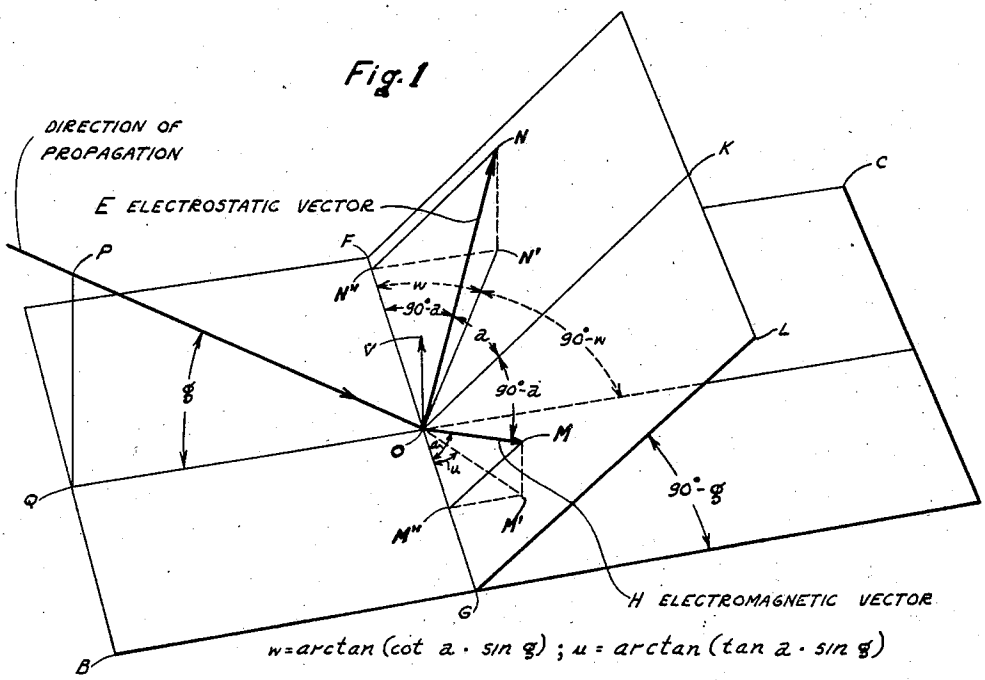
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DIRECTIONAL ANTENNA ARRAY

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Fig. 1



$w = \arctan(\cot a \cdot \sin g)$; $u = \arctan(\tan a \cdot \sin g)$

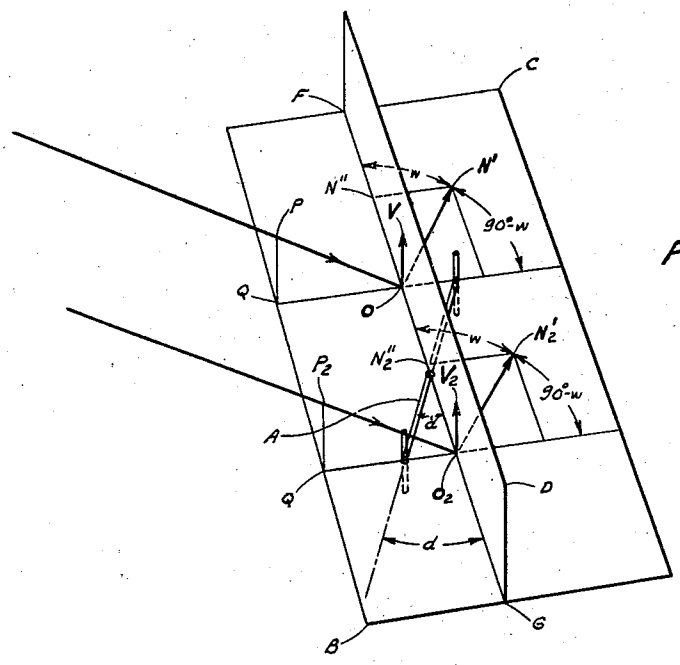


Fig. 2

INVENTOR.
HENRI G. BUSIGNIES
BY Paul R. Adams
ATTORNEY

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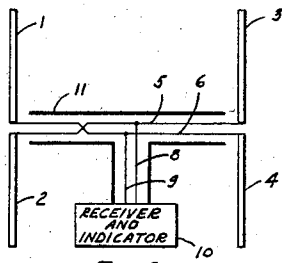


