May 13, 1941. E. C. CORK ET AL 2,242,023

AERIAL

Filed Dec. 9, 1939

Fig. 1

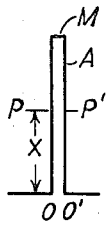


Fig. 2

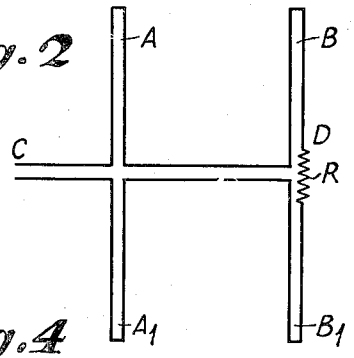


Fig. 3

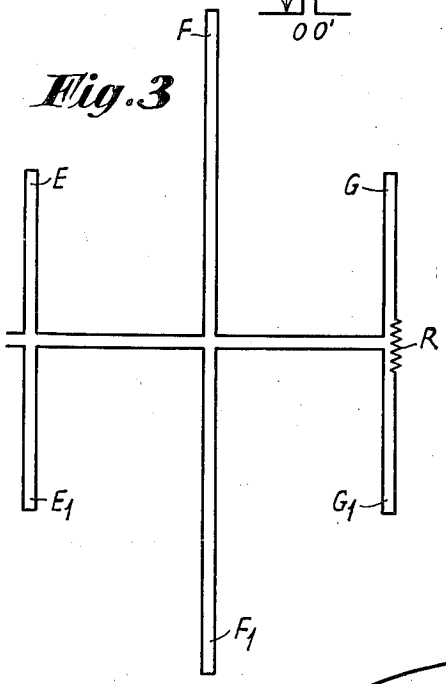


Fig. 4

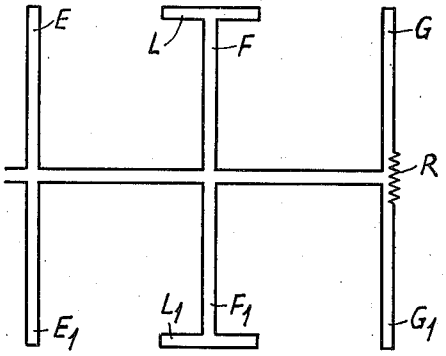
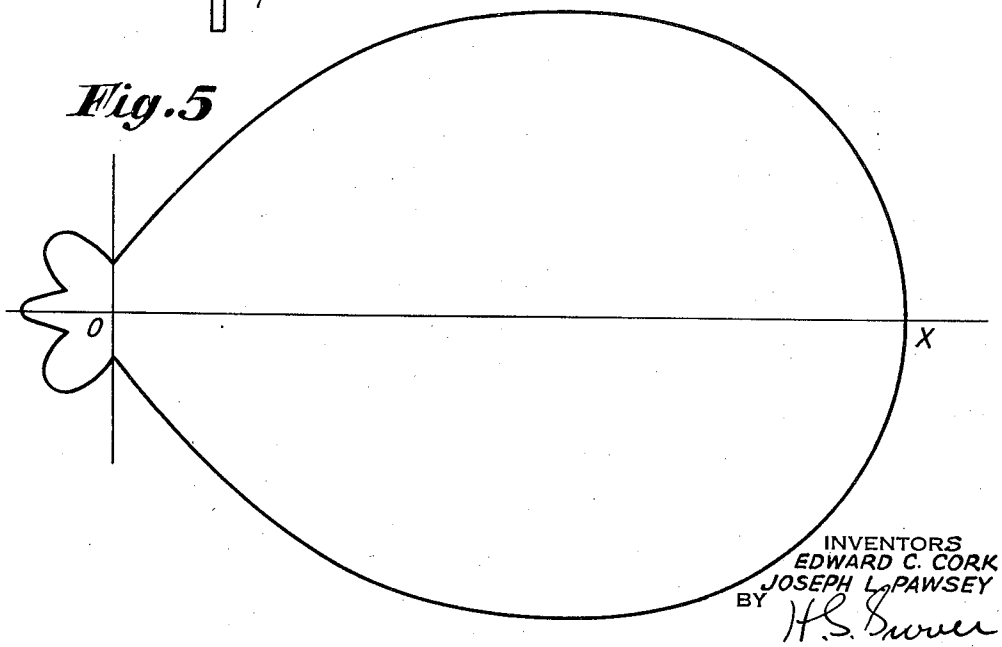


