This invention relates to directional antenna systems and more particularly to antenna arrays and feeders therefor. Efforts have been made heretofore to provide high resolution antenna arrays, such that the beam width is less than about one degree. Such arrays are generally used with a separate reflector to produce the desired vertical pattern, generally cosecant. The advantages of the array-reflector combination over the single fed antenna-reflector combination are that separate control of azimuth and elevation patterns is possible, the reflector may comprise a simple cylindrically curved member and better control is obtained of polarization. The main disadvantage, however, is the greater complexity of the feeding system for the array. To obtain a linear array it has been proposed heretofore to employ an end-fed waveguide or coaxial line provided with slots and/or dipoles, or a pill box. In end-fed arrays, the difficulties experienced are shift of beam with frequency, mutual impedance between adjacent slots and the large number of slots required. The pill box or sectoral lens is objectionable because of its large size and weight.

One object of this invention is to provide a novel end-fire radiator structure readily adaptable for use in linear arrays and which is relatively simple in construction, light weight and relatively inexpensive.

Another object of this invention is to provide a novel linear array, either vertically or horizontally polarized; and a further object is the provision of an improved feeder system or power divider for such a linear array.

One of the features of this invention is the use of a “line-above-ground” type of transmission line or waveguide, the end of which is modified to provide an end-fire radiator similar in shape to that of a horn radiator. Such end-fire radiators are further employed in side by side relationship to form a linear array, line-above-ground power dividers being employed as feeders.

Still another feature of the invention is the manner of obtaining power division for antenna feeding purposes to obtain desirable impedance matching and a desired radiation pattern with a minimum of reflections in the feeder system. Where rectangular waveguides are employed as feeders, power division is relatively easy while control of phase is difficult because two dimensions, length and width, must be controlled. Where coaxial lines are employed, the length only need be controlled, but difficulties are encountered in supporting the inner conductor at frequencies above 3000 mc/sec. In accordance with the present invention, these difficulties are overcome by employing a line-above-ground type of energy divider for effecting division of radio frequency power in the microwave region. In this form of divider the phase of the radio frequency energies along the different branches may be controlled by proper determination of the width of the line conductor and the relative length of the branches.

The above-mentioned and other features and objects of this invention and the manner of attaining them will become more apparent by reference to the following description taken in conjunction with the accompanying drawings, wherein:

Fig. 1 is a plan view of an end-fire antenna according to the principles of this invention;

Fig. 2 is a longitudinal sectional view taken along line 2—2 of Fig. 1;

Fig. 3 is an H-plane pattern of the radiation of the antenna type illustrated in Figs. 1 and 2;

Fig. 4 is a view in plan of a linear array and power feeder arrangement in accordance with the principles of this invention;

Fig. 5 is a longitudinal sectional view taken along line 5—5 of Fig. 4;

Fig. 6 is a plan view of an array with the end-fire antenna structures disposed for horizontal polarization of radiation;

Fig. 7 is a view in side elevation with parts broken away, taken along line 7—7 of Fig. 6;

Fig. 8 is a view in plan of a modified form of linear array and power feeder arrangement;

Fig. 9 is a view in side elevation of the array taken along line 9—9 of Fig. 8;

Fig. 10 is a view in plan of a power feeder for three radiators;

Fig. 11 is a view in side elevation of one branch of the feeder taken along line 11—11 of Fig. 10; and

Fig. 12 is a view in plan of a further embodiment of a linear array, arranged to minimize radiator reflections.

Referring to Figs. 1 and 2, the “line-above-ground” type of transmission line or waveguide employed as a feeder, end-fire antenna comprises a first or planar conductor 1 and a second or line conductor 2 spaced apart by a thin strip or layer of dielectric material 3. The two conductors 1 and 2 are preferably of flat strip form, the line conductor being wider than the line conductor so that propagation of microwave energy therealong is in a mode similar to the TEM mode. The line conductor, however, may be round or otherwise shaped, if desired. The parameters of importance are the width of the line conductor 2 and the thickness of the spaced dielectric 3. The dielectric material may be polystyrene, polyethylene, Teflon, Fiberglas or laminated Fiberglas impregnated with Teflon, quartz, or other suitable material of high dielectric quality. The transmission line may be made up of strip material or made in accordance with printed circuit technique. For additional information regarding the characteristics of this form of transmission line reference may be had to the copending application of M. Arditi and P. Parzen, Serial No. 286,764, filed May 8, 1952, Patent No. 2,774,046, issued December 11, 1956.