Fig. 3

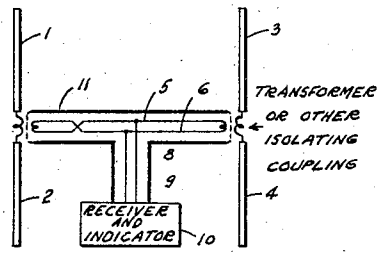


Fig. 6

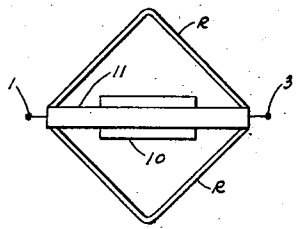


Fig. 4

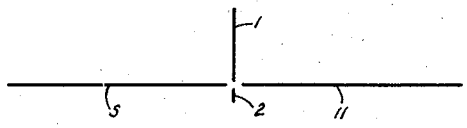


Fig. 7

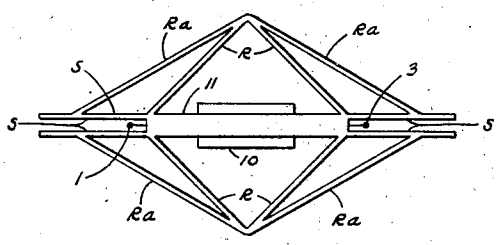


Fig. 5

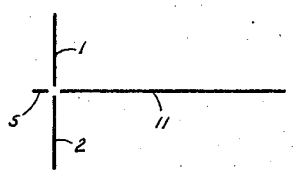


Fig. 8

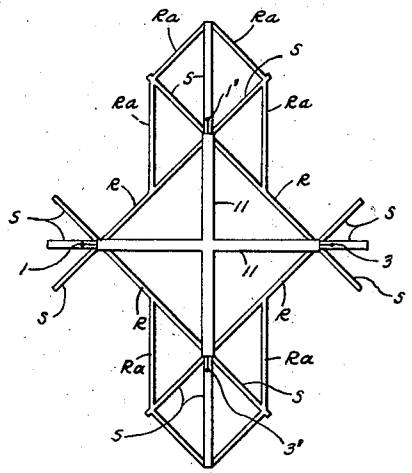


Fig. 9

INVENTOR.
HENRI G. BUSIGNIES
BY Paul R. Adams
ATTORNEY

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DIRECTIONAL ANTENNA ARRAY

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Fig. 10

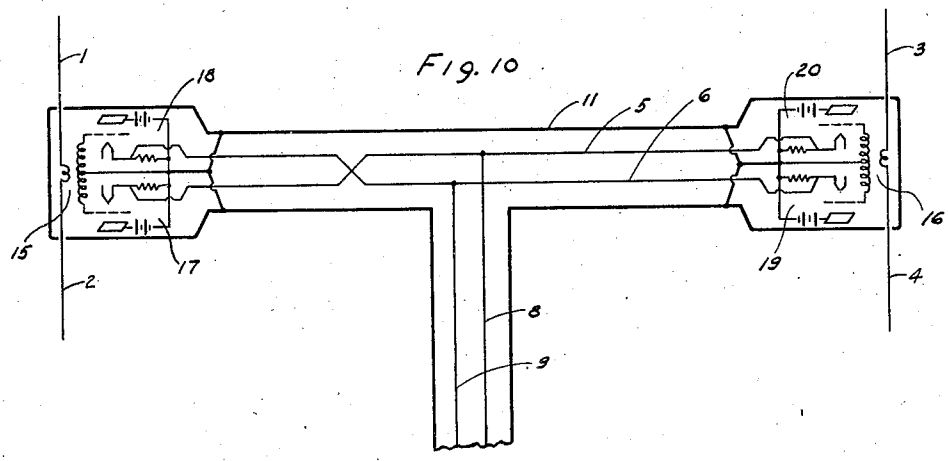


Fig. 11

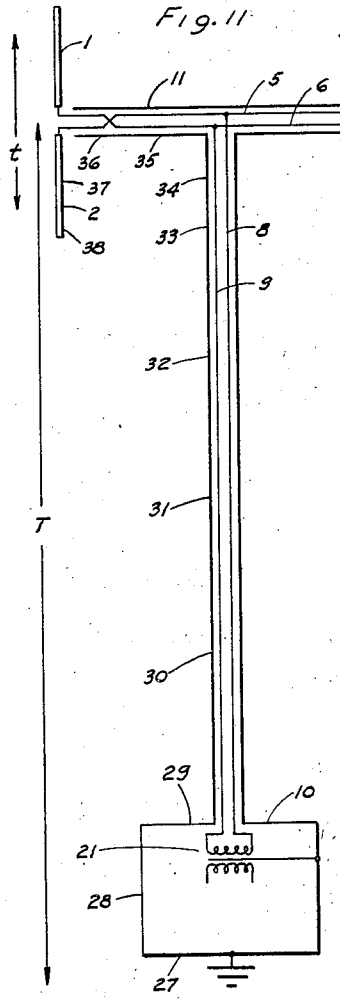


Fig. 14

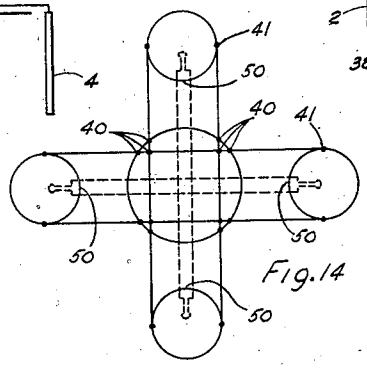


Fig. 12

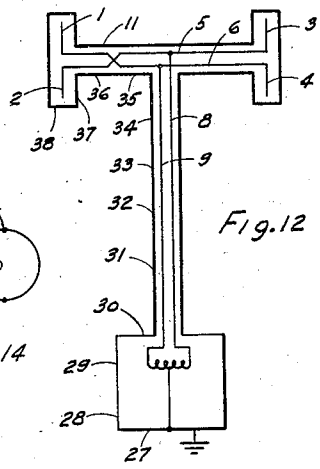
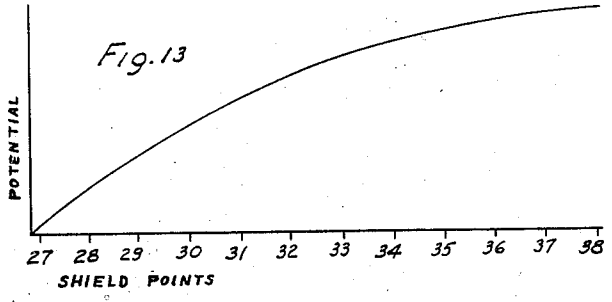


Fig. 13



INVENTOR.