Fig. 5



INVENTORS
EDWARD C. CORK
JOSEPH L. PAWSEY
BY H. S. Brower
ATTORNEY

Patented May 13, 1941 2,242,023

UNITED STATES PATENT OFFICE

2,242,023

AERIAL

Edward Cecil Cork, Ealing, London, and Joseph Lade Pawsey, Ickenham, England, assignors to Electric & Musical Industries Limited, Hayes, Middlesex, England, a company of Great Britain

Application December 9, 1939, Serial No. 308,378
In Great Britain August 3, 1939

6 Claims. (Cl. 250—11)

The present invention relates to aerials of the kind wherein the aerial consists of lengths of conductor arranged substantially in the line of extension of the aerial, said lengths alternating with and connecting in series folded lengths or loops of conductor arranged at an angle to said line.

In Franklin Patent #2,053,658, granted September 8, 1936, aerial arrays of the kind set forth are described in which the overall length of the aerial is long relative to the working wavelength, the length of conductor between adjacent loops being approximately a quarter of a wavelength or an odd plurality of quarter wavelength long, the lengths of folded conductor or loops having an overall length measured along the conductor of one half wavelength or an odd plurality of half wavelengths, the whole arrangement being such that the radiation from those lengths which are at an angle to the general line of extension of the aerial is additive in one direction and to a considerable extent mutually cancelling in the opposite direction, while the total radiation for the remaining lengths is equal to or approximate to zero.

The object of the present invention is to produce a highly directive array to be used in places of high signal strength.

A feature of the invention is the provision of an aerial of the type set forth having similar equally spaced loops in which the length of conductor between adjacent loops and the length of conductor in each loop is not respectively approximately a quarter and a half of a wavelength or odd multiples thereof long respectively, but in which, nevertheless, the properties and separations of the loops are such as to give minimum or zero radiation in a desired direction or desired directions.

It is known, as described, for example, in British Patent specification No. 218,661 accepted April 2, 1925, that a coplanar array of elements can be made to be both highly directive and to occupy a small space if it is arranged that the magnitudes and phases of the currents fed into or derived from the separate elements of the aerial are related in a suitable manner.

A further feature of the invention is the provision of an aerial of the type set forth in which the spacing and lengths of the loops and the strengths of the radiation from the individual loops are such as to give minimum radiation in a desired direction or desired directions.

A still further feature of the present invention is the provision of an aerial of the type set forth in which the phasing of the radiation from the various loops is adjusted to a desired value to give minimum radiation in a desired direction or desired directions by loading the loops or the lengths of conductor connecting the loops and an important subsidiary feature of the invention is the method of loading the loops which consists in modifying their form, for example, by providing supplementary folds or turns therein to provide capacitative or inductive loading. In accordance with this last feature, an aerial can be provided which will occupy a very restricted compass and yet have a highly directional radiation diagram.

The nature of the invention and the method of carrying the same into effect will readily be understood from the following description with reference to the accompanying drawing, in which:

Figure 1 is an explanatory diagram showing a single loop of an aerial of the kind to which the invention relates,

Figures 2, 3 and 4 show diagrammatically examples of aerial arrays according to the invention, and

Figure 5 is the radiation diagram of the array shown in Figure 4.

Referring to Figure 1 of the drawing, A is a single folded loop of a series phase array. In the case where a travelling wave $a \cos pt$ is fed into one end of the loop (a being a constant, p pulsatance and t time), the phase of the wave at a point P in the first branch of the loop, distant x from the point o will be

$$pt-\frac{2\pi x}{\lambda}$$

where λ is the wave length of the wave. If the total length of the aerial is l, the phase of the wave at the point P′ in the second branch of the loop at a distance x from the outgoing end O′ of the loop will be

$$pt-2\pi\frac{(2l-x)}{\lambda}$$

Thus since the loop is reversed at its crown M, the radiation from the loop from the juxtaposed points P and P′ will depend upon the current sum:

$$a\cos\left(pt-\frac{2\pi x}{\lambda}\right)-a\cos\left(pt-\frac{2\pi}{\lambda}\right)$$

$$=2a\sin\left(pt-\frac{2\pi l}{\lambda}\right)\sin 2\pi\frac{(x-l)}{\lambda}$$

$$=a'\sin\left(pt-\frac{2\pi l}{\lambda}\right)$$

where

$$a'=\frac{2a\sin 2\pi(x-l)}{\lambda}$$

and by integration it can be shown that the field radiated by the loop is proportional to

$$\sin^2\frac{\pi l}{\lambda}$$

Thus, the effect of the loop will be equivalent to that of a simple element fed from one end and having a stationary wave on it with a phase corresponding to that of the travelling wave at the crown M of the loop.