The forward end of the line conductor 2 is flared as indicated at 4 and angled outwardly with respect to the planar conductor 1 at a desired acute angle α. This presents a horn type of radiator with open sides, the usual vertical side walls being unnecessary. While the dielectric 3 is shown extended to the forward end of the planar conductor 1, it may, of course, be terminated at the bend 5, and if desired, in a tapered manner. Forming a part of the planar conductor is an angular member 6 which provides a radio frequency trap a quarter air wavelength in depth to prevent currents from occurring on the bottom side of the planar conductor.

Fig. 3 shows an H-plane pattern 7 obtained from an end-fire antenna in accordance with the structural arrangements illustrated in Figs. 1 and 2. The front lobe shows the directivity of the antenna. The frequency employed was 9400 mc/s. The horn construction employed had the following dimensions: the line conductor 2 was $\frac{1}{4}$" wide, the end of the flared portion 4 was $\frac{1}{14}$".
the length of the flared portion was 2”, this length being in the order of \( \frac{H}{\lambda} \).

Fig. 2, and the dielectric 3 was \( \frac{3}{4}” \) thick and of Fiberglas material.

The array shown in Figs. 4 and 5 is made up of a plurality of individual horn-like radiators of the type shown in Figs. 1 and 2. While four such radiators 8, 9, 10 and 11 are shown, a smaller or larger number may be employed as desired. Each radiator includes a flared portion 4 inclined at a suitable angle with reference to the plane of the line conductor 2. The planar conductor 1 is extended as shown in Figs. 4 and 5 to comprise the lower plate 12 of a parallel plate system including an upper plate 13. The parallel plates 12 and 13 are provided at the ends thereof with flared portions 14 and 15 which function as a horn radiator. While these parallel plates need not be closed at the side walls thereof, they are in the present embodiment so connected by side walls 16 and 17. The flared portion of the radiators are spaced from the upper wall 13 and in effect constitute transducer structures for launching or receiving of energy between the line-above-ground type of feeder network and the rectangular or parallel plate waveguide 12, 13. Since the radiators 8 to 11 are disposed between the plates 12 and 13 there is no need for the trap 6 shown in Fig. 2, the flared portions 14 and 15 functioning as the radiator surfaces.

The network feeding system for the array shown in Figs. 4 and 5 comprises a main line-above-ground type of waveguide 20 comprising a first or planar conductor 21 and a second or line conductor 32 spaced apart by a layer of dielectric material 23. For the power division the planar conductor 21 is extended laterally as indicated at 24 and may comprise a width corresponding to the width of the plate 12. The line conductor 22 branches out into individual feeders for the radiators 8 to 11. The ratio of power in the desired ratio is obtained by providing an impedance transformer section 25, wherein in the line conductor 22 is changed in width before branching into separate branch feeders 26 and 27. The transformer section includes a tapered portion 25a of length \( a \) and a second portion 25b of length \( b \) of an impedance equal to the two lead impedances of branches 26 and 27 in parallel. The length \( c \) of the tapered portion is selected greater than a half guide wavelength so as to provide a gradual transition between the low impedance portion 25b and the higher impedance of the input line 22. The branch 26 is provided with a transformer section 28 for coupling to two additional branches 29 and 30 which feed radiators 8 and 9. The branch 27 likewise includes a transformer section 31 which is coupled to branches 22 and 33 to feed radiators 10 and 11. Reflections from the junctions of the branches are minimized by making the line lengths to the junctions different by a quarter wavelength at the mid band of the operating frequency. For example, the length of the branch 26 to the transformer 28 is shown as length \( c \) while the corresponding length of branch 27 is

\[
\frac{c + \lambda}{4}
\]

Likewise, the length of the branches 29 and 30 from transformer 28 to the radiators 8 and 9 are shown to be a length

\[
\frac{d + \lambda}{4}
\]

while the corresponding lengths of branches 32 and 33 are of length \( d \). By so arranging the different lengths in the feeder network like phase is obtained at the array of radiators 8 to 11.

While the radiators of the array shown in Figs. 4 and 5 are illustrated as horn-like structures, it will be readily apparent to those skilled in the art that other end-fire radiators or transducers may be substituted therefor. Examples of dipole and slot radiator arrangements that may be so employed are disclosed in my copending application, Serial No. 329,775 filed January 6, 1953, Patent No. 2,794,185, issued May 28, 1957 to which reference may be had.

The array illustrated in Figs. 4 and 5 provide for a radiation beam vertically polarized. In Figs. 6 and 7 another array is shown in which the same type of radiators are illustrated revolved 90° between the parallel plates 12a and 13a so that radiation is obtained from the parallel plates horizontally polarized. Each of the radiators 34 and 35 are provided with line-above-ground waveguides comprising a planar conductor 36, a line conductor 37 spaced by a layer of dielectric material 38. The planar conductors 36 of the two feeders are of the same width as the spacing between the plates 12a and 13a. Since the parallel plates 12a and 13a may be sufficiently supported by the feeder structure, they need not be provided with side walls, as indicated in Figs. 4 and 5. Such side walls, however, may be provided, if desired. Many more than the two radiators 34 and 35 may, of course, be provided. The feeding system for the radiators of Fig. 6 may, of course, include a power divider network arrangement similarly as illustrated in Figs. 4 and 8.