HENRY G. BUSIGNIES

BY Paul R. Adams

ATTORNEY

Patented Apr. 29, 1947 2,419,672

UNITED STATES PATENT OFFICE

2,419,672

DIRECTIONAL ANTENNA ARRAY

Henri G. Busignies, Forest Hills, N. Y., assignor to Federal Telephone and Radio Corporation, a corporation of Delaware

Application March 12, 1942, Serial No. 434,427

10 Claims. (Cl. 250—11)

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The present invention relates to directional antenna arrays and more particularly to arrays comprising vertical dipoles for direction finders and the like.

It is an object of the present invention to provide an antenna array of the vertical dipole type for use in direction finders. It is a further object to provide such an array which shall be comparatively free from the influence of horizontally polarized wave energy.

It is also an object to provide such an antenna array which shall be comparatively free from so-called "high antenna" effect.

In general it is an object to provide a directional array comprising two vertical dipoles coupled to a two-conductor transmission line and associated with conductive means of such form that said array shall deliver to said line a transverse current (i. e., one which flows in one conductor and out the other conductor in balanced fashion) preferably proportional to the difference between the vertical polarized wave energy arriving at a given instant at each of the two dipoles and which shall be comparatively free from the production of parallel currents over the two conductors of such transmission line.

It is a further object of the invention to provide such an array which shall be suitable for any desired use and which shall be adapted for receiving or transmitting vertical polarizations to the exclusion of horizontally polarized energy and which shall be free from "high antenna" effect as a transmitting or receiving antenna.

It is a more particular object of my invention to improve the so-called H type Adcock antenna so as to render the same less responsive to horizontal polarizations and more nearly free from omni-directional reception due to "high antenna" effect than previously known arrays of this type.

The so-called H type Adcock antenna, as previously constructed, usually has two shielded transmission lines each having one transposition therein, said lines extending horizontally at right angles to one another across the center of the array, and four vertical dipoles connected to the four ends of such shielded transmission lines. The output for such antenna is taken from two downwardly extending shielded transmission lines respectively connected to the centers of the two horizontal lines. The two outputs are usually applied directly or through transformers, to stators of a so-called "goniometer" or crossed-stator vario-coupler. Alternatively, the H type Adcock may comprise only two dipoles and only one

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horizontal transmission line thus yielding only one output. In such case the complete array is rotatable if intended to be used for direction finding purposes.

Briefly, the improvement contemplated by my invention comprises adding cross-link conductors to more closely interconnect the two perpendicularly disposed horizontal transmission lines thus forming a sort of horizontal web, and preferably further providing conducting means extending beyond the ends of these horizontal transmission lines so that the conductive web thus formed extends out beyond the vertical dipoles.

The exact nature of my invention may best be understood from the following detailed description taken in conjunction with the attached drawings in which

Figs. 1 and 2 are three dimensional vector diagrams useful in explaining the invention;

Fig. 3 represents a simple H type Adcock array of prior art type;

Figs. 4 and 5 are plan views of simple H type Adcock arrays modified in accordance with different forms of my invention;

Fig. 6 represents an improved isolated-dipole type of H Adcock array in accordance with the prior art;

Figs. 7 and 8 are schematic diagrams useful in explaining the manner in which horizontally polarized energy could act upon the type of array shown in Fig. 6;

Fig. 9 is a plan view of a four-dipole array such as would be obtained by combining two of the simple arrays shown in Fig. 3, said array being modified in accordance with my invention to minimize sensitivity to horizontally polarized energy and "high antenna" effect;

Fig. 10 illustrates a preferred coupling arrangement to be used in the arrays of Figs. 4, 5 and 9;

Fig. 11 represents a prior art Adcock array similar to that in Fig. 3 but modified to more clearly illustrate the occurrence of the "high antenna" effect;

Fig. 12 represents an imaginary structure useful in explaining the action of my invention;

Fig. 13 represents the voltage distribution along the shields of the structures of Fig. 11 and Fig. 12;

Fig. 14 represents a conductive network which is of a somewhat different shape from that shown in Fig. 9.

In order to clearly understand the nature of my invention it is desirable to consider in detail the nature of the errors which occur with the H type Adcock antenna as hitherto constructed. In general, the errors observed in connection with

such H type Adcock antenna are produced by two causes: the reception of horizontally polarized energy and the omni-directional reception of vertically polarized energy in a non-differential manner by virtue of the so-called "high antenna" effect. Both such forms of reception would theoretically be cancelled if there were absolutely perfect balance between the two dipoles of a pair, the two halves of each dipole, both sides of each transmission line and the shield, and the two sides of the receiving apparatus, such as transformers, goniometer, stators, etc. As a practical matter, a very small degree of unbalance is unavoidable in respect to each of these supposedly symmetrical arrangements and, as a result of such unbalance, very substantial errors in the direction observed may take place.

It is an object of the present invention to reduce the magnitude of such errors for a given accuracy of balance of the several parts of the system.

For a better understanding of the manner in which such errors are reduced, in accordance with my invention, a detailed analysis of the production and reception of horizontally polarized energy, as well as an analysis of the "high antenna" effect, will be useful. Fig. 1 shows the manner in which horizontally polarized energy occurs in a wave which was originally transmitted with vertical polarization but which has been reflected from the Heaviside layer so as to arrive in a downward direction with a partially rotated direction of polarization. The line PO represents the direction of propagation of the arriving wave, this line being inclined at an angle g with respect to the horizontal. The line QO is the projection of PO on the horizontal or ground plane B—C. The vector $\overline{ON}$ represents the magnitude and direction of the electro-static vector E, $\overline{ON'}$ being the projection of this vector upon horizontal plane B—C and $\overline{ON''}$ being the projection of this vector upon the line FG which is normal to QO and is the line of intersection of the plane B—C and the plane F—L, which latter is normal to the direction PO at the point o.

