Sept. 11, 1928. | 1,683,739

J. S. STONE

DIRECTIVE ANTENNA ARRAY

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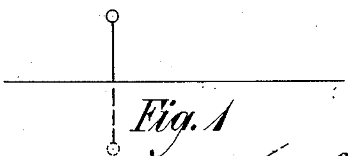

Fig. 1

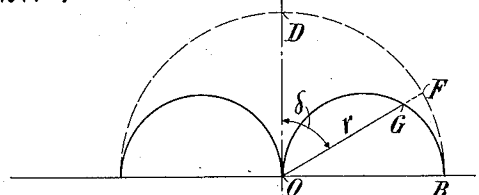

Fig. 1a

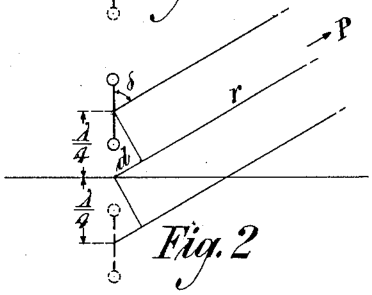

Fig. 2

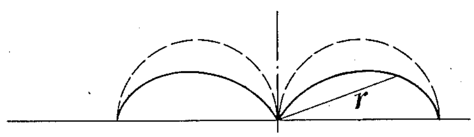

Fig. 2a

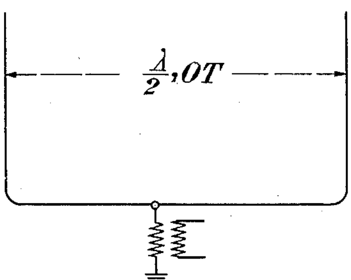

Fig. 3

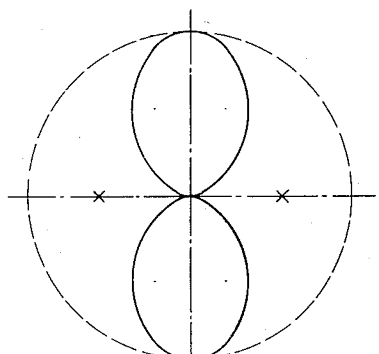

Fig. 3a

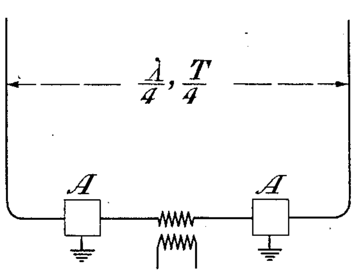

Fig. 4

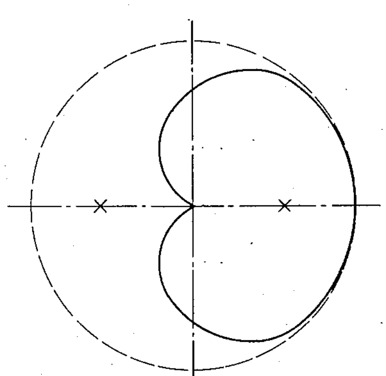

Fig. 4a

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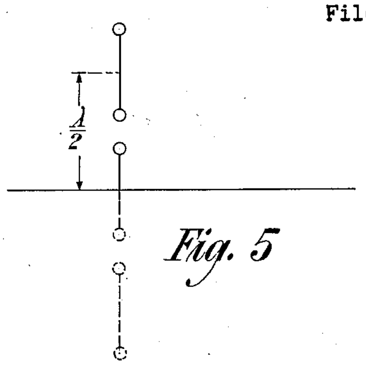

