April 2, 1940. A. ALFORD 2,195,880

DIRECTIONAL ANTENNA ARRAY

Filed April 30, 1937 2 Sheets-Sheet 1

FIG.1.

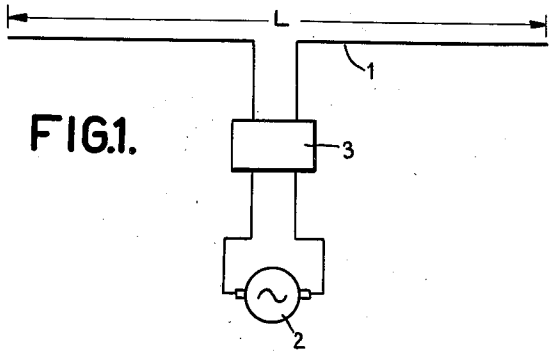


FIG.2.

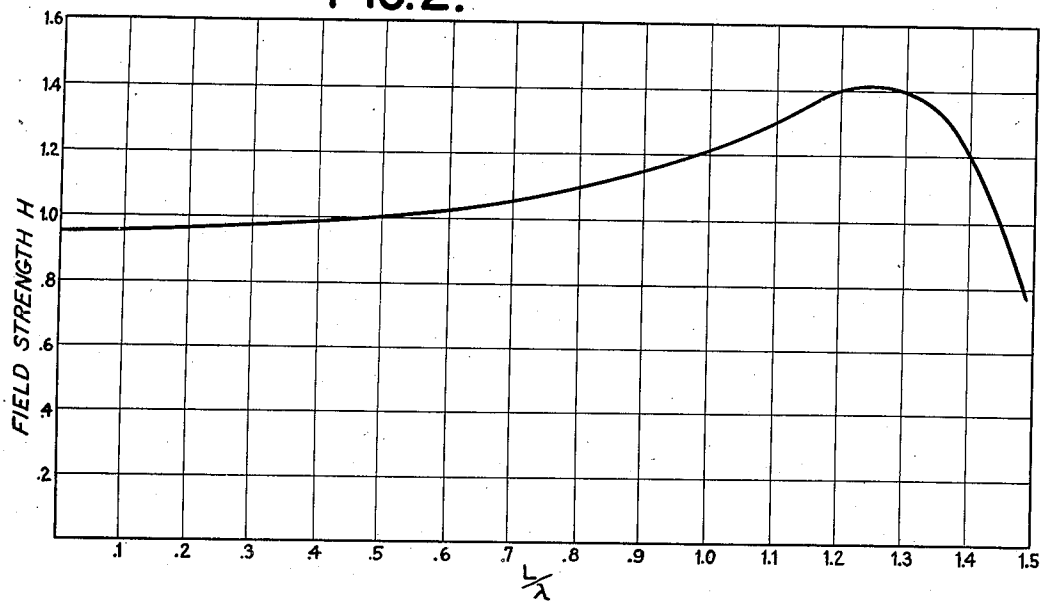
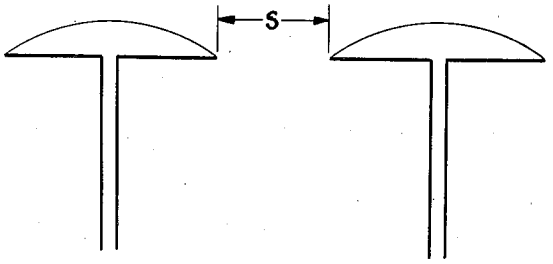


FIG.3.



INVENTOR
ANDREW ALFORD

BY E. O'Rinney

ATTORNEY

April 2, 1940. A. ALFORD 2,195,880

DIRECTIONAL ANTENNA ARRAY

Filed April 30, 1937 2 Sheets-Sheet 2

FIG.4.