In similar manner the vector $\overline{OM}$ represents the electro-magnetic vector H, its projection on the horizontal plane B—C being $\overline{OM'}$ and its projection on the line FG being $\overline{OM''}$. The vectors $\overline{ON}$ and $\overline{OM}$ lie in the plane F—L since both the electro-magnetic and electro-static vectors are perpendicular to the direction of propagation, as is well known. The line OK represents the trace which would be made in oblique plane F—L by passing a vertical plane through the point O so as to contain the lines QO and PO.

The angle a represents the angular deviation of the electro-static vector $\overline{ON}$ from the line OK. If this angle a were zero so that vector $\overline{ON}$ coincided with the line OK the polarization would be spoken of as vertical polarization, in spite of the fact that the vector $\overline{ON}$ would still not be perpendicular to the plane B—C. If the angle a is 45° the polarization of the wave is said to have 45-degree polarization, although again the inclination of the vector $\overline{ON}$ with respect to the horizontal (i. e., the angle NON') would be different from 45°.

As is clear from an inspection of Fig. 1 the electro-static vector $\overline{ON}$ may be resolved into two vectors $\overline{ON'}$ and $\overline{N'N}$, the first of these being the horizontal component of the electro-static force and the second being the vertical component thereof. The vertical component $\overline{N'N}$ has, for convenience, been redrawn as $\overline{OV}$ extending upward from the center of the diagram. The magnitude of the horizontal component $\overline{ON'}$ can be readily shown to be $E \cos^2 \cdot \sin^2 g + \sin^2 a$ while the magnitude of the vertical component $\overline{N'N}$ or $\overline{OV}$ can be shown to be $E \cos a \cdot \cos g$. The angle w of the horizontal component $\overline{ON'}$ with respect to the line FG is arc tan (cot $a \cdot \sin g$).

In similar fashion, for the magnetic vector H it can be shown that the horizontal component $\overline{OM'}$ is $H \sin^2 a \cdot \sin^2 g + \cos^2 a$, that the vertical component $\overline{M'M}$ is $H \sin a \cdot \cos g$, and that the angle u of $\overline{OM'}$ with respect to the line FG is arc tan (tan $a \cdot \sin g$).

Referring now more particularly to Fig. 2 which represents the manner in which the different components of the electro-static vector E affect an Adcock antenna, it will be noted that the ground plane B—C, the direction of propation PO, and the vertical and horizontal components $\overline{OV}$ and $\overline{ON'}$ of the electro-static vector are illustrated exactly as in the case of Fig. 1, the reference characters employed being the same to facilitate comparison. For clarity of illustration, however, the electro-magnetic vector H with its several components, as well as the inclined reference plane F—L have been omitted from Fig. 2 and a vertical plane F—D has instead been passed through the line FG so as to contain the vector $\overline{OV}$.

In addition, a second ray of the arriving electro-magnetic wave has been represented by the vectors $\overline{P_2O_2}$, $\overline{O_2N'_2}$ and $\overline{O_2V_2}$ which represent respectively the direction of propagation and the horizontal and vertical components of the electro-static vector at a second reference point O_2.

An H type Adcock array A is shown with its horizontal limb lying in the reference plane B—C and its dipoles extending half above and half below this plane. If such array were responsive solely to vertical polarized energy, which would be the ideal case, a null reading would be obtained with the array rotated so as to lie in the plane F—D. In practice, however, such an Adcock array is always slightly responsive to horizontal polarized radiation, and the array A may thus have to be rotated as shown so as to deviate by an angle d from the plane F—D. Under some conditions the phase with which the horizontally polarized energy arrives at the receiver of the array may be exactly opposite to the phase with which the vertically polarized energy arrives at such receiver (in spite of the fact that the vertically polarized energy is differentially received so as to give a maximum of signal at the time of maximum rate of change of the vertical electric vector rather than at the time of the maximum value of this vector). If this phase relationship exists, a sharp apparently perfect null will be obtained when the array A is rotated to a certain position inclined with respect to the plane F—D as shown.

The magnitude of the angle d (representing the deviation of the array from plane F—D at the time that the false null is obtained) depends upon the relative sensitivity of the array with respect to the vertically and horizontally polarized wave energy, as well as upon the ground angle g and polarization angle a of the wave. There are several factors which tend to make the angle d rather large even when the sensitivity of the array with respect to horizontally polarized energy

is only 2% or 3% of the sensitivtiy for vertically polarized energy:

In the first plane it may very well happen that the magnitude of the horizontal electro-static component $\overline{ON'}$ is substantially greater than the magnitude of the corresponding vertical component $\overline{OV}$. For the standard wave having a ground angle of 45° and a polarization angle of 45° the horizontal component exceeds the vertical component by more than 73%. Thus, for 10 micro-volts per meter of vertical intensity there would be 17.3 micro-volts per meter of horizontal intensity in a standard wave.

In the second place, the Adcock is designed to receive vertically polarized energy in a differential fashion; and thus, if the wavelength is long as compared to the separation between the two dipoles, it may very well happen that the maximum difference between the voltages intercepted on the two dipoles may be less than the maximum voltage intercepted by either one. Thus, with dipoles one meter high and one meter apart and a wavelength of say eight meters, if the vertical field strength be assumed to be ten micro-volts per meter, the maximum voltage intercepted by each dipole will be ten micro-volts. The maximum difference in the voltages intercepted by the two dipoles, however, even when the array is turned in the direction for maximum reception (i. e., perpendicular to the plane F—D) would be only 7.7 micro-volts.