Fig. 5

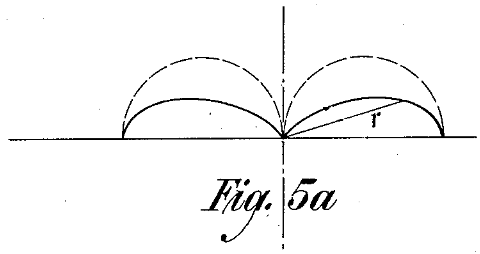

Fig. 5a

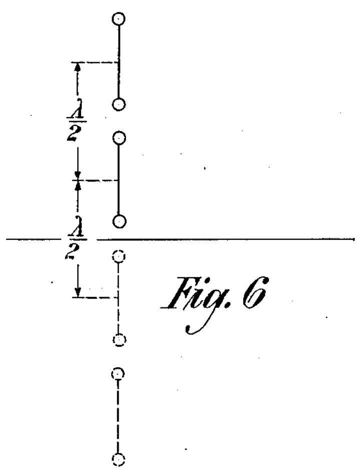

Fig. 6

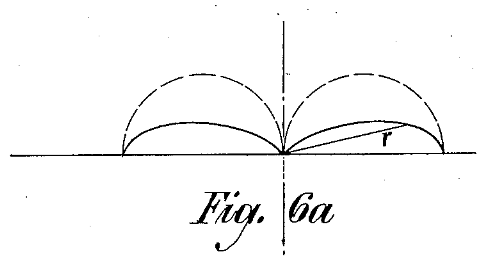

Fig. 6a

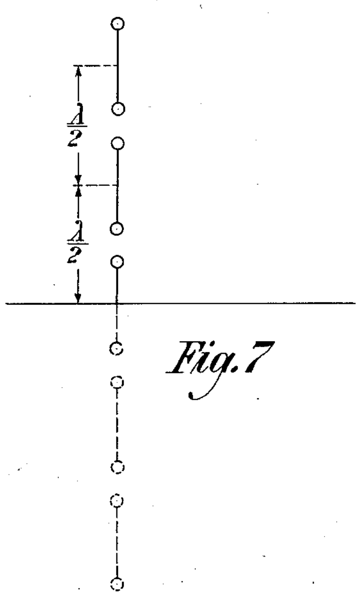

Fig. 7

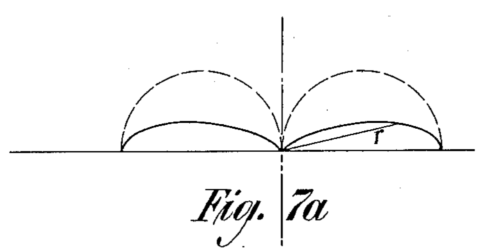

Fig. 7a

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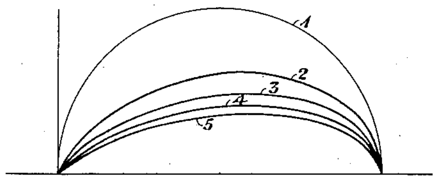

Fig. 8

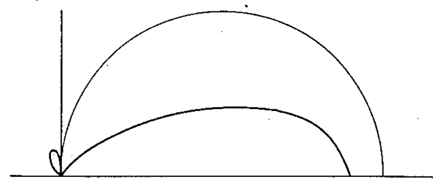

Fig. 9

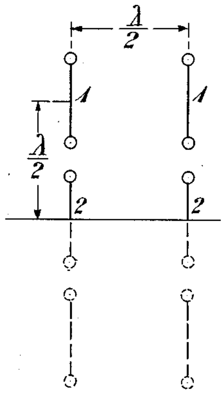

Fig. 10

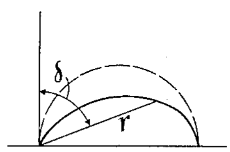

Fig. 10a

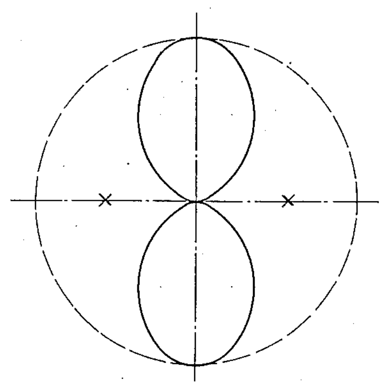

Fig. 10b

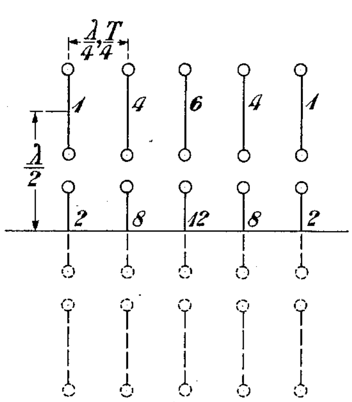

Fig. 11

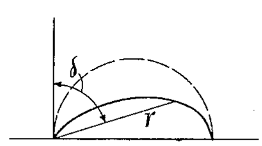

Fig. 11a

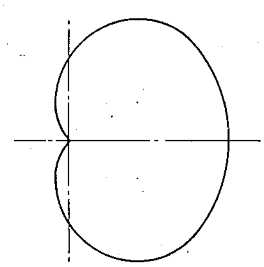

Fig. 11b

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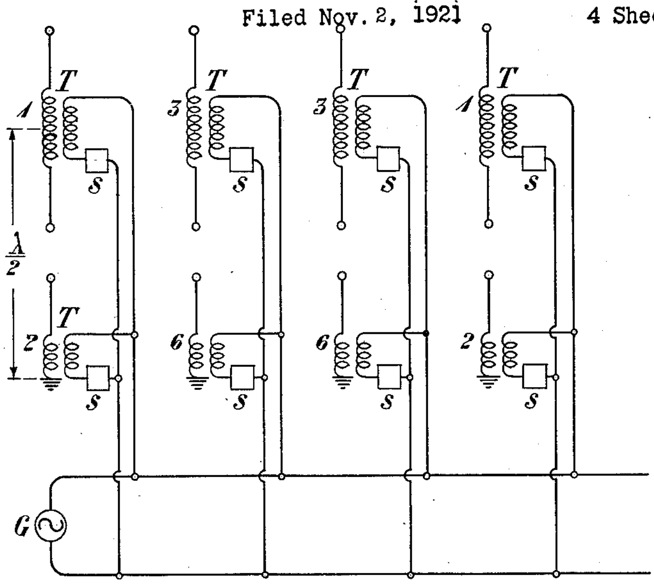

Fig. 12

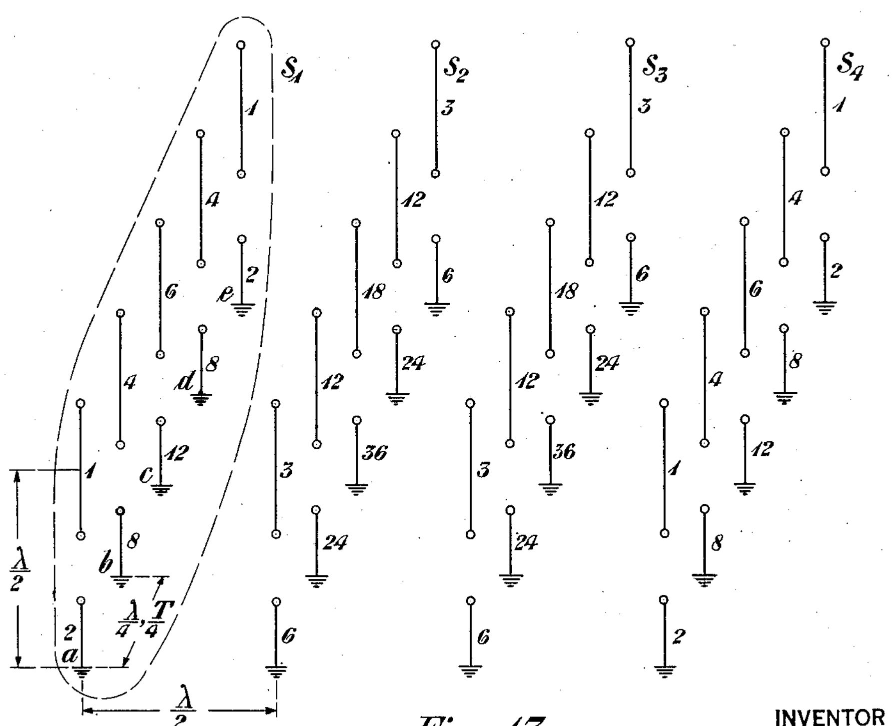

Fig. 13

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Patented Sept. 11, 1928. 1,683,739

UNITED STATES PATENT OFFICE.

JOHN STONE STONE, OF SAN DIEGO, CALIFORNIA, ASSIGNOR TO AMERICAN TELEPHONE AND TELEGRAPH COMPANY, A CORPORATION OF NEW YORK.

DIRECTIVE ANTENNA ARRAY.

Application filed November 2, 1921. Serial No. 512,271.

The principal object of my invention is to provide a new and improved directive radio transmitting or receiving station, and one which is directive not merely laterally but also vertically, that is, one which prevents the spreading of radiation into the upper atmosphere. Another object of my invention is to provide a radio station with a plurality of antennæ so arranged as to avoid the so-called fading away effect common in radio signaling. A further purpose of my invention is to eliminate a difference in day and night signaling, commonly experienced in radio communication. Still a further object is to limit the sensitivity of a radio receiving station to strays coming to it from the upper atmosphere. Other objects of my invention have to do with such matters as securing a convenient and compact distribution of the antennæ at such a station, exciting them in proper amplitude and phase relation, and obtaining an angular distribution of intensity for the array corresponding substantially to a polar diagram of a single loop. The invention is an improvement in and extension of another invention disclosed in my pending application, Serial No. 434,947, filed January 4, 1921.

In present day radio signaling, it is found that signals between stations with suitable ground connections utilizing wave lengths of 600 meters or more, are of the same intensity by day and by night when the stations are a short distance from each other, say of the order of 50 or 100 miles. But for greater distances, the signals between such stations are more intense at night than in the day, this phenomenon increasing as the distance between the two stations increases. Furthermore, the signals between such stations are not subject to the phenomenon of fading away of signals when the stations are relatively close together, but again, as the distances become greater than 50 or 100 miles, the phenomenon of fading away makes itself felt, becoming more pronounced as the distances increase. It has also been observed in this connection that the greater the frequency of oscillations, or the shorter the wave lengths used, the more marked is the phenomenon of fading away of signals and of the differences between day and night intensities.

Various theories have been proposed to explain these phenomena, and the one which is most commonly accepted is that they are due to the presence of a stratum of the atmosphere at relatively high altitudes which is sufficiently rarefied to admit of the development of appreciable conductivity by solar radiations. More specifically, they are probably due to the absorption and reflection of the radiations by the ionized upper layers of the atmosphere which result in the production, at the earth's surface, of phenomena akin to interference. It has been estimated that this rarefied stratum of the atmosphere is about 35 miles above the surface of the earth and it is probable that the conductivity of the stratum is largely due to solar radiation of high actinic power in that altitude and to the presence of large quantities of electrons which have been emitted by the sun. In radio signaling we are dealing, therefore, with electromagnetic waves traveling between two conducting layers, one of these being the earth and the other a rarefied stratum of atmosphere.

In view of the facts stated above as to the distances at which the disturbing effects of fading away and difference of day and night intensity occur, it is quite evident that only when stations are separated by a distance of an order greater than that of the conducting stratum from the earth will the ionization of the upper atmosphere be effetcive in modifying the wave transmission. If the atmosphere were at rest and the conductivity of the rarefied stratum remained fixed in quality and in position, we would probably not be aware of its presence, but the atmospheric ocean is subject to continuous surgings of gigantic proportions, made evident by our barometers, and observations at great elevations show that the wind velocities increase as the distance from the earth increases. It is, therefore, to be concluded that the conducting stratum of the atmosphere is not fixed but is subject to irregular wave motions of great amplitude and wave length. This then accounts for the irregularity in the two phenomena under consideration, and the impossibility of predicting what this may be. Furthermore, the fading away of signals is observed at short wave lengths and at considerable distances of transmission, even at night, which indicates a more or less permanent condition of ionization of certain parts of the atmosphere, although that part of the atmosphere may not be receiving direct radiation from the sun.

In order to overcome these effects, it is my purpose, as disclosed in this invention, to set up an antenna array which will confine the electromagnetic waves to a comparatively thin layer adjacent to the surface of the earth, so that the energy of these waves will not diffract into the conducting layer of the atmosphere, or, at most, will do so to a slight extent only. This is accomplished by making the antenna directive in a vertical plane, and the invention may be conveniently combined with my invention described in the pending application noted above, under which circumstances, not only do I obtain directivity in a lateral sense but also in a vertical sense. The invention will be better understood by reference to the figures of the accompanying drawing and their description, which follows hereinafter. In said drawing, Figure 1 shows a grounded antenna and indicates how it is equivalent, through its image in the earth, to a Hertz doublet, and Fig. 1^a shows a polar diagram in a vertical plane for such an antenna; Figs. 2 to 7 represent developments of this antenna system into more complex systems to be described hereinafter, and Figs. 2^a to 7^a represent the corresponding polar diagrams taken in a vertical plane. Fig. 8 is a digram showing the polar diagrams of Figs. 1^a, 2^a, 6^a, and 7^a brought together for the sake of comparison. Fig. 9 shows the polar diagram for the system shown in Fig. 5 with a ratio of amplitude of vibration between the middle doublet and the elevated doublet of 1.8. Fig. 10 shows a combination of two sets of vertical antennæ. Figs. 10^a and 10^b are polar diagrams of the vertical and horizontal characters of the system shown in Fig. 10. Figs. 11, 11^a, and 11^b show a further extension of the principle shown in Fig. 10 with corresponding diagrams. Fig. 12 is one arrangement that may be used for maintaining proper phase and amplitude relations in the various antennæ. Fig. 13 is a composite system showing a further extension of the invention shown in Figure 11.

I have in my above noted pending application shown how the energy of radiation from a radio transmitter may be concentrated in the direction of the receiving station, this concentration being mainly in the horizontal or earth's surface plane. This lateral compression or narrowing of the ray was explicitly described, but the structures therein also effect a substantial earthward concentration of the energy in the vertical plane, with the result that in addition to the admitted advantages flowing from the lateral restriction of the energy radiated, the system possesses, to a considerable degree, the advantage of increased constancy of transmission, due to a greater measure of freedom from the conducting stratum of the atmosphere.

Briefly, the structure of the present invention consists in superposing oscillators of the Hertz type in such a way as to constitute, together with the images below the earth's surface, a linear array of sources which shall be directive in a vertical plane, much as a similar source may be made directive in the horizontal plane.

In the case of a simple Hertz oscillator or doublet the field of force above the earth's surface at any point P, whose distance r from this source is large compared with the length of the oscillator, is given by the expression

$$\begin{aligned} E &= \frac{bm^2}{r} \sin(\varpi t - mr) \sin\delta \\ H &= \frac{bm\varpi}{ar} \sin(\varpi t - mr) \sin\delta \end{aligned} \qquad (1)$$

where E and H are the vectors representing the electric and magnetic forces, respectively, at the point P; b is the electric moment of the oscillator; m is the ratio of the periodicity ϖ of the wave to the velocity of propagation of the wave; δ is the angle which the radius vector to the point P makes with the vertical, and a is the constant resulting from the use of electrostatic units in the definition of b. These are also the equations in case of a grounded antenna in which the doublet is made up of the physical antenna and its electrical image, and is well understood in the art. It is not necessary in this specification to give a derivation of these equations, for this may be found in a number of publications, such, for example, as "The Principles of Electric Wave Telegraphy and Telephony" by Fleming, page 391, published 1910, or "Electric Oscillations and Electric Waves" by Pierce, page 432, published in 1920, but from these equations it is seen that the points of equal intensity for either the electric or magnetic force in any vertical plane through the source are given by the polar diagram OAB of Fig. 1^a in which the radius vector r, making the angle δ with the vertical, gives the distance at which the force has a given value. Or at any point F on the arc DB the electric and magnetic forces will be proportional to the vector OG, that is, the diagram OAB gives the angular distribution of intensity of radiation for such a source. It will be seen that the source is a duo-directional doublet in any vertical plane passing through the source. It will also be noted that there is no radiation in a vertical direction and that the diagram OAB is a semicircle with OB as a diameter.

If, now, a complete physical doublet be held vertically and above the earth it will have its image in the conducting earth, as shown in Fig. 2, and the polar diagram representing forces at any distance from the source is shown in full lines in Fig. 2^a. For the sake of comparison the polar diagram for the single doublet of Fig. 1 is shown in dotted lines on Fig. 2^a. The form of the polar diagram of Fig. 2^a will obviously depend upon the phase relation and amplitudes of the waves arriving at a point P and this will depend upon the actual phase relation and amplitudes of the oscillations in the doublets and the spacing of the doublets. As a property of electrical images it will be apparent that the oscillations in the physical and imaginary doublets will be in phase and in order to attain the objects which I have in mind I find that it is desirable to have the centers of these doublets separated by a distance corresponding to a half-wave length; in other words, the center of the physical doublet should be $\frac{\lambda}{4}$ above the surface of the earth, and the polar diagram of Fig. 2^a has been constructed on this basis. The electric force due to the physical doublet, at some remote point P will be

$$E_1=\frac{A}{r}\sin\left(wt-mr-\frac{2\pi d}{\lambda}\right)\sin\delta$$

where d is the difference in distance to the point P as measured from the center of the physical oscillator and a point on the earth directly beneath it and will be equal to

$$\frac{\lambda}{4}\cos\delta.$$

Similarly the electric force at the same point P, due to the imaginary oscillator, will be

$$E_2=\frac{A}{r}\sin\left(wt-mr+\frac{2\pi d}{\lambda}\right)\sin\delta$$

The resultant electric force at the point P will then obviously be the sum of these two effects and will be equal to

$$E=\frac{2A}{r}\sin(wt-mr)\cos\left(\frac{\pi}{2}\cos\delta\right)\sin\delta \quad (2)$$

and the plot of this equation is that shown in full line of Fig. 2^a. The point P in all practical work will be sufficiently remote so that lines drawn to it from the centers of the doublets will be parallel. From this it will be seen that the maximum intensity at the surface of the earth has its full value but that for points elevated above the surface of the earth the intensity of the force is relatively less than would be indicated by the polar diagram of Fig. 1^a. The actual intensity for the system of Fig. 2 is double that of the intensity for Fig. 1 as shown by equation 2, but for better comparison the polar diagram in this, as well as in following figures, has been drawn of the same dimensions.

A further extension of my invention is shown in Fig. 5 in which a grounded half doublet and a complete doublet are arranged vertically above each other, which with their images in the earth give a total system consisting of three doublets. For the purposes of this invention I find it desirable to have the oscillations in the two physical doublets in phase and then, in accordance with the phenomena of electrical images, the oscillations in all of doublets, physical and imaginary, will be in phase. Further for my purposes, and for reasons which will appear from the equations, I find it desirable to have the center of the upper physical doublet $\frac{\lambda}{2}$ above the surface of the earth and also to make the amplitude of the oscillations in the grounded antenna double that of the elevated antenna. By a process similar to that followed in Fig. 2 it can be shown that the electric intensity at a remote point P will be given by

$$E=\frac{4A}{r}\sin(wt-mr)\,[\cos(\pi/2\cos\delta)]^2\sin\delta \quad (3)$$

and the polar diagram will be that shown in full lines of Fig. 5^a the dotted lines, again for comparison, being used to represent the polar diagram in the case of a single doublet. It will be observed that the contraction of the diagram in a vertical direction is more marked than in Fig. 2^a. In equations (2) and (3) as well as the following equations I have said nothing of the magnetic force for the reason that it will always bear a constant relation to the electric force, this relation being that of the coefficients of equation (1).

Further extensions of the same idea are shown in Figs. 6 and 7. In Fig. 6 two complete physical doublets are placed with their centers $\frac{\lambda}{2}$ apart, the lower having its center $\frac{\lambda}{4}$ above the earth, and which, with their electrical images, constitute the equivalent of four boublets vertically arranged with their centers $\frac{\lambda}{2}$ apart. In this case again I find it desirable to have the oscillations in the two physical doublets in phase, thus the oscillations in the imaginary doublets also come in phase. In the case of Fig. 7, two physical doublets and one grounded half doublet are arranged vertically, forming with their images the equivalent of five doublets having their centers $\frac{\lambda}{2}$ apart, the oscillations again being in phase for all the doublets. If, in the case of Fig. 6, the amplitudes of the oscillations in the doublets, starting at the top, have the relation 1, 3, 3, 1 it can be shown, as for equations (2) and (3) that the electric intensity at a remote point P is given by

$$E=\frac{8A}{r}\sin(wt-mr)\left[\cos\left(\frac{\pi}{2}\cos\delta\right)\right]^3\sin\delta \quad (4),$$

Similarly if for Fig. 7, with five doublets, the amplitudes bear the relation 1, 4, 6, 4, 1 the electric intensity will be

$$E=\frac{16A}{r}\sin(wt-mr)\left[\cos\left(\frac{\pi}{2}\cos\delta\right)\right]^4\sin\delta \quad (5).$$

The polar diagrams are shown in Figs. 6ª and 7ª and it is observed that commencing with Fig. 1ª there is a progressive delimination of the electric force to the earth's surface as one goes to systems with a larger number of vertical doublets. For sake of better comparison I have brought the polar diagrams of Figs. 1ª, 2ª, 5ª, 6ª and 7ª together in Fig. 8, numbered 1 to 5 respectively. These curves, showing half of each diagram only, are plotted quite accurately.

From the equations corresponding to the various figures it will be seen that the amplitudes of the oscillations in the various antenna have been made to bear a relation to each other of the binomial coefficients and that in this case the polar diagrams and their equations take on a very simple form so that the binomial law holds for the vertically arranged antennæ in the same manner as for the horizontally arranged antennæ of my copending application. In general, for any number of doublets, n, half of which are imaginary and in which the distance from center to center of adjacent doublets is $\frac{\lambda}{2}$ and in which the binomial relation for amplitudes is used, it can be shown that the electric force or intensity will be

$$E=\frac{2^{n-1}A}{r}\sin(wt-mr)\left[\cos\left(\frac{\pi}{2}\cos\delta\right)\right]^{n-1}\sin\delta \quad (6)$$

and as n increases the flattening of the polar diagram will increase correspondingly.

The equation (6) is derived on the basis that the amplitudes of the oscillations in the antennæ bear the relationship of the binomial coefficients. This is highly desirable for when it is followed the polar diagrams take on the simple forms shown in Figs. 2ª, 5ª, 6ª and 7ª and the equations themselves reduce to the simple form of equation 6. On the other hand it should be understood that this relationship is not necessary for obtaining at least partial concentration of the radiation towards the earth's surface. A certain amount of departure from this relationship is permissible without causing serious complications. If, for example, in the system of Fig. 5 the middle doublet, which is half physical and half imaginary, has an amplitude of vibration of 1.8 instead of 2 as compared with the amplitude of the elevated doublet, the polar diagram, taken in a vertical plane, will then be of the form in Fig. 9. For comparison the polar diagram of Fig. 1 is also shown on this figure and it is apparent that substantial concentration towards the earth's surface has been obtained, but the diagram, as a whole, is not so simple. In case of further departure from the binomial relation the diagram will become still more complex and the maximum electric intensity obtained in the one direction becomes continually less.

In my pending application I have shown in Fig. 3 an antenna like that of Fig. 3 of this application in which the two branches are $\frac{\lambda}{2}$ apart and the oscillations therein are in phase, Fig. 3ª of this application shows the polar diagram in a horizontal plane for such an antenna and it is seen that it is duo-directional at right angles to the plane of the antenna. At a great distance from the antenna pair its effect is equivalent to a single source half-way between the two branches but still having a polar diagram like that of Fig. 3ª. For convenience I called this equivalent source in my copending application a consequent source of the first order. I further described the combined effect of two such consequent sources of the first order, and a single source which would be the equivalent of these I called a consequent source of the second order, etc. In that application I also considered the case where the two branches of the antenna are $\frac{\lambda}{4}$ apart and the oscillations are in quarter phase relationship as in Fig. 4, and in this case the polar diagram is uni-directional as indicated in Fig. 4ª. Here again the single source placed at the center of the antenna of Fig. 4 which would be equivalent thereto, was called a consequent source of the first order, being, however, uni-directional. By suitable combinations of a plurality of these uni-directional and duo-directional sources I showed how it was possible to obtain a lateral compression of the electric field resulting in lateral directivity to any degree desired.

In this invention I propose to combine with my present idea of horizontal concentration the lateral compression or directivity disclosed in my copending application. This is shown, for example, in Fig. 10, in which there is a combination of two sets of vertical antennæ, each set comprising three doublets, these doublets being half physical and half imaginary. If these two sets are spaced $\frac{\lambda}{2}$ apart and maintained in phase the two doublets in a given horizontal plane will act as a duo-directional antenna of the type shown in Fig. 3. With such a system the polar diagram for the electric force, taken in a vertical plane will be that shown in Fig. 10^a and the concentration of the radiation towards the surface of the earth is substantial. At the same time the polar diagram for the electric force taken in a horizontal plane is that shown in Fig. 10^b and is duo-directional. The amplitudes of the oscillations in the antennæ, considered vertically, are those given by the binomial relation which for this system will mean that the grounded antenna will have double the amplitude of the elevated antenna.

A further extension of this same principle is shown in Fig. 11. In this case there is shown a horizontal array of five doublets, there being three such horizontal arrays, half physical and half imaginary, as indicated by the full and the dotted lines. In this case the antennæ in a given horizontal plane are related in the manner shown in Fig. 4, that is, they are spaced $\frac{\lambda}{4}$ apart and the oscillations are in quarter phase relationship. Also the amplitude of the oscillations in any given horizontal plane follow the binomial relation, as explained in my copending application which for five antennæ means amplitudes having the relation of 1, 4, 6, 4 and 1. Since the binomial relationship also holds for a given vertical array a grounded antenna will have double the amplitude of the corresponding elevated one, and the amplitude of the oscillations in any given antenna can then be readily calculated. This is shown by numerals adjacent the various radiators. The resulting polar diagram in a vertical plane is shown in Fig. 11^a and the corresponding horizontal polar diagram is shown in Fig. 11^b.

It is, of course, essential to provide means for maintaining proper phase and amplitude relations in the various antennæ. One arrangement for accomplishing this is shown in Fig. 12, in which each vertical set again comprises three doublets, half physical and half imaginary, and each horizontal plane contains four linearly arranged antennæ. The oscillations in any given vertical set must be in phase and the amplitudes are in accordance with the numerals adjacent each antenna. The antennæ are shown as excited by means of transformers T, the primaries of which are connected to some source of high frequency oscillations G. Each circuit may be supplied with a phase shifter and amplitude control represented conventionally at *s*, by means of which it is possible to control the phase and amplitude of the oscillations in each of the antennæ.

Obviously a large number of other arrangements could be used for supplying power to the various antennæ in the proper amplitude and phase relation and I do not wish to be limited to the one just described inasmuch as this is for illustrative purposes only.

A further extension of this invention, in order to obtain increased concentration of radiation, is shown in Fig. 13, this combining the advantages of the narrowness of the radiation diagram of the duo-directional antenna of Fig. 3 with the uni-directional characteristic of the antenna of Fig. 4 in substantially the manner indicated in my copending application. In this Fig. 13 I have shown a series of five grounded antennæ, *a*, *b*, *c*, *d* and *e* arranged linearly and spaced $\frac{\lambda}{4}$ apart and in quarter phase relationship as indicated, which will then yield a uni-directional system. At the same time in order to obtain concentration to the surface of the earth I place an antenna vertically above each of these antennæ, *a*, *b*, *c*, *d* and *e*, all of which results in a system substantially like that shown in Fig. 11 and included within the dotted portions S_1 of Fig. 13. In order now to take advantage of the narrowness inherent in the duo-directional combination I use a plurality of these systems S_1, as shown at S_2, S_3 and S_4. The corresponding antennæ in the systems S_1 to S_4 are spaced $\frac{\lambda}{2}$ apart and are excited in phase. The amplitudes in the three co-ordinate directions are in accordance with the binomial relationship and the particular system shown have the relative values indicated by the numerals adjacent each antenna. With such a system a high degree of directivity, both laterally and vertically, is obtained and this directivity may be further increased by extending the system in any one of the three co-ordinate directions, the particular extension depending upon the particular results which it is desired to obtain.

While I have shown the application to my invention of the lateral directive systems of my copending application, it is to be understood that so far as the vertical concentration is concerned, this being obtained by the disposition of antennæ vertically one above the other and excited in suitable amplitude and phase relationship, it may be used in connection with any form of lateral directive antenna or antennæ systems. Also it should be emphasized that while the invention as a whole has been described in a connection with a transmitting station, the directivity which it possesses is equally evident if the system is used for reception. As a result, then, of the use of such a system as that of Fig. 13

for reception it will be found that there is obtained a high degree of freedom from disturbances, such as static, coming from the direction of the upper atmosphere and at the same time high directivity as considered in a horizontal plane.

What is claimed is:

1. In radio signaling, a radiating system comprising a plurality of primary radiators arranged vertically, each radiator consisting of a vertical oscillator.

2. In radio signaling, a plurality of antennæ at different altitudes, and means to energize them as respective primary radiators of the same frequency and in such phase and amplitude relation as to concentrate the radiation along the surface of the earth.

3. In radio signaling, a plurality of primary vertical oscillators each constituting an antenna, said oscillators being arranged vertically above one another, and means to excite said oscillators in determinate amplitude and phase relation with one another.

4. In radio signaling, a radiating system comprising a plurality of antennæ consisting of vertical oscillators arranged vertically above each other, the oscillation phase being the same for all the antennæ.

5. In radio signaling, a directive radiating system comprising a plurality of antennæ arranged vertically above each other, the antennæ being spaced one-half wave length apart.

6. In radio signaling, a radiating system adapted to concentrate the radiation to a definite angle with the horizontal and comprising a plurality of antennæ arranged vertically above each other spaced one-half wave length apart, the oscillations in said antennæ being maintained in definite phase relationship.

7. In radio signaling, a radiating system comprising a plurality of radiating doublets arranged vertically one above the other, the amplitudes of the oscillations being related as the binomial co-efficients for a number corresponding to double the number of doublets.

8. In radio signaling, a radiating system comprising a plurality of doublets arranged in vertical array, the amplitudes of the oscillations being related as the binomial coefficients for a number corresponding to double the number of doublets in the vertical array, means for maintaining the oscillations in the antennæ in the same phase.

9. In radio signaling, a radiating system comprising a plurality of doublets arranged in vertical array, the amplitudes of the oscillations being related as the binomial coefficients for a number corresponding to double the number of doublets in the vertical array, the antennæ being spaced one-half wave length apart, means for controlling the phase of oscillations in the antennæ.

10. In radio signaling, a radiating system comprising a grounded antenna, which with its image in the earth constitutes a radiating doublet, a second radiating doublet placed at a different level from the first and adapted to co-operate with it to limit the radiation of power in a vertical direction.

11. In radio signaling, a radiating system comprising a vertical grounded primary radiator, a second vertical ungrounded primary radiator in a different horizontal plane from the first and co-operating therewith to limit the radiation of energy in a vertical direction.

12. In radio signaling, a radiating system comprising a vertical grounded radiator, and a plurality of ungrounded radiators, each placed in a different horizontal plane, the radiators being adapted to co-operate with each other to concentrate the radiation of power to a definite angle with the horizontal.

13. In radio signaling, a radiating system comprising a vertical grounded radiator, a plurality of ungrounded vertical radiators arranged above the first mentioned radiator and in different horizontal planes, means for controlling the amplitude and phase relationship of the oscillations so as to concentrate the radiation of power to a definite angle with the horizontal.

14. In radio signaling, the method of concentrating the radiation in one direction only, which consists in radiating power from a plurality of radiators in different horizontal planes.

15. In radio signaling, the method of concentrating the radiation in one direction only which consists in radiating power from a plurality of radiators in different horizontal planes with a definite phase relationship between the oscillations of the different radiators.

16. In radio signaling, the method of concentrating the radiation in one direction only which consists in radiating power from a plurality of radiators in different horizontal planes with a predetermined phase and amplitude relation between the oscillations in the several radiators.

17. In radio communication, the method of signaling which comprises radiating oscillatory power from a plurality of radiators in different horizontal planes, the spacing of these planes and phase relationship of the oscillations being so maintained as to concentrate the radiation of power in one direction only.

18. In radio communication, the method of signaling which comprises radiating power from a plurality of radiators in different horizontal planes, the spacing of these planes and the phase and amplitude relation of the oscillations being so maintained as to concentrate the radiation of power in one direction only.

19. In radio signaling, the method of obtaining concentration of energy which con-

sists in radiating power from a plurality of points arranged vertically above each other and so spacing these points and relating the phase and amplitudes of the oscillations therefrom that the power is radiated substantially in one direction only.

20. In radio signaling, an antenna array comprising a plurality of radiating systems arranged in linear array, each system comprising a plurality of separate vertically arranged primary radiators.

21. In radio signaling, an antenna array comprising a plurality of radiating systems arranged in linear array, each system comprising a plurality of separate vertically arranged primary radiators, the systems being so spaced as to give radiation in certain directions only.

22. In radio signaling, an antenna array comprising a plurality of radiating systems arranged in linear array, each system comprising a plurality of separate vertically arranged primary radiators, the spacing and phase relationship of the oscillations in the systems being such as to give radiation in certain directions only.

23. In radio signaling, an antenna array comprising a plurality of radiating systems arranged in linear array, each system comprising a plurality of vertically arranged radiators, the systems being spaced a half-wave length apart.

24. In radio signaling, an antenna array comprising a plurality of radiating systems arranged in linear array, each system comprising a plurality of vertically arranged radiators, the systems being spaced a half-wave length apart, and the oscillations being maintained in the same phase.

25. In radio signaling, an antenna array comprising a plurality of radiating systems arranged in linear array, each system comprising a plurality of separate vertically arranged primary radiators, the spacing of the systems and the phase and the amplitudes of the oscillations being such as to give a unidirectional radiation.

26. In radio signaling, an antenna array comprising a plurality of radiating systems arranged in linear array, each system comprising a plurality of vertically arranged radiators, the systems being spaced one-quarter wave length apart, and being maintained in quarter phase relationship with each other.

27. In radio signaling, a radiating system comprising a surface array of radiators arranged in the two horizontal coordinate directions, a second horizontal surface array of radiators placed in a second horizontal plane and adapted to cooperate with the first surface array to concentrate the radiation of power substantially in one direction only.

28. In radio signaling, a volume antenna array comprising a plurality of radiators arranged in three coordinate directions, a central station and conductive means therefrom to all of the antennæ of said array for the transfer of energy between said station and the said antennæ.

29. In radio signaling, a volume antenna array comprising a plurality of radiators arranged in three coordinate directions, the spacing of the radiators in the three coordinate directions being such as to give lateral and vertical directivity.

30. In radio signaling, a volume antenna array comprising a plurality of radiators arranged in three coordinate directions, the amplitude of the oscillations in the antennæ along any coordinate line being related as the binomial coefficients for a number equal to the number of radiators in that coordinate direction.

31. In radio signaling, an antenna array comprising a plurality of radiators arranged in at least two co-ordinate directions, one of which is vertical, the amplitude of the oscillations in the antennæ in each co-ordinate line being related as the binomial coefficients for a number equal to the number of radiators in that co-ordinate direction.

In testimony whereof, I have signed my name to this specification this 24th day of October, 1921.

JOHN STONE STONE.