, the real impedance component of said device being small compared with the imaginary component thereof.

3. In a unidirectional radio transmitting antenna, two open ended antenna wires diverging in the direction of radiation, means for feeding said wires in phase opposition, an impedance device connected to each wire intermediate its ends to divide the wire into two sections with said device in electrical shunt to one section and a phase delay device connected in each wire at a point adjacent said impedance device.

4. In combination, an electrically long open ended antenna, and an electrically short open ended wire connected therewith at a point which is electrically at a short distance from the open end of the antenna, the length of said wire and the length of the short section of antenna being such that the resultant impedance of both of them in parallel is equal to the surge impedance of the antenna at said point.

5. In a unidirectional antenna, a transmitter, two line conductors connected therewith and fed in phase opposition, two electrically long antennae, each connected at one end with one of the conductors, the two antennae being open ended and inclined with respect to one another at an angle depending on the direction of radiation desired, an electrically short open ended wire connected to each antenna intermediate its ends and in electrical shunt to a portion of the antenna whereby standing waves may be produced thereon, the radiation resistance of the portion having standing waves together with the length and positioning of the electrically short open ended wire being determined substantially to eliminate the occurrence of reflected waves between the transmitter and the points at which the wires are connected.

6. In combination, an open ended antenna, and an open ended wire connected to the antenna at a point intermediate the ends of the latter so as to divide the antenna into two sections with the connected open ended wire in electrical shunt to one section, and a phase delay device connected in series with the other section of said antenna at a point near the point of connection of said open ended wire.

7. In combination, an electrically long open ended antenna, a transmission line connected therewith, a reflection producing impedance connected with the antenna intermediate its ends, and a phase delay device connected in series with the antenna between the transmission line and the point at which the impedance is connected with the antenna, the value of said impedance and the phase angle of said phase delay device being such that the backward radiation produced by the different portions of said antenna mutually cancel.

8. In a unidirectional antenna, a transmitter, two line conductors connected therewith and fed in phase opposition, two electrically long antennae, each connected at one end with a conductor, the two antennae being open ended and inclined with respect to one another at an angle depending on the direction of radiation desired, an electrically short open ended wire connected with each antenna intermediate its ends, and a

phase delay device connected in series with each antenna between the transmission line and point of connection of the wire and at a point near said point of connection.

9. In combination, a bi-laterally active antenna system of great electrical length and consisting of a plurality of sections connected in series, and means for making the activity of one section in one direction equal in magnitude and opposite in phase to the activity of another section in said one direction.

10. In combination, a bi-laterally directive antenna system of great electrical length and consisting of a plurality of wires divided into a plurality of sections connected in series, means for feeding said wires in phase opposition, and means for making radiation from one section in one direction equal in magnitude and opposite in phase to radiation of another section in said one direction.

11. In combination, an open ended V antenna of great electrical length and divided into an inner and an outer section connected in series, and means for making the radiation from the inner section in the direction of the apex equal in magnitude and opposite in phase to the radiation from the outer section in the direction of the apex.

12. In combinaation, an open ended V antenna each leg of which is of great electrical length and is divided into an inner section near the apex and an outer section connected in series, means for feeding the legs in phase opposition, and means for making the radiation from the inner section in the direction of the apex equal in magnitude and opposite in phase to the radiation from the outer section in the direction of the apex, and means for making radiations from the two sections of the antenna add efficiently in the direction of the diverging open ends.

13. In combination, a bilaterally active antenna system of great electrical length and consisting of a plurality of sections connected in series, and means operative at either one of two predetermined frequencies for making the activity of one section in one direction equal in magnitude and opposite in phase to the activity of another section in said one direction.

14. An antenna system comprising an antenna proper, and means for dividing the antenna into two sections so that the phase difference between radiations in the desired direction from the two sections at the beginning thereof is given by

$$\left[1-\frac{l}{2\lambda}(1-\cos\theta)\right]360°$$

where l is the length of the antenna, λ the working wavelength, and θ the angle the antenna makes with the direction of most efficient radiation.

15. An antenna having a conductor, and means for dividing said conductor into two sections so that the phase relation of radiation in the undesired direction from the two sections at beginning thereof is substantially

$$\frac{l}{2\lambda}(1-\cos\theta)360°—180°$$

where l is the length of the conductor, λ the working wavelength, and θ the angle the conductor makes with the direction of most efficient radiation.

16. In an antenna system, an open ended conductor fed at the opposite end, an impedance connected with the conductor intermediate its ends and so proportioned that

$$\rho+\frac{S^2(1-\rho)^2e^{-j\frac{4\pi l}{\lambda}}}{1-\rho S^2e^{-j\frac{4\pi l}{\lambda}}}=0$$

where

$$\rho=\frac{Z_0+Z-ZZ_0}{Z_0+Z+ZZ_0}$$

Z_0 being the surge impedance of the whole conductor, Z the value of said impedance looking into it at its point of connection with the conductor, e the base of natural logarithms, S^2 is the ratio of the amplitudes of the reflected to the forward wave in the outer section at the beginning thereof and l the length of the conductor between its open end and the point of connection of said impedance.

17. An antenna system comprising a source of energy, an antenna wire, means for feeding energy from said source to one end of said antenna wire, and means for making the radiation from said antenna wire uni-laterally directional, said means comprising an impedance device connected to said wire intermediate the ends thereof and at such a point thereon that wave energy fed to the antenna is reflected from said point as well as from the free end of said wire in such phase that substantial cancellation of the radiation produced by said reflected waves occurs in space.

18. An antenna system according to claim 17 characterized by the fact that said impedance device is a reactive element having two terminals, one of which is free and the other connected to said antenna wire.

19. An antenna system according to claim 2 characterized by the fact that said impedance device is a reactive element having a free terminal and another terminal which is connected to said antenna wire, the reactance of said element and the point of connection thereof to the antenna wire being such that the impedance of the outer section of the antenna wire is matched to the surge impedance of the inner section.

20. An antenna system according to claim 17 characterized by the provision of a phase delay device connected in series with the antenna wire between the transmission line and the point of connection of said impedance device and at a point near the latter point.

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