In the third place, since the Adcock is used in a null manner for determining directions, no useful signal resulting from the vertically polarized wave will be received when the Adcock is in truly correct position. Even when the Adcock is turned as much as 5° from its truly correct position (i. e. when angle *d* of Fig. 2 is 5°), the useful reception of vertically polarized energy is only 8.7% of the maximum possible reception (i. e. 8.7% of 7.7 micro-volts in the example above assumed).

Thus, if the three effects are considered together, a standard wave of 8-meters wavelength acting upon an Adcock which has two 1-meter vertical dipoles joined by a 1-meter horizontal transmission line could produce in the horizontal transmission line 25.8 times as much voltage as could be usefully produced as the difference between two vertical voltages intercepted by the dipoles when the array is 5° from plane F—D. This means that even if the shielding and degree of balance of the system is so great that only 4% of the energy intercepted by the horizontal transmission line is received in the associated receiving equipment, an error of more than 5° may occur if the phases of the horizontal energy transmitted to the receiver and the vertical energy transmitted thereto are such as to oppose one another. It is therefore clear that an Adcock to give reasonably accurate indications should be designed to be insensitive to horizontal radiations to the highest possible degree.

The manner in which such reduction in sensitivity to horizontally polarized radiation is attained in accordance with the present invention can best be seen from Figs. 3, 4, 5, 6 and 7.

Fig. 3 represents the simplest form of Adcock array wherein the vertical dipoles 1—2 and 3—4 are directly galvanically connected to the horizontal transmission line 5—6 which is, in turn, connected over the vertical line 8—9 to the receiver and indicator 10. If the arms 1 and 4 are one meter apart horizontally, the difference

in potential between these arms in the presence of a horizontal component of 17.3 micro-volts per meter would naturally be 17.3 micro-volts. The presence of the shield 11, however, somewhat reduces the magnitude of the potential difference since this shield is an excellent conductor disposed horizontally in the immediate vicinity of the dipoles and thus acts to attenuate the horizontal electric component in its immediate vicinity. If the shield 11 could be considered to be at all times an equi-potential surface, the attenuation of the horizontal electric component immediately adjacent this shield would be complete. In practice shield 11, although it may have negligible resistance, ordinarily has a very substantial inductance and thus is far from being an equi-potential surface.

In accordance with one feature of my invention shield 11 is rendered of far lower impedance, and therefore more nearly an equi-potential surface, by providing between its ends additional conductor means R, as shown in Fig. 4, which is a plan of a simple Adcock such as shown in Fig. 3 with added conductors according to my invention. These conductor means R, together with the shield 11 itself, form a flat network or web of conductors which therefore has a comparatively low inductive impedance and thus more nearly approaches an equi-potential surface. By this means the strength of the horizontal electric component in the vicinity of the Adcock array is diminished, thus greatly diminishing the flow of parallel currents over the two wires 5 and 6 of the horizontal transmission line.

In accordance with a further feature of my invention illustrated in Fig. 5, conductor means S are also extended outward from the shield 11 in a horizontal direction so as to extend well outside of the dipoles, and preferably also additional conductive means such as R_a are extended to meet these extensions S so as to reduce the inductance of the latter. By these arrangements the horizontal electric component between the dipoles and in the vicinity thereof is very greatly attenuated. Such attenuation of the horizontal electric component may be considered as resulting from a reflection (with reversal of electrostatic phase) of the horizontally polarized component arriving at the network 11, R, R_a, S. Such reflection decreases the horizontal electric component to zero in the immediate vicinity of the flat conducting network which produces the reflection.

It may be noted that the conducting arrangements applied, as shown in Figs. 4 and 5, are essentially confined to a horizontal plane and therefore produce substantially no effect upon the vertically polarized energy arriving in the vicinity of the Adcock array. At the same time these arrangements very substantially reduce the amount of pickup of horizontally polarized energy and thus greatly reduce the flow of parallel currents through the two wires 5, 6 of the horizontal transmission line. Thus for a given degree of unbalance the amount of transverse current delivered to transmission line 8—9 is greatly reduced.

In the foregoing discussion it has been assumed that the Adcock array was of the simplest type wherein the dipoles are directly galvanically joined to the horizontal transmission line. A much better form of Adcock is the type wherein the dipoles are galvanically and capacitatively separated from the horizontal transmission line, the energy therefrom being transmitted to this transmission line by means of isolating trans-

formers or other coupling arrangements. The preferred type of coupling arrangement for such an Adcock is illustrated in Fig. 10, the coupling being here effected not only through transformers 15, 16 but also through two pairs of coupling triodes 17—18 and 19—20, which are connected with their load resistors on the cathode side so as to produce a large amount of negative feedback. Preferably, these tubes have a high inherent voltage amplification factor but because of the negative feedback the effective voltage gain thereof is smaller than unity (e. g. about .4 to .7 for a mutual conductance of 5000 to 9000 micromhos) and is very nearly independent of variation in supply voltages, tube characteristics, etc.

The schematic representation of Fig. 6 which shows the dipoles 1—2 and 3—4 coupled to the line 5,6 should be understood to represent either a transformer coupling or a transformer and vacuum tube coupling such as shown in Fig. 10, or any other type of isolating coupling, although a plain transformer coupling is illustrated to simplify the drawing of this figure.

Comparing Fig. 6 with Fig. 3 it will be noted that the parallel currents in wires 5, 6 resulting from the horizontal electric component will be eliminated, except to the extent that distributed capacity through the transformer or other coupling means permits a current flow from dipole 1—2 to the wires 5, 6 and thence out to the dipole 3—4. In spite of the substantial suppression of the parallel currents due to horizontally polarized electric energy however, some reception of such horizontally polarized energy may still occur if the halves of one of the dipoles, such as 1—2, are unbalanced. Let us assume, for example, that the limb 1 is somewhat longer than the limb 2. At first sight it might appear that in spite of such unbalance no horizontally polarized energy could influence either of these limbs. If consideration is given to the presence of shield 11 which constitutes essentially a horizontal conductor, it will be noted that such shield 11 will receive the horizontally polarized energy and re-radiate this in a form having some vertical components so as to enable this energy to influence both of the limbs 1 and 2. From another viewpoint the transfer of energy from the horizontal electric component of the arriving wave to the limbs 1 and 2 of the dipole may be analyzed as follows.