Figure 2 of the drawing shows a simple form of the invention, the arrangement comprising two similar loops A and B connected in series and fed from one end C and connected at their other D through a terminating resistance R to loops B_1 and A_1 on a further aerial conductor which are the mirror images of loops B and A respectively. The separation of the loops A and B can be any fraction, say

$$\frac{\lambda}{n}$$

of a wavelength. The terminating resistance R is preferably equal to twice the characteristic impedance of each aerial conductor in space and serves to eliminate reflection.

It can be shown that if the loops A and B are formed a distance d apart, then at a distant point in an axial plane, i. e., a plane passing through the axis of symmetry of the aerial, and perpendicular to the plane of the aerial, and in a direction at an angle θ to the latter plane the difference in phase of the radiation from the two loops is

$$\alpha=\alpha'+\frac{2\pi d}{\lambda}\cos\theta$$

where α' is the difference in phase between the travelling wave in the aerial at the crowns of the two loops. Thus the radiation from the aerial in a direction normal to the plane of the aerial will have two components whose difference in phase will be equal to the phase difference of the travelling wave at the crowns of the two loops A and B. Thus, if the lengths of the loops and their separation is such that the phase difference in the travelling wave at the crowns of the loop is π, that is to say, if the electrical length of the conductor between the two crowns is half a wavelength, the net radiation in a normal direction will be a minimum. The minimum will be zero assuming that the currents in the two elements are equal in magnitude so that the magnitude of the radiations from the two similar loops are equal. If, however, there is attenuation along the aerial conductor the magnitudes of the radiations would not, in general, be equal, but could be rendered equal by slightly varying the length of one of the loops. The radiation diagram in the above-mentioned axial plane will be approximately a figure 8. The same directional diagram will also be secured if the effective length of the conductor between the crowns of the two loops is any odd multiple of half a wavelength.

In general if the length of conductor between the crown of the loops A and B is equal to an odd number of half wavelengths plus or minus a fraction of a wavelength

$$\frac{\lambda}{n}$$

where

$$\frac{\lambda}{n}$$

is the separation of the loops, as referred to above, the resulting radiation diagram of the aerial shows a minimum in the direction of either C or D, and if the spacing is small, the diagram in an axial plane perpendicular to the plane of the aerial is substantially a cardioid.

Diagrams having minima in other directions than along the axis can be obtained by suitable choice of the lengths of the loops relative to the spacing in such manner that the relation

$$\alpha'=-\frac{2\pi d}{\lambda}\cos\theta$$

is satisfied in the required direction.

A further form of the present invention is shown in Figure 3 of the drawing. In this case the array comprises three pairs of loops E, E_1, F, F_1, and G, G_1, the end loops E, E_1 and G, G_1, being made equal in size and the centre loops F, F_1 being made larger than the two end loops.

In this case, if the electrical separation between the crowns of the loops is equal to half a wavelength and the ratio of the field radiated from each end loop to the field radiated from the middle loop is 1:2 then the arrangement will operate in a similar manner to that described in British patent specification No. 218,661 with reference to Figure 1 thereof and the radiation diagram of the arrangement will be an elongated figure 8.

Thus:

If the distance between adjacent loops is a, the radiation from a point in a direction at an angle θ to the plane of the aerial will be

$$E\cos\left(pt+\pi-\frac{2\pi a\cos\theta}{\lambda}\right)+2E\cos pt+E\cos\left(pt-\pi+\frac{2\pi a\cos\theta}{\lambda}\right)$$

$$=2E\cos pt+E\cos\left(pt+\pi-\frac{2\pi a\cos\theta}{\lambda}\right)+E\cos\left(pt-\pi-\frac{2\pi a\cos\theta}{\lambda}\right)$$

$$=2E\cos pt+2E\cos pt\cdot\cos\left(\pi-\frac{2\pi a\cos\theta}{\lambda}\right)$$

$$=2E\cos pt\left(1-\cos\frac{2\pi a\cos\theta}{\lambda}\right)$$

If a is small compared with unity, we may write the result

$$2E\cos pt\left\{1-\left[1-\frac{1}{2}\left(\frac{2\pi a\cos\theta}{\lambda}\right)^2\right]\right\}=E\cos pt\cdot\frac{4\pi^2a^2}{2}\cdot\cos\theta$$

given a directional diagram in the form of an elongated figure 8.

In this arrangement, if the relative radiation from the end loop E, E_1, and F, F_1 is slightly increased by increasing their relative lengths and the spacing between the loops is adjusted, a setting can be obtained in which the double minimum in the elongated figure 8 will be separated into two separate minima, and one of the lobes of the diaphragm will be reduced in size as is represented in Figure 5 of the drawing.

In a further preferred form of the invention similar to that shown in Figure 3, the field radiated from each end loop and each centre loop respectively are in the ratio 1:2 while the length of conductor between the crowns of the loops E, E_1 and G, G_1 and F, F_1 is

$$\frac{\lambda}{2}\pm\frac{\lambda}{n}$$

In this case a radiation diagram can be obtained in the form of an elongated cardioid. This arrangement gives a somewhat greater sensitivity

in the desired direction but less directivity. The theory of aerials having spaced radiating elements and the methods of obtaining different directional diagrams therefrom is more fully discussed in the aforesaid patent specification No. 218,661.

In order to reduce the size of aerials according to the invention, devices for inductively or capacitatively loading the wire may be adopted and loaded conductor wire may be used. For example, instead of using elongated loops F and F_1 such as are shown in Figure 3, the ends of the loops, which contribute very little to the radiation, can be folded as shown at L and L_1 in Figure 4.

These folded sections may consist of simple folded extensions of the aerial conductor as shown in Figure 4, or alternatively they may include coils or condensers. Such devices may be applied to any of the loops. In a particular case of the aerial shown in Figure 4 arranged to operate on a mid-band frequency of 45 mc./sec., the aerial was formed of 22 S. W. G. copper wire, the resistance R being about 800 ohms, the parallel folded conductors being maintained two inches apart; the loops all being two feet eleven inches long; the width of the parts L and L_1 being eighteen inches, and the length of conductor between one loop and the next being two feet seven inches.

The form of the radiation diagram obtained with this aerial is shown in Figure 5. This has already been discussed generally above, and is in the form of a distorted figure 8 having an axis OX in the plane of the aerial. The radiation is a minimum in directions at right angles to the axis through O and also in directions of approximately $\pm 150°$ to the line OX, almost the whole of the radiation being directed generally to the right as shown in the drawing. It will be realised from the dimensions given above and Figure 5 that the invention provides a highly directive and compact array, of which the radiation diagram can be easily controlled. It will be understood that in constructing practical forms of the invention, the current distribution in the aerial may not be exactly predicted by simple theory bases on the assumption that the velocity of propagation of electrical wire along a conductor is equal to that of light, but the departure in dimensions necessary owing to non-agreement with theory have been found in practice to be small, and of the order of a few per cent.

We claim:

1. An aerial of the type set forth comprising a series of similar equally spaced loops arranged in a common plane and means for connecting all of said loops in series to a source of wave energy, the length of conductor from a point in each loop to a corresponding point in each adjacent loop being equal to a multiple, including unity, of a quarter wavelength minus a fraction less than a quarter of a wavelength.

2. An aerial of the type set forth comprising a series of similar closely spaced loops arranged in a common vertical plane and means for connecting all of said loops in series to a source of wave energy, the length of conductor from a point in each loop to a corresponding point in each adjacent loop being equal to a multiple, including unity, of a quarter wavelength minus a fraction less than a quarter of a wavelength.

3. An aerial of the type set forth in claim 1 in which the spacing and lengths of the loops and the strengths of the radiation from the individual loops are such as to give minimum radiation in a desired or desired directions.

4. An aerial of the type set forth comprising a series of similar equally spaced loops arranged in a common plane and means for connecting all of said loops in series to a source of wave energy, the length of each of said loops and the spacing between said loops being determined by the relation

$$\alpha = -\frac{2\pi d}{\lambda}\cos\theta$$

wherein α is the length of the loops in terms of electrical phase difference between corresponding points, λ is the wavelength of said energy, d is the spacing between loops and θ is the angle relative to the axis of said antenna along which minimum radiation is desired.

5. An aerial according to claim 4 in which the physical length of the loops is arranged to be less than the electrical length by means of serially connected loading in said loops.

6. An aerial according to claim 4, arranged to be fed from one end, and comprising two series of loops, one series being physically arranged to appear as a mirror image of the other and the series being connected at the end remote from the feeder through an impedance of such a value as substantially to eliminate reflected waves.

EDWARD CECIL CORK.
JOSEPH LADE PAWSEY.