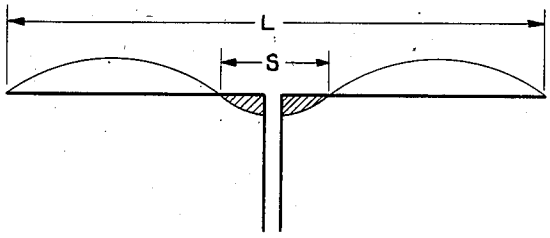


FIG.5.

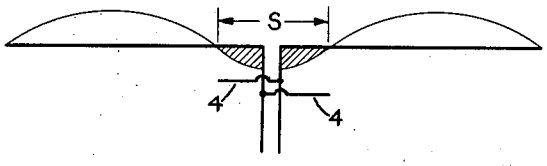


FIG.6.

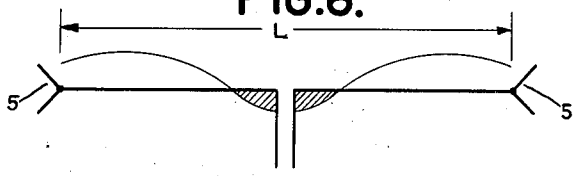


FIG.7.

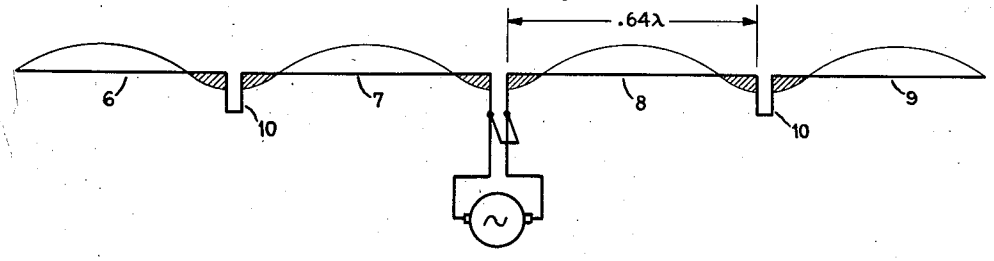
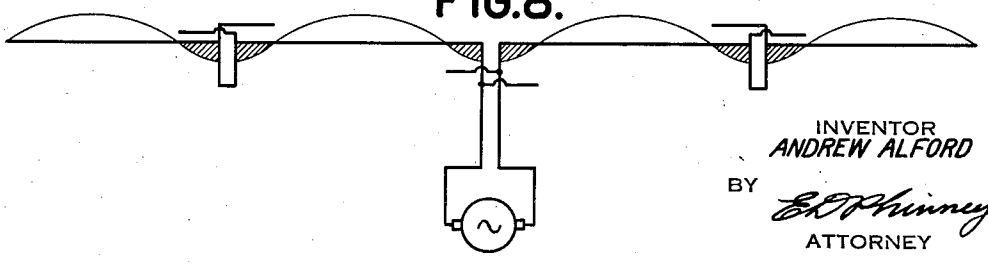


FIG.8.



INVENTOR
ANDREW ALFORD
BY
E. D. Rhinney
ATTORNEY

Patented Apr. 2, 1940

2,195,880

UNITED STATES PATENT OFFICE

2,195,880

DIRECTIONAL ANTENNA ARRAY

Andrew Alford, New York, N. Y., assignor to Mackay Radio and Telegraph Company, New York, N. Y., a corporation of Delaware

Application April 30, 1937, Serial No. 140,039

4 Claims. (Cl. 250—11)

This invention relates to directional antenna arrays and pertains more particularly to antenna arrays utilizing a parasitic reflector and adapted for the transmission of a plurality of different frequencies at the same time.

It is an object of my invention to provide an antenna array whch is simple in construction and still is adapted for the transmission of a plurality of different frequencies either simultaneously or separately.

Heretofore it has been customary to use the so-called dipole or half-wave antenna for the transmission of only a single frequency. In fact the very name of the antenna itself, expresses the thought that it is to be used for a single frequency only. But such antennae are, in truth, not extremely sharp in their transmitting qualities being, on the other hand, relatively aperiodic and adapted for the transmission of a fairly wide band of frequencies. The only difference between an antenna when it is operated as a true half-wave or dipole antenna and when it is energized with a frequency different from a half-wave value lies in the impedance which the antenna presents to the transmission line. In the case where the radiated frequency is such that half-wave operation results, the impedance presented by the antenna to the transmission line is resistive whereas if a different frequency is transmitted the impedance will contain a capacitative or inductive component. But if proper provision is made for the matching of the antenna to the transmission line over the range of frequencies which it is desired to transmit, it will be found that the so-called half-wave type antenna, consisting of two equal halves fed at the center by means of a two-wire transmission line, may be operated in an efficient manner over at least a two to one range of frequencies.

Just as directional arrays may be constructed of a number of half-wave elements, so can they also be constructed of similar elements of other than a half-wave length. For the sake of simplicity such antennae as last mentioned will be called pseudo half-wave antennae or pseudo half-wave elements. A number of pseudo half-wave elements may be arranged in line and be fed in phase so as to produce a highly concentrated but a bi-directional radiation pattern. Unlike the ordinarily accepted half-wave devices of the prior art, such an array is adapted for the transmission of two or three or more preselected frequencies. Generally speaking, an array of this kind would have a maximum gain at that frequency at which the length of the individual pseudo half-wave element would be in the neighborhood of 1.2 wavelengths and would be somewhat less at all other frequencies. The decrease in gain with a change in frequency starting from the frequency of maximum gain is rather slight.

The main advantage of this multi-frequency array is relatively high gain per unit space, while a disadvantage is the fact that the array is bi-directional. This latter disadvantage is particularly serious when a directional array is to be used at the higher frequencies and for communication over relatively long distances. The bi-directional character of the radiation frequently results in the so-called echo difficulties.

The above mentioned and further objects and advantages of my invention and the manner of attaining them, will be more fully explained in the following description taken in conjunction with the accompanying drawings.

Fig. 1 is a diagrammatic view of an antenna system embodying my invention.

Fig. 2 is a curve illustrating the field strength of an antenna according to my invention.

Fig. 3 is a diagrammatic view of an antenna system, used to explain my invention.

Figs. 4, 5, 6, 7 and 8 are further illustrations of antennae according to my invention.

Fig. 1 shows a pseudo half-wave antenna 1 fed with a source of unit power 2. The antenna impedance is assumed to be matched at a given frequency by the matching device 3 to the surge impedance of the transmission line and the impedance of the source of unit power 2 is assumed to be the same at all frequencies. When the arrangement in Fig. 1 is operated at a number of different frequencies it will be assumed unless otherwise stated, that the matching device 3 is such that the antenna impedance remains matched to the transmission line at each frequency. Under the assumed conditions the pseudo half-wave will radiate, if the resistance of the wires is neglected, a unit of power at each frequency.

Then, if an antenna of length L were in space so that the effects of ground reflection could be neglected, the field produced by the antenna at a distant point located in the plane bisecting the antenna at right angles would vary with frequency in the manner shown in Fig. 2. In this figure the abscissa L/λ is the overall length of the antenna in terms of wavelength and is thus proportional to frequency. The ordinate is proportional to the field strength at the distant point.

Fig. 2 clearly shows that the pseudo half-wave antenna is per se capable of producing comparable field strength at the distant point over a wide range of frequencies.

When the ohmic resistance of the conductors is considered this range of frequencies over which the antenna can function successfully is somewhat reduced. Indeed when L/λ is less than .5 the radiation resistance on a current loop basis falls rather rapidly as L/λ is decreased, with the result that the currents produced by the unit power in the section of transmission line between the antenna and the matching device 3 is increased. The current in the matching device 3 also increases. Thus for a given power delivered to the antenna the I^2R losses increase as L/λ decreases so that for very small values of L/λ the field produced at the distant point falls off and approaches zero. With the usual type of construction this decrease in radiation efficiency does not take place immediately upon a decrease of L/λ below .5, but takes place gradually and may be considered to be relatively small when L/λ is more than .25.

Thus in actual practice a pseudo half-wave antenna may be considered to be an efficient radiator from L/λ of say .3 up to $L/\lambda=1.45$ or almost a 5:1 frequency range. Over a two to one frequency range from .7 to 1.4 it is always more efficient than a half-wave.

When the antenna has been installed at a certain height above ground the effective range of frequencies which may be used for communicating with a given point may be still further reduced under certain circumstances because the maximum of radiation may take place at the desired angle to the horizon at one frequency and at some other undesired and ineffective angle at a second frequency. When the two frequencies are used for communication with two different points which are approximately on the same great circle this may or may not be true. This situation is common to all kinds of antennae operated at more than one frequency and is not a peculiarity of the pseudo half-wave antennae or pseudo half-wave arrays, and it need not be discussed here in detail.

The pseudo half-wave antennae which have lengths between .8λ and 1.40λ are particularly useful as elements in arrays because they result in greater signal strength at the distant point per feeder.

In order that the action of these pseudo half-wave antennae in arrays may be more clearly understood the following elementary explanation of the action of such an antenna with $L\lambda>1.0$ is offered.

It is well known that the field produced at the distant point by an array consisting of two half-wave antennae which are fed individually and placed end-on as shown in Fig. 3 depends on the distance S between the half-wave elements. For small values of S the mutual impedance between the elements tends to reduce the currents produced in the half-wave elements by a unit of power and thus decreases the field at the distant point. For small values of S the field at a distant point increases as S is increased.

A pseudo half-wave antenna such as shown in Fig. 4 has a current distribution which is very similar to that of two separate half-wave antennae shown in Fig. 3. The only difference between the two current distributions is the additional current in opposite phase indicated by the shaded area in Fig. 4. When distance S is relatively small the current in the shaded areas is also small and the field produced by this current at the distant point is likewise quite small. This field, however, tends to oppose the field produced by the main radiating portion of the structure. Thus as L is increased beyond 1.0λ, at first the effect is to decrease the mutual impedance between the two halves of the antenna and thus to increase the field produced at the distant point by a transmitter of unit power. When L is still further increased the radiation from the shaded area in Fig. 4 becomes appreciable and begins to cancel out the main radiation thereby decreasing the field H at the distant point. It is this phenomenon which causes the decrease of the field H when $L>1.30\lambda$. This effect may be made to take place for values of $L>1.3\lambda$ by cancelling out some of the radiation from the shaded portion in Fig. 4 by providing an auxiliary radiator 4—4 energized 180° out of phase with the main radiator, as shown in Fig. 5.

On the other hand the peak radiation may be produced for smaller values of L by loading the ends of the antenna with some form of capacity 5—5, for example as shown in Fig. 6.

When a number of pseudo half-wave antennae are operated together in an array it becomes necessary to insure that they cooperate with each other in such a way as to produce maximum field at the distant point. The exact calculation of mutual interaction between pseudo half-wave elements is rather complicated but approximately correct results may usually be obtained by considering each pseudo half-wave antenna as two separate half-wave antennae spaced a distance $S=L-\lambda$. This assumption becomes more nearly correct when an auxiliary radiator as shown in Fig. 5 is employed. When such an auxiliary radiator is not used then the error in the calculation is due to the field produced by the auxiliary radiator. As this field is usually not very large it may be neglected in the calculation of interaction between the elements.

Thus it is found that when two pseudo half-wave antennae are connected in broadside and parallel to each other they should be about .6 to .75λ from each other for best results. Separations between ends of .2λ to .6λ are found to be satisfactory when two pseudo half-wave antennae are in broadside and in line with each other.

From the above discussion it is also clear that a broad-side antenna such as shown in Fig. 7, consisting of a number of sections 6, 7, 8, 9, each approximately .64λ long, which radiates maximum energy in the plane at right angles to the antenna produces greatest radiation when the phase changers 10, 10 are so adjusted that the phase delay is about $\frac{1}{4}\lambda$ and not $\frac{1}{2}\lambda$ as is generally assumed. This type of an antenna becomes less and less aperiodic per se as the number of half-wave radiating portions is increased. Moreover, when a large number of radiating portions are employed the phase changers located further away from the ends also begin to radiate. For this reason it is probably best to use coils instead of loops as phase changers in the elements next to the feeder.

It has already been explained that pseudo half-wave antennae per se are efficient radiators over a fairly wide band of frequencies. Now, in accordance with the teachings of my copending applications, Serial Nos. 12,451 filed March 22, 1935, and 118,886 filed January 2, 1937 and Patent No. 2,127,198, the impedances of these an-

tennae may be matched to the impedance of the transmission line at a plurality of frequencies under substantially the conditions herein above assumed. Moreover, by using the procedure explained in my copending application, Serial No. 118,886, it is possible to operate a pseudo half-wave antenna or a number of them on several frequencies simultaneously.

In order that echo phenomena on the longer radio circuits may be reduced it is usually necessary to provide an antenna which is substantially unidirectional. To achieve this end an array of pseudo half-waves may be provided with a reflector. This reflector may be either of the fed or of the parasitic type. When the reflector is fed it is usually made similar to the radiator in every respect and is placed at some fraction of the operating wavelength behind or ahead of the radiator and is fed in such phase that the back radiation is cancelled.

When an array of pseudo half-waves is operated at more than one frequency, reflectors of the parasitic type are usually easier to tune, require less material and as a rule provide sufficiently high front to back ratio for practical purposes. For these reasons this type of reflector will be described in some detail.

The parasitic reflector which is well known consists simply of a length of wire placed in back of the radiator anywhere from a .2λ to .3λ and adjusted to such length that the back radiation from it in the back direction is about 180° out of phase with the radiation from the antenna. Parasitic reflectors of this type are suitable at one frequency only.

While I have described particular embodiments of my invention for the purposes of illustration, it will be understood that various modifications and adaptations thereof may be made within the spirit of the invention as set forth in the appended claims.

For example while in the above description antenna arrangements embodying my invention have been described in connection with transmission the same arrangements may be used for reception of signals.

What I claim is:

1. An antenna comprising a plurality of pairs of radiating elements disposed in line, each of said pairs of elements having a length of approximately 1.3λ at the highest frequency at which it is desired to operate, a transmission line interconnected between the adjacent ends of said pairs and a phase changer intermediate the adjacent ends of the elements forming each pair, each of said phase changers being adapted to effect a change of phase of approximately 90° at said frequency.

2. An antenna according to claim 1 wherein an auxiliary radiator is provided for each of said oppositely disposed radiating elements, each said auxiliary radiators forming in effect an extension of the element with which it is connected and overlapping the other of said elements, the length of said other of said elements not so overlapped being approximately one-half wavelength at the operating frequency.

3. An antenna comprising a plurality of pairs of radiating elements disposed in line, each of said pairs of elements having a length of approximately 1.3λ at the highest frequency at which it is desired to operate, a transmission line interconnected between the adjacent ends of said pairs and a phase changer intermediate the adjacent ends of the elements forming each pair, each of said phase changers being adapted to effect a change of phase of from 60° to 120° at said frequency.

4. An antenna comprising a pair of oppositely disposed radiating elements fed at their adjacent ends and having auxiliary radiators connected at their adjacent ends in overlapping relation, the overall length of said pair of elements being in excess of one wavelength at the operating frequency and the combined length of said auxiliary radiators being approximately equal to the said overall length less one wavelength.

ANDREW ALFORD.