Sept. 14, 1954 H. J. RIBLET ET AL 2,689,305

ANTENNA

Filed July 9, 1945 2 Sheets-Sheet 1

FIG. 1

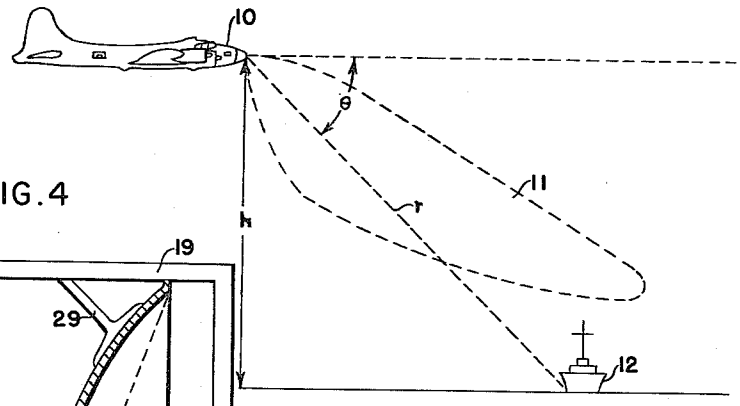


FIG. 4

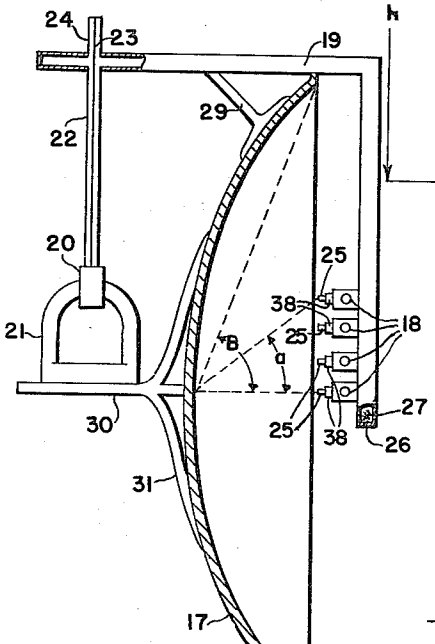


FIG. 5

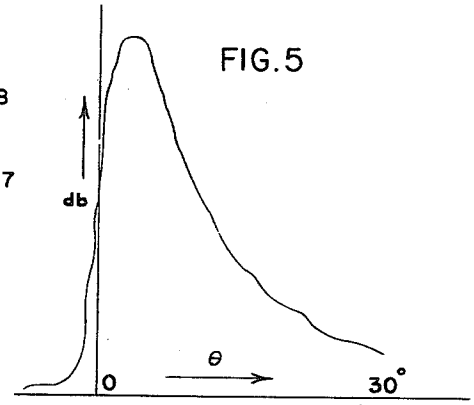


FIG. 6

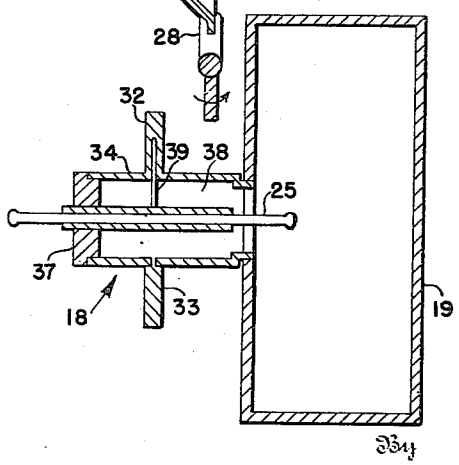
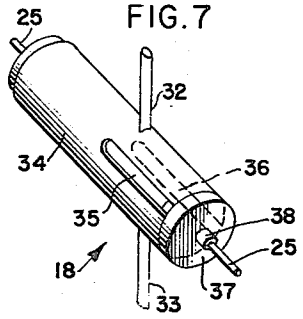


FIG. 7



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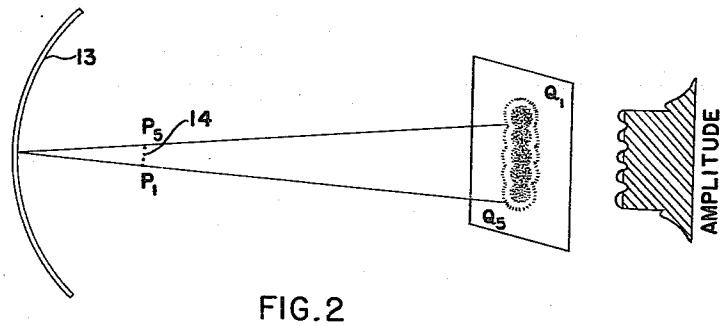
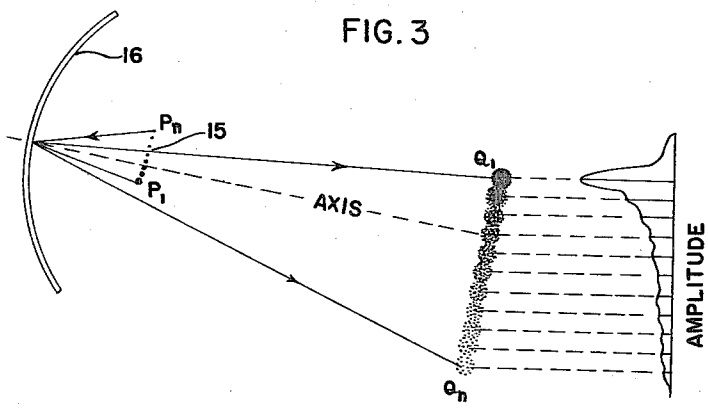


FIG. 2

FIG. 3



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Application July 9, 1945, Serial No. 604,025

20 Claims. (Cl. 250—33.65)

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This invention relates broadly to the formation of unidirectional electromagnetic wave radiation and more particularly to devices for obtaining particularly desirable radiation patterns and characteristics therein.

In wave propagation it frequently becomes desirable to project in one direction all or substantially all the energy emanating from a given antenna or antenna array. Directional radiation characteristics of this nature are particularly favorable for use in radio echo apparatus in order to indicate the bearing or elevation or both of the objects producing the reflections.

Since the advent of the so-called microwave region of the radio frequency spectrum, radiators or antennas resembling point sources have been available. Antennas of this type readily lend themselves to use with parabolic reflectors in facilitating the synthesis of unidirectional diffraction patterns. For instance, in airborne radio object-locating equipment it is generally desired to provide a pattern which will enable a continual and simultaneous search of both near and far objects remotely disposed on the earth's surface or at equal elevations relative to the antenna. A radiation pattern applicable for this purpose can be attained by a mechanical arrangement which "nods" or "tilts" the axis of the parabolic reflector in a vertical plane which inevitably involves the use of intricate mechanical and electrical features including rotary joints in both the antenna feed line and reflector support member. A more favorable scheme for producing an equivalent vertical distribution of the radiation pattern may be attained through the synthesis of the desired pattern by means of a suitably chosen antenna array and excitation system.

It is here to be understood that even though the invention will be largely shown and described as applied to airborne equipment it can also be applied to other apparatus, such as for example, a beacon system.

It is an object of this invention to construct an antenna arrangement particularly adaptable for airborne radio object-locating use in providing a continual search of near and far objects.

It is another object of this invention to provide an antenna arrangement for use in synthesizing a desired radiation pattern.

It is another object of this invention to provide an antenna arrangement for use in connection with a parabolic reflector for producing a $\csc^2\theta$ radiation pattern, wherein the angle θ is measured with respect to the axis of directivity of the parabolic reflector and in one quadrant of a plane intersecting said axis.

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Other objects and features of the present invention will become apparent upon a careful consideration of the following detailed description when taken together with the accompanying drawings, the figures of which are not to be construed as a definition of the limits of the invention.

In the drawings:

Fig. 1 is a pictorial representation of a typical use for the present invention.

Fig. 2 is a diagrammatic side elevation view illustrating the pattern produced by projection of a linear array of dipoles adjusted for equal intensity according to the present invention and also illustrating the amplitude of the diffraction pattern.

Fig. 3 is a diagrammatic side view similar to Fig. 2 in which the pattern is produced by a linear array of dipoles with tapered intensity according to the invention.

Fig. 4 is a view partially in cross-section of a typical antenna arrangement constructed in accordance with the teaching of this invention.

Fig. 5 is a plot of the power in the radiation pattern at a given point versus the angle relative to the axis of directivity of a typical antenna system constructed in accordance with the teachings of the present invention.

Fig. 6 is a cross-sectional view of a rectangular wave guide feed system; and

Fig. 7 is a perspective view of a dipole radiator such as may be used in the present invention and as shown in cross-section in Fig. 6.

Reference is now had to Fig. 1 wherein there is shown a sketch illustrating the principles and practicability of flaring a radiation pattern in the vertical plane. Herein is shown an airplane 10 from which the desired radiation pattern 11 is projected for use in detecting objects remotely disposed on the earth's surface, such as the ship 12. As shown in the figure, the amount of energy reaching objects on the surface of the earth is normally inversely proportional to r^2. But since

$$r^2=\frac{h^2}{\sin^2\theta}$$

the actual amount of energy reaching the targets will be directly proportional to the $\sin^2\theta$. Hence, in order to provide uniform illumination along the earth's surface and within a given range of θ, the vertical distribution pattern must contain a

$$\text{corrective factor}=\frac{1}{\sin^2\theta} \text{ or } \csc^2\theta$$

For practical reasons, flaring of the radiation pattern should be limited to about 30 or 40 de-

grees measured relative to the axis of the paraboloid. Also, the axis of the paraboloid should be tilted downward at an angle of about 20° from the horizontal in order to provide adequate illumination forward or laterally from the plane depending upon the orientation of the antenna. Thus, the angular distribution of energy will be confined between the limits of $\theta=20°$ and $\theta=50°$ or 60° depending upon the degree of flare and tilt.

Since in radio object-locating use the same antenna is used in transmitting and receiving, the directive characteristic of the antenna will enter into both transmission and reception. Thus, the antenna pattern herein set forth will compensate for the relative weakness of echoes from similar reflecting objects disposed over the earth's surface.

Special fanning or flaring of the diffraction or radiation pattern, such as a $\csc^2\theta$ pattern as referred to above is particularly useful in connection with radio object-locating systems such as are used for long range search, blind bombing and beacons. It is also desirable to have a ship-borne antenna which will produce a square diffraction or radiation pattern which will continue to illuminate the target with a constant intensity as the ship rolls.

The present invention is concerned with means for flaring out the diffraction or radiation pattern so as to simulate any desired pattern of greater width including a square pattern and more particularly a $\csc^2\theta$ pattern. In essence, the teachings of the invention are that if a series of radiating elements are placed in the focal plane of a parabolic reflector and the current distribution along the i^{th} element varies as $f(i)$ then the diffraction pattern resulting will be approximately the projected image of the current distribution, or $f(i)$ also. A dipole array, for example, may be used to illuminate a parabolic reflector and the currents feeding the dipoles adjusted to produce a beam pattern will be approximately $\csc^2\theta$. In general this invention comprises the "projection method" of modifying the antenna so that its diffraction pattern will approximate the desired polar diagram and employs a modified feed placed substantially in the focal plane of a reflector.

Fig. 2 shows a paraboloidal reflector **13** illuminated by a radiating source **14**. Source **14** comprises a linear array of radiating elements such as dipoles P_1–P_5 fed in a conventional manner and located in a plane substantially perpendicular to the axis of reflector **13** at the focal point thereof as more fully explained hereinafter.

It is well known that when a luminous point source is projected by an optical system the angular width of the diffraction pattern image is of the order of

$$\frac{\lambda}{D}$$

where λ is the wavelength of the illuminating energy and D is the diameter of the reflector. On the other hand when a collection of point sources such as P_1–P_5 of Fig. 2 is projected, the diffraction pattern Q_1–Q_5 is, according to the superposition theorem, the sum of the individual diffraction patterns. This results in a blurred and inverted image of the source. According to this, the diffraction pattern of the paraboloidal reflector **13** is essentially the projected image of the current distribution in the focal plane of the reflector **13**, and both electron currents and displacement currents are included.

In the projection of a light source, intensity patterns are added since the phases of the individual radiating atoms are random. However, in the case of microwaves, amplitude patterns are added because the relative phases of the antenna feed currents are fixed with respect to the phase of the generator. Two embodiments of the "projection method" according to this invention are shown in Figs. 2 and 3.

Fig. 2 shows how a square or pie-shaped pattern can be produced. Each dipole of the array P_1–P_5 placed at the focus of parabolic reflector **13** is adjusted so as to radiate with approximately the same intensity, and this results in a diffraction pattern Q_1–Q_5 in which each of the individual point image patterns are of equal intensity and hence of equal amplitude. Thus a substantially square pattern of uniform amplitude is produced as indicated in the amplitude diagram of Fig. 2.

Fig. 3 shows the "projection method" as applied to obtaining a fan-type beam such as a $\csc^2\theta$ beam. In this modification a linear array type feed **15** such as a plurality of dipoles P_1–P_n (n being an integer) are placed in the focal plane of parabolic reflector **16**. The intensity of dipoles P_1–P_n is adjusted to give tapered illumination and to produce the pattern Q_1–Q_n as indicated by the relative size of the points P_1–P_n and the relative shading of the patterns Q_1–Q_n. The reflector **16** is preferably tilted in order to minimize the distortion which occurs for dipoles placed off the reflector axis. It is noted that if two adjacent dipoles are made 180° out of phase a zero would appear in the diffraction pattern. It is therefore preferable that the phase difference between adjacent dipoles should not exceed 60° to 90°.

Referring now to Fig. 4 there is shown a typical embodiment of the present invention comprising a parabolic reflector **17** and a plurality of equally spaced dipole radiators **18** each projected from the same broad side of a suitable wave guide transmission line **19** and so arranged as to constitute a linear antenna array. To facilitate further discussion, the dipole radiator nearest the excitation source will hereinafter be referred to as the "initial dipole," whereas the dipole farthest disposed from said source will be referred to as the "terminating dipole." In this arrangement the outer diameter of the paraboloid is preferably chosen as a function of the number and spacings of the dipoles. A rough approximation of the preferred diameter may be had by setting the angle α, described by a pair of lines drawn through the extreme end dipoles and convergent on the paraboloid vertex, equal to a minor fraction, say ½ the angle β between the axis and a line drawn between the vertex and the outer edge of the paraboloid. For example, an antenna array comprising 6 dipoles having ½ λ_g spacing excited at approximately 10 cm. have been used in cooperation with a 10 foot paraboloid.

In synthesizing diffraction patterns, such as the $\csc^2\theta$ pattern, by means of a paraboloid reflector and linear antenna array, it is usually desirable to position all the radiation sources in the focal plane of the paraboloid, that is, a plane which is situated perpendicular to the axis of the paraboloid and passes through the focal point thereof as referred to hereinabove with reference to Figs. 2 and 3. Due, however, to certain unavoidable reflections set up by the wave guide itself, an apparent radiation source will be established which will lie at some point between the dipole plane and the common side of the wave guide

from which the dipoles project. Hence, in order to secure optimum results the linear array of dipoles will actually be positioned in a plane parallel to, but closer to the vertex of the paraboloid than the focal plane. In view of the foregoing analysis it appears that there exists an optimum spacing between the dipoles and the broad surface of the wave guide from which they project. This spacing is usually so adjusted that the reflected wave from the wave guide will reinforce the direct radiation into the paraboloid. Spacings in the order of one-quarter wavelength or an odd multiple thereof, where the wavelength is that measured in space, have been found to provide adequate reinforcement of the direct radiation.

As previously mentioned, the dipoles **18**, constituting the linear array, are in general fixed at equal intervals along the wave guide **19** and in such a manner as to cause a predetermined degree of flare in the diffraction pattern. An increase in the overall length of the array will broaden the total flare angle. Variations in spacing of the dipoles affect their relative phases which cause minor changes in the smoothness of the flared beams. For instance two equally excited adjacent dipoles 180° out of phase will have a zero or null between their peaks. Here the flare of the pattern is confined to the vertical plane below the axis of the paraboloid since the antenna array is situated entirely above the paraboloid axis. Spacings of $\frac{2}{3}\lambda$ or the approximate equivalent of $\frac{1}{2}\lambda_g$ where λ and λ_g are the wavelengths measured in air and in the guide respectively, have been used to produce a flare of about 30°. Spacings of this order will cause adjacent dipoles to be excited in near phase opposition thereby producing a null in the diffraction pattern, which effect is highly undesirable and may easily be remedied by alternately reversing the electrical orientation of the dipoles **18**.

To provide excitation of the dipoles, radio frequency energy derived from a suitable source such as the magnetron **20** and magnet **21** is transmitted to the wave guide **19** by way of a suitable coupling link such as line **22** which contains an outer conductor secured to the wave guide and an inner conductor penetrating the magnetron field as a pick-up loop. In order to excite oscillations of the desired mode such as the $TE_{0,1}$ mode in wave guide **19** the inner conductor **23** of the coupling line **22** extends through the wave guide **19** parallel to the shorter dimension sides thereof and is terminated at the opposite side by a suitable terminal plug **24**.

In the antenna array each dipole **18** is provided with a variable pick-up loop **25** adapted to penetrate an adjustable depth into the wave guide **19** so as to provide a means for controlling intensity of radiation or power from each dipole. As will be understood the power radiated is proportional to the square of the current. The pick-up probes **25** may be adjusted to produce the same or different amounts of radiation from each dipole as indicated with reference to Figs. 2 and 3. Here, for example, wherein consideration is primarily given the $\csc^2\theta$ pattern, the pick-up loops **25** are adjusted to produce a different amount of radiation from each dipole. An excellent $\csc^2\theta$ pattern has been obtained when the terminating dipole adjacent the end **26** of the wave guide **19** has been adjusted so that its current is a certain value I which can be set forth as a standard or a unit amount. The next dipole up the guide toward the source and adjacent the terminating dipole is adjusted to receive a ½ unit, the next a ⅓ unit and so on up the array. Generalizing, the current, which is representative of the intensity of radiation, in each dipole can be represented by the formula

$$I_n\frac{I}{n}$$

where n is the position of the dipole relative to the terminating dipole and I is the unit current heretofore defined. Therefore, since intensity of radiation or power is proportional to the square of the current, power is inversely proportional to n squared. A radiation pattern simulating the curve shown in Fig. 5 has been obtained with this arrangement where the angle θ is measured in a downward vertical direction from the axis of the paraboloid. Here the angle θ is confined to the space below the axis, since the array itself is situated entirely above the axis with the terminating dipole on the axis.

Energy proceeding along the guide **19** toward end **26** diminishes by amounts depending upon the proportions abstracted therefrom by the dipoles **18**. Usually, however, a small amount, perhaps 5 to 10%, of the total energy will not be picked up by the dipoles. This residual energy, even though it is a comparatively small amount of the total energy should not be allowed to remain in the guide and thereby set up standing waves. Therefore, a suitable piece of absorbent material, such as cotton gauze impregnated with graphite, is usually inserted into the end of the guide as indicated by the dotted lines **27**.

Thus far consideration has been given the antenna only in a fixed orientation. It may be desired, however, to apply the present antenna system to either a sector scan or a P. P. I. (plan position indication) type of radio object-locating equipment wherein the antenna is used to scan a circular expanse about a given reference point. Hence, the paraboloid **17** is then rotated about a vertical axis by way of a suitable rotating mechanism coupled to a supporting yoke such as yoke **28**. Guide **19** and the associated antenna array may then be held in the proper plane by any suitable means such as the brace member **29** secured to the paraboloid **17**. With this operating condition it may become desirable to rotate the transmitter and certain other components of the system in unison with the antenna. Such a system can then utilize a platform or support **30** secured to the back of the paraboloid by way of any suitable brace scheme **31** capable of containing the transmitter as here represented by the magnetron **20** and magnet **21**. The receiver may then be coupled to the antenna through wave guide **19**, a rotatable joint and a suitable T-R switch of known form for decoupling the receiver from the antenna during pulse transmission. The latter two features are not shown here since they do not constitute a part of the applicant's invention.

The particular type dipole radiator, feeding and supporting members used in abstracting energy from the wave guide **19** is not critical and may, for example, be similar to that shown in Figs. 6 and 7. The dipole arms **32** and **33** are both supported in a tubular member **34** which may be suitably secured to the wave guide **19** as indicated. Member **34** is provided with a pair of diametrically opposite longitudinal slots **35** and **36**, 90° disposed from the plane of the dipole arms **32** and **33** and closed at one end by plug **37** which also serves as a support for an inner

tubular member 38. Slot 36 is indicated diagrammatically in Figure 7. The inner tubular member 38 is secured to the dipole arm 32 by a pin 39 which cooperates with plug 37 in coaxially supporting the inner member 38 within member 34. Snugly but slidably engaged within the inner member 38 is an energy pick-up rod 25 extending an adjustable depth into the guide 19.

The longitudinal slots 35 and 36 each have a total length of ½ λ so that the outer tubular member 34 is effectively divided into upper and lower segments, the central portion of which may be excited by the energy picked up by probe 25 so as to cause an R. F. voltage to appear across the dipole arms 32 and 33. Hence by adjusting the depth of penetration of probe 25 into wave guide 19 the intensity of radiation emanating from the dipole may be regulated as desired.

Although we have shown and described only a certain and specific embodiment of the present invention, we are fully aware of the many modifications possible thereof. Therefore it is desired that this invention is not to be limited to the precise details set forth.

What is claimed is:

1. An antenna system for synthesizing a desired radiation pattern comprising a rectangular wave guide, a plurality of dipole radiators, including an initial and a last dipole radiator, projected from a common side of said guide at nearly one-half wavelength intervals so as to constitute a co-linear antenna array, a paraboloidal reflecting means, means positioning said array in a plane perpendicular to the axis of said reflecting means with the last dipole of said array lying in the horizontal axial plane of said reflecting means, the diameter of the reflecting means being such that the angle between the axis and a line drawn from the vertex to the initial dipole is but a minor fraction of the angle between the axis and a line drawn from the vertex to the edge of the reflecting means, means for energizing all dipole radiators simultaneously, and a means for adjusting the radiation intensity emanating from each of said dipoles.

2. An antenna as claimed in claim 1 wherein the adjusting means adjusts the radiation intensity from the dipoles to produce a radiation pattern from the reflecting means which varies substantially as the square of the coescant of the radiation angle measured from the axis of directivity of the paraboloidal reflecting means.

3. An antenna system for synthesizing a desired radiation pattern comprising a paraboloid reflecting means, a rectangular wave guide, a plurality of dipole radiators projected from a common side of said guide at one-half wavelength intervals to form a linear antenna array, means positioning said array in a plane perpendicular to the axis of said reflecting means and having the last dipole thereof lying in an axial plane of said reflecting means, and means for adjusting the radiation intensity from said dipoles to various predetermined values.

4. An antenna system for synthesizing a desired radiation pattern comprising, a parabolic reflecting means, a plurality of coplanar radiation sources positioned in a plane perpendicular to the axis of said parabolic reflecting means and having the last source thereof lying in the horizontal plane intersecting said axis, means for adjusting the intensity of each of said sources to conform to the product of an arbitrary intensity unit times the reciprocal of the relative position number of the source counted from the last source.

5. An antenna system for synthesizing a desired radiation pattern comprising, a parabolic reflecting means, a rectangular wave guide section, a plurality of equally spaced dipole radiators projected from a common side of said wave guide to form a linear antenna array, means positioning said array in a plane perpendicular to the axis of said parabolic reflecting means with the last dipole thereof lying in a plane that intersects the axis of said reflecting means, means for simultaneously energizing all of said dipole radiators, and means for adjusting the radiation intensity from each of said dipoles.

6. An antenna system for synthesizing a desired radiation pattern comprising, a parabolic reflecting means, a series of spaced coplanar radiation sources positioned in a plane perpendicular to the axis of said parabolic reflecting means and having the last source of said series lying in a plane intersecting said axis, and means for adjusting the intensity of radiation from each of said sources to a different value.

7. An antenna system for synthesizing a desired radiation pattern comprising, a paraboloid reflecting means, a rectangular waveguide, a plurality of dipole radiators projected from a common side of said guide at one half wavelength intervals to form a linear array, means positioning said array in a plane perpendicular to the axis of said reflecting means and having an end dipole thereof lying in the horizontal axial plane of said reflecting means, and means for adjusting the radiation intensity of each of said dipoles so that the intensity of radiation of said end dipole is some arbitrary value R and the intensity of radiation of each of the other dipole radiators is equal to R/n^2 where n is the position number of the dipole radiator relative to the end dipole radiator where said end dipole radiator has the position number 1.

8. Apparatus for synthesizing a directional radiation pattern $f(i)$ having predetermined characteristics comprising a series of equally spaced coplanar energy radiation sources, a parabolic reflecting means for directing energy radiated from said radiation sources, and means for adjusting the radiation intensity of each of said sources relative to the radiation intensity of an end source so that the radiation intensities of said sources, as progressively measured from said end source, follow the curve $f(i)$.

9. Apparatus for synthesizing a directional radiation pattern $f(i)$ comprising a series of coplanar radiators, a parabolic reflector for directing energy radiated from said radiators, said radiators being disposed substantially along a line through the focus of said reflector, means for adjusting the intensity of radiation of said radiators relative to the radiation in tensity of one of said radiators so that the radiation intensities of said radiators, as progressively measured from said one radiator, follow the function $f(i)$, and means for simultaneously energizing all of said radiators.

10. The apparatus defined in claim 9 wherein the phase difference between the currents in adjacent radiators is less than 90°.

11. The apparatus defined in claim 9 wherein the plane of said radiators is substantially perpendicular to the axis of said parabolic reflector.

12. The apparatus defined in claim 9 wherein said means for adjusting the currents of said radiators causes said currents to vary inversely

as the distance of each radiator from the focus of said parabolic reflector.

13. An antenna system for synthesizing a desired radiation pattern comprising, a paraboloid reflecting means, a rectangular wave guide, a plurality of dipole radiators projected from a common side of said guide at one-half wavelength intervals to form a linear antenna array, means positioning said array in a plane perpendicular to the axis of said reflecting means and having the last dipole thereof lying in the horizontal axial plane of said reflecting means, and means for adjusting the current in each of said dipoles so that the current in said last dipole is some arbitrary value R and the current in each of the other dipole radiators is equal to R/N, where N is the position number of the dipole radiator relative to the last radiator when said last dipole radiator has the position number 1.

14. The antenna system of claim 1, wherein the angle between the axis of said paraboloidal reflecting means and the line drawn from its vertex to the edge thereof is at least four times as great as the angle between said axis and a line drawn from said vertex to said initial dipole.

15. The antenna system of claim 1, wherein the electrical orientation of alternate dipole radiators is reversed relative to their adjacent radiators so as to avoid excitation in phase opposition.

16. The antenna system of claim 1, wherein the plane in which said dipole radiators are disposed is displaced from the focal plane of said paraboloidal reflecting means toward the vertex thereof, the displacement from the focal plane being sufficient to place the apparent radiation source, between the common side of said guide and the plane of said radiators, within said focal plane.

17. The antenna system of claim 16, wherein said dipole radiators are spaced from said common side of said guide by an amount equal to a quarter of a wavelength of the operating frequency as measured in space.

18. The antenna system of claim 17, wherein each of said dipole radiators is respectively mounted upon a wave guide projecting from a common wall of said rectangular wave guide, the two poles of each dipole being disposed 180° apart and projecting from the circumference of their supporting wave guide, each supporting wave guide having a pair of longitudinal slots, each slot having a length of one-half wavelength, said slots being 180° apart and at right angles to the dipoles.

19. The antenna system of claim 18, wherein said rectangular wave guide is energized at its end remote from said last dipole, and further including energy dissipation means terminating the end of said rectangular wave guide adjacent said last dipole.

20. The antenna system of claim 19, wherein the axis of said paraboloidal reflecting means is tilted at an angle with the horizontal.

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