In Figs. 8 and 9, another array is shown wherein the flared radiator portions 39, 40, 41 and 42 are extended so as to flare into the adjacent radiators and thus form integrally the forward upper plate 43 of the slot radiator. The lower plate 44 comprises an extension of the ground conductor 45 which underlies the feeder network connected to the radiator portions 39 to 42. The power dividing network of the feeders constitute curved junctions which contain transformer sections as indicated at 46. The width of the main line conductor 47 is gradually curved throughout the section 46 to the wider low impedance width required for the two branches 48 and 49 into which it is divided. The transformer section 46 is of a length \( e \) which preferably is greater than a half wavelength. The junction 50 coupling branch 48 with branches 51 and 52 feeding radiators 39 and 40 is similar to that shown at 46. The branches 53 and 54 coupled to the branch 49 is likewise provided with a transformer junction 55 similar to that shown at 46. The curvature is so chosen for the turns of the branches 48, 49, 51, 52, 53 and 54 and the junctions thereof as to avoid loss due to radiation at such bends at frequencies in the order of 6,000 to 12,000 mc./sec. and higher. In other words, where

\[
\frac{h}{\lambda}
\]

is in the order of about \( \frac{\lambda}{2} \), where \( h \) is the thickness of the dielectric spacing between conductors, the curved form of Fig. 8 is preferred. For lower frequencies of the order of 3000 to 6000 mc./sec. the network feeder may be of the configuration shown in Fig. 4 without appreciable loss due to radiation. In other words, the form of Fig. 4 is satisfactory where

\[
\frac{h}{\lambda}
\]

is in the order of about \( \frac{\lambda}{4} \). In order to minimize reflections from these junctions, the branch lines are chosen of different lengths, the branch 48 being one quarter wavelength longer than the branch 49, and the branches 53 and 54 being one quarter wavelength longer than the branches 51 and 52.

The particular type of power divider and minimum curvature of bends that may be employed in a network of the form illustrated in Fig. 8 are treated in greater detail in my copending application of D. J. Le Vine, Serial No. 336,671, filed February 13, 1953, Patent No. 2,836,798, issued May 27, 1958, to which reference may be had.

Figs 10 and 11 have been shown by way of example to indicate how the junction may be arranged for three
or more branches. While the same type of transformer junction as that shown in Fig. 4 is employed in this illustration as indicated at 5, it will be understood that a curve junction such as shown in Fig. 8 may be employed. The low impedance section of the junction is divided into three branches 57, 58 and 59. Where it is desirable to have these branches feeding an array of radiators in linear arrangement some provision must be made with regard to relative lengths of the branches. The center branch 58 is accordingly bowed up sufficiently so that the three branches are of equal length thereby insuring equal phase at the radiators coupled to the three branches. The view shown in Fig. 11 indicates the bowing up of branch 58 with reference to the plane 60 of the planar conductors of the branches 57 and 59.

Where a linear array of radiators are fed in phase, the reflections of the radiators are likewise in phase and while minimized by making the branch lines of the feeder network of different lengths, the reflections may be further minimized by making the length of the feeders adjacent the series of radiators of different lengths.

Fig. 12 shows such a feeder arrangement, a transducer array being indicated diagrammatically at 61, 62, 63, 64 and 65, the radiators being disposed as parallel plates as indicated at 66, in the plan view of Fig. 12. Assuming that the feeders for the transducers 61 to 65 are fed with a phase front as indicated by the line 67, it will be noted that the length of the feeders from the phase front 67 to the different transducers are of different lengths. The line of the transducers is disposed at an angle $\theta$ with respect to the phase front 67. The radiating edge 68 of the parallel plates is selected at an angle $\beta$ with respect to the wave front 67. Where the ratio $\frac{\lambda_0}{\lambda_g}$ (Air wavelength) $\frac{\lambda_g}{\lambda_g}$ (guide wavelength) does not vary with frequency, the beam will emerge normal to the plane of the radiator edge 68. The angle $\theta$ is chosen such that $\sin \theta = D/2a$, where $D =$ aperture width between the parallel plates and the angle $\beta$ is chosen such that $\tan \beta = \frac{\lambda_0}{\lambda_g}$ $\tan \theta$

While I have described above the principles of my invention in connection with specific apparatus, it is to be clearly understood that this description is not intended to limit the scope of my invention as set forth in the objects thereof and in the accompanying claims.