The arriving horizontal electric energy excites shield 11 so that the latter develops standing voltage waves along its length, the voltage being maximum positive at the left end of shield 11 at the instant when it is maximum negative at the right end and zero in the center. The electrostatic coupling between shield 11 and limb 1 is such that the inherent capacity of the upper end of limb 1 is fairly equally distributed over the left and center portions of shield 11 while the electro-static capacity of the lower part of limb 1 extends in much larger proportion to the extreme left end of shield 11 than to the more remote parts of this shield. Accordingly, the voltage variations along shield 11 are transmitted in different degree to different parts of limb 1. It is true that equal and opposite voltage values would be transmitted to limb 2 if the latter were perfectly balanced with respect to limb 1, and thus if the two limbs 1 and 2 are exactly alike the only net effect would be a small current flowing simultaneously in both limbs 1 and 2 and out through the distributed capacity of the coupling transformer to the shield 11. If the coupling transformer itself were also perfectly balanced, such current would have no effect upon transmission line 5, 6 or upon the receiver 10.

In practice it is very likely to occur either that the dipoles 1 or 2 are unequal with respect to electro-static capacity with regard to shield 11 thus giving a current flow from one limb to the other or that the coupling transformer will be slightly asymmetric so that the previously mentioned flow of current from the limbs in parallel through the transformer's distributed capacity to the shield 11 will set up a slight current in the secondary of this transformer. As previously mentioned, in connection with the analysis of Figs. 1 and 2, even a 4% unbalance would lead to an error of more than 5°.

Furthermore, it should be noted that even if the distributed capacities of the coupling transformer could be perfectly balanced and the sizes and shapes of the two limbs 1 and 2 made identical, some asymmetry is likely to occur by reason of proximity to the ground or other objects, or even by reason of the proximity of the shielded down lead 8, 9. It will thus be clear that even with the improved type of Adcock shown in Fig. 6 wherein the dipoles are isolated from the horizontal transmission line 5, 6, it is a difficult matter to attain by balancing alone a satisfactory degree of freedom from response to horizontally polarized energy. In accordance with the present invention a very great improvement in this respect can be effected by providing additional conductive members R as shown in Fig. 4.

As previously described the effect of such additional members is to form with the horizontal shield 11 a flat conducting network whose overall inductance is exceedingly low. The whole network thus formed tends more nearly to approach the characteristics of an equi-potential surface, and the voltage differences between the different portions of the shield 11 are very greatly reduced. By such reduction of these voltage differences the pickup of energy by the limbs 1 and 2 is very nearly eliminated. If the pickup is considered from the standpoint of re-radiation it will be clear that the resultant of the arriving wave and the re-radiated wave will be almost zero in the vicinity of an equi-potential surface and therefore the pickup by dipoles 1 and 2 will be substantially negligible. If, on the other hand, the pickup of energy by these limbs is analyzed as being produced by the diverse coupling of different portions of the limbs to different portions of shield 11 through the distributed capacities thereof, it will still be seen that a reduction in the voltage differences between the different parts of shield 11 will largely eliminate such pickup.

The arrangement of Fig. 5 wherein the members S are extended beyond the dipoles 1 and 3 will also be found advantageous with the isolated type of dipole illustrated in Fig. 6, although at first sight the advantage of such an arrangement may not be apparent.

Fig. 7 will be helpful in illustrating how the addition of extensions S still further reduce pickup of horizontally polarized energy by the limbs 1 and 2. In Fig. 7 shield 11 and the extensions S are shown as being of equal length, and the limbs 1 and 2 of the dipole are shown as being of exceedingly unequal length. Such an exaggerated showing is merely made to render the theory more clear. Referring to Fig. 7 it should be noted that, even if the limb 2 were completely removed, no energy could be induced in the limb 1 in response to the pickup of horizontal electric

energy by the shield 11 and extensions S, if the latter are perfectly symmetrical about the limb 1; the reason for this is that the right end of shield 11 would become negative at the same time that the left end of extension S became positive, and the effects thereof upon the limb 1 would mutually cancel.

On the other hand, as previously pointed out and as schematically illustrated in Fig. 8, the pickup by the limbs 1 and 2 would be equal and would thus tend to cancel if these two limbs were identical (and coupled through a perfectly balanced coupling transformer), even though the extension S was made negligibly small in comparison to the shield 11. By providing an extension S which extends out beyond the vertical dipole a substantial distance (desirably at least one-third the length of one of the dipole limbs and preferably twice this much) the amount of voltage picked up by each limb of the dipole due to horizontally polarized energy is reduced very substantially. At the same time, the balancing effect due to the two dipoles is maintained. Thus, both the balancing effects of Fig. 7 and Fig. 8 are present to some degree and thereby the amount of pickup of horizontally polarized energy is reduced to a negligibly small value.

The foregoing descriptions have been based upon the assumption that the Adcock array, whether of the simple type shown in Fig. 3 or of the isolated-dipole type shown in Fig. 6, consisted of a single H rotatably mounted. In other words, it has been assumed that the Adcock array comprised only two dipoles and one horizontally disposed interconnecting transmission line, the whole array being arranged to be rotated for determination of the nulled direction. While such an arrangement may well be used for very short wavelengths, it is preferable in very many cases to employ a double Adcock array consisting of two such H's mounted at right angles to each other and coupled to a goniometer so that by rotating the goniometer the effect of rotating a single H array may be attained without actually physically moving any part of the antenna array.

In accordance with the preferred form of my invention such a crossed H Adcock array is employed, and the horizontal conductive web is formed by joining together the two shields 11 and 11' of the two H type antenna structures, and by arranging additional conductors R so as to interconnect these crossed shields 11 and 11'', as shown in Fig. 9. In such a form extensions S may conveniently be formed as the extensions of conductors R and of the shields 11 and 11', respectively. If desired, the ends of these extensions S may be interconnected with each other and with the links R by means of additional links R_a so as to minimize the inductance of such extensions. Such an arrangement is shown in the upper and lower corners of Fig. 9. Alternatively, the extensions S may be open-ended as shown at the other two corners of Fig. 9. Preferably, all four corners of one array are treated in the same fashion so that all four corners have the extensions S open-ended or alternatively all four corners are provided with cross links R_a.

In place of the network formed by extensions S and cross links R_a around each dipole, a solid sheet of material may be used around each dipole. Preferably, however, the main conductive network incorporating the two transmission lines 11, 11' and covering the area bounded by the four dipoles, is made in the form of a network of

closed meshes rather than a solid conducting sheet. The meshes of the network taken together should enclose a large area. A solid sheet which provided closed conducting paths enclosing an equal area would be unnecessarily heavy and would offer an unnecessarily large wind resistance.

It is a further object of my invention to minimize also the omni-directional sensitivity with respect to vertically polarized energy which occurs by reason of the so-called "high antenna" effect. The nature of this effect can best be understood by reference to Fig. 11 which again represents a simple directly connected H type Adcock similar to that shown in Fig. 3. In order to more clearly point out the nature of the "high antenna" effect this array is shown as having a height T several times greater than the height *t* of its individual dipoles 1—2 and 3—4. Furthermore, for definiteness in discussion a portion of the receiving and indicating equipment 10 has been shown in detail, this portion comprising a shielded input transformer 21.

As clearly shown in Fig. 11, the mean height T of the antenna array as a whole is several times greater than the effective difference in height *t* of the two limbs of one dipole. Accordingly, the variations of potential of a complete dipole 1—2 with respect to ground are far greater than the differences in potential of the two sides of such a dipole, thus resulting in large parallel currents which flow into all limbs of all dipoles co-phasally and then flow co-phasally down over the two wires 8 and 9 of the vertical transmission line, thence by distributed capacity from the primary of transformer 21 to the shield thereof and then to ground. If the transformer 21 is perfectly balanced, such currents will produce no effect in the secondary of this transformer but, as previously mentioned, a perfect balance is not readily attainable in practice. In most actual direction finding systems therefore a very substantial amount of energy is received from the vertical electric component of an arriving wave even when the antenna array is in such position that a null should be received. It has already been proposed to minimize this "high antenna" effect by isolating the dipoles of the Adcock array with transformers or other isolating means as schematically shown in Fig. 6. Since all transformers have some distributed capacity however, any unbalance in such isolated transformers, or in the dipoles themselves, will produce circulating currents. It is therefore desirous to minimize, as far as possible, the amount of pickup due to the "high antenna" effect. In order to better understand how this may be effected in accordance with my invention it will be useful to consider the schematic diagrams of Figs. 12 and 13.

Fig. 12 schematically represents a galvanically connected type H Adcock whose shield 11 has been modified so as to completely surround both dipoles of the array. Neglecting the obvious fact that such an arrangement would eliminate the useful reception, it will be apparent that no parallel currents will be produced in wires 8, 9 as a result of the difference in potential between ground and the limbs of any of the dipoles. This freedom from parallel currents in 8, 9 will still be observed even though the inductance of shield 11 prevents it from all being continuously at ground potential, provided only that the resistance of this shield 11 is negligible, which is usually the case.

As a result of the inductance of the shield it would actually be found, in the case of the apparatus of Fig. 12, that the potential at different points 27 through 38 of the shield 11 would vary in the manner indicated by the curve in Fig. 13. Nevertheless, if the conductivity of the shield were adequate practically no current would flow in any of the wires enclosed by such shield. The explanation of this is somewhat as follows: When the end portion of the shield 11 rises to the high potential represented in Fig. 13 as between points 27 and 38, the whole dipole 1—2 which is enclosed within this portion of the shield rises to substantially the same potential without the need for the addition of any electrical charge to bring it to this potential. The reason for this is that the dipole 1—2 has substantially zero distributed capacity with respect to earth since practically all of its distributed capacity closes upon the surface of the shield near points 27—38. Therefore, when these parts of the shield have a potential of say, 10 millivolts, the potential of the enclosed dipole 1—2 would inherently be about 10 millivolts even if this dipole were wholly insulated and even if the wires 5, 6 were eliminated to prevent any flow of current into or out of the dipole.

In the arrangement of Fig. 11, however, the dipole 1—2 has a very substantial distributed capacity to ground and, in addition, has a great deal of further distributed capacity which closes upon points of the shield 11, such as points 35, 34 remote from the dipole. Therefore, in order to bring this dipole 1—2 of Fig. 11 to a potential of say 10 millivolts, a substantial current is required even if the adjacent portion 36 of the shield 11 has already been brought to a potential of 10 millivolts. This substantial current is necessary to charge to 10 millivolts potential these portions of the dipoles distributed capacity which close upon the ground or upon such points as 35, 34, 33, etc. No current is needed to charge those portions of the distributed capacity which close upon portion 36 of the shield, for this portion 36 of the shield is at the desired potential of 10 millivolts.

Although it is not desirable to enclose the dipoles in the manner shown in Fig. 12 since this would eliminate all useful reception, an effect somewhat similar in nature can be obtained by the provision of a network of the type shown in Fig. 5 or Fig. 9 which extends over a substantial horizontal area around each dipole. When such network is provided it will be found that a very large portion of the natural capacity of a dipole limb, such as limb 1, will close upon the network thus formed. The result will be that there will be a substantially smaller distributed capacity between the limb 1 and ground (or between the limb 1 and some lower voltage part of the shield such as point 34 or 33). Even if the dipoles are galvanically connected to the transmission lines as shown in Fig. 11, the magnitude of the "high antenna" effect will be substantially reduced and the parallel currents flowing in the transmission lines 8 and 9 will be considerably smaller than if the conductive network had not been provided.

The amount of reduction of the "high antenna" effect which is obtainable by provision of a conductive low impedance network in the horizontal plane is ordinarily not sufficient and therefore I prefer that in addition to this measure some means be provided for isolating the dipoles 1—2 and 3—4 from the horizontal transmission line 5—6. Such isolation may be effected by a plain coupling transformer or by a coupling transformer with grounded shielding between its windings, or preferably by a combination of a coupling transformer and triode coupling means as shown in Fig. 10. Even when some such arrangements for isolating the dipoles from the horizontal transmission line are provided, the provision of a horizontal planar conductive network, such as illustrated in Figs. 5 and 9, will still be found advantageous for reducing the "high antenna" effect, as well as for reducing the responsiveness to the horizontally polarized energy.

It will be understood that any flat conductive structure having closed conductive loops which surround a reasonably large area can be used. A solid sheet would give the required electrical effect although I prefer a network of closed meshes such as shown in Figs. 4, 5 and 9 because of its reduced weight and wind resistance. The invention is particularly advantageous when applied to a crossed H Adcock (having four dipoles and two horizontal lines). When so applied the two tubular shields of the two horizontal transmission lines are preferably incorporated as part of the network as shown in Fig. 9.

Alternatively, however, a network may be constructed as a unit and then applied to an Adcock. Such a network could be made up of five circles and four rods as shown in Fig. 14, being welded at all the intersection points such as 40, and at all tangent points such as 41. The relative size and position of the Adcock for which the network is designed is shown dotted in Fig. 14. Preferably the network should be electrically connected to the crossed horizontal shields of the Adcock at points 50, if not at all points where it crosses them. The network as shown in Fig. 14 encloses an area somewhat smaller than the area of the square marked by the dipoles of the corresponding Adcock. It would be better if a rod were connected between the points 41, other rods being similarly connected between other corresponding points to make the area enclosed by the network larger than the area of the square marked by the dipoles. Very useful effects can be observed with networks which enclose only one-fifth the area of said square.

Although I have described my invention in particular in connection with applications wherein horizontally polarized components of the electrostatic vector E are undesirable, it is clear that the principles thereof are equally applicable where, say, vertical polarization is undesirable. In such cases, it is of course clear that the above discussion is applicable when considered in a quadrature sense, that is, with the dipoles disposed horizontally and the shielding structure normal thereto.

Even though I have shown and described certain embodiments of my invention for purposes of illustration it should be understood that modifications, adaptations and alterations thereof occurring to one skilled in the art may be made without departing from the scope of my invention as defined in the appended claims.

What I claim is:

1. A directive antenna array including dipole antenna means oriented in a given longitudinal sense, and conductive shield means lying in a plane substantially normal to said dipole means having one part surrounding a transmission line and a second part defining a two-dimensional structure extending laterally from said first part intermediate the ends thereof.

2. A directive antenna array includng two dipoles interconnected by a transmission line and

disposed parallel to each other, shield means shielding said line, and means connected to said shield means and forming therewith a two-dimensionally extensive conductive structure lying substantially in a plane normal to said dipoles and including closed conductive meshes of substantial area.

3. A directive antenna array comprising two generally vertical dipoles interconnected by a generally horizontal transmission line, shield means shielding said line, and means forming a two-dimensionally extensive conductive structure lying substantially in a plane normal to said dipoles and including closed conductive meshes of substantial area.

4. A directive antenna array comprising two generally vertical dipoles interconnected by a generally horizontal transmission line, shield means shielding said line, and means connected to said shield means and forming therewith a two-dimensionally extensive conductive structure lying substantially in a plane normal to said dipoles and including closed conductive meshes of substantial area.

5. An array according to claim 3, further comprising additional conductive means connected to said conductive structure and extending out beyond each of said dipoles.

6. An array according to claim 3, further comprising additional conductive means connected to said conductive structure and forming closed conductive meshes of substantial area.

7. An array according to claim 3, further comprising isolating coupling means coupling said dipoles to said transmission line in respect of

transverse currents while providing substantial isolation thereof in respect of parallel currents.

8. A directive antenna array comprising four generally vertical dipoles interconnected by two generally horizontal transmission lines, shield means shielding said lines, and means interconnecting said shield means and forming therewith a two-dimensionally extensive conductive structure lying substantially in a plane normal to said dipoles and including closed conductive meshes of substantial area.

9. A crossed H type Adcock array comprising four generally vertical, spaced dipoles and two generally horizontal lines interconnecting said dipoles, elongated shields for said lines, and conductive links interconnecting the successively adjacent ends of said shields.

10. A directive antenna array including dipole antenna means oriented in a given longitudinal sense, and shield means lying in a plane substantially normal to said dipole means and comprising a two-dimensionally extensive conductive structure wherein said structure includes closed conductive meshes of substantial area.

HENRI G. BUSIGNIES.

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