1. An antenna array comprising a planar conductor, a main line conductor, a plurality of branch line conductors, dielectric means spacing said main line and branch lines in a plane disposed in parallel relation with respect to said planar conductor, said main and branch lines each being of a width smaller than the width of said planar conductor and lying within the confines of said planar conductor thereby providing in conjunction with said planar conductor waveguides for propagation of radio frequency wave energy in a mode simulating substantially the TEM mode, radiators coupled to said branch lines at the ends thereof, and a junction coupling said main line to said branch lines including an impedance transformer section, said radiators each comprising an extension of said branch line conductor, said extension being flared outwardly and disposed at an acute angle to the plane of said planar conductor.

2. An antenna array according to claim 1, wherein said impedance transformer comprises a conductive portion of a width greater than the width of said main line conductor to present an impedance equal to the load impedance of said branch lines in parallel and another portion interconnecting said main line conductor to said low impedance portion of greater width, said interconnecting portion being tapered and of a length equal to at least one-half guide wavelength.

3. An antenna array according to claim 2, wherein said branch line conductors and said main line conductor are of substantially equal width.

4. An antenna array according to claim 1, wherein the impedance transformer includes a section of line tapered from the width of said main line conductor to twice the width thereof and said branch line conductors comprise two conducting portions of a width corresponding to the width of said main line conductor.

5. An antenna array according to claim 1, wherein the radiators number more than two and said branch line conductors are further divided by transformer junctions into additional branch line conductors for coupling to said radiators, the corresponding lengths of certain of said branch line conductors being different by one quarter wavelength to minimize reflections from the junctions thereof.

6. An antenna array according to claim 1, further including parallel plate conductors with said radiators disposed therebetween and flared outwardly at an acute angle as transducers of parallel plate conductors comprising a radiating horn.

7. An antenna array according to claim 6, wherein said flared extensions are connected at the ends of the flared portions thereof to the upper of said parallel plates.

8. In combination, a planar conductor, a plate conductor disposed in space parallel to said portion of said planar conductor forming therewith a parallel plate waveguide for radio frequency wave energy, a line conductor narrower than said planar conductor disposed in space parallel to said planar conductor also providing in conjunction therewith a waveguide for radio frequency wave energy, the end portions of said line conductor being flared outwardly and disposed at an acute angle to the plane of said planar conductor as a transducer for coupling radio frequency wave energy from one to the other of said waveguides.

9. In combination, a planar conductor, a plate conductor disposed in space parallel to one portion of said planar conductor forming therewith a parallel plate waveguide for radio frequency wave energy, a plurality of line conductors spaced apart in a plane parallel to and between said planar conductor and said plate conductor, said line conductors each being narrower than said planar conductor and lying within the confines of said planar conductor to form therewith waveguides for radio frequency energy, and the end portions of each of said line conductors being flared outwardly and disposed towards said plate conductor and at an acute angle to the planes of said planar and plate conductors.

10. A combination according to claim 9, wherein said flared portions are connected to said plate conductor.

11. In combination, a planar conductor, a plate conductor disposed in space parallel to one portion of said planar conductor forming therewith a parallel plate waveguide for microwave energy, a feed line comprising a second planar conductor, a line conductor and dielectric means spacing said line conductor in parallel relation to said second planar conductor to provide for propagation of radio frequency wave energy, said line conductor being narrower than said second planar conductor, said second planar conductor being electrically coupled to said first mentioned planar conductor and said line conductor being electrically coupled to said second mentioned planar conductor and said plate conductor and provided at its end with a flared portion disposed at an acute angle to the plane of said second planar conductor.

12. A combination according to claim 11, wherein said second planar conductor is disposed at right angles to said planar and plate conductors.

13. An antenna comprising a first conductor, a second
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conductor, dielectric means spacing said conductors in substantially parallel relation to provide a waveguide for transmission of radio frequency wave energy therealong, said first conductor being wider than said second conductor to present a planar surface with respect to said second conductor, and said second conductor having the end portion thereof flared outwardly and disposed at an acute angle to the plane of said planar surface.

14. An antenna according to claim 13, wherein said first conductor is provided with a wave trap substantially one quarter of a wavelength in depth extending across the bottom surface thereof.

15. In combination, a planar conductor, a plate conductor disposed in spaced parallel relation to one portion of said planar conductor forming therewith a parallel plate waveguide for microwave energy, the forward end of said parallel plate waveguide being open for slot radiation of energy, a main line conductor, a plurality of branch line conductors, dielectric means disposing said main line conductor and said branch line conductors in a plane parallel to said planar conductor, said main line conductor and said branch line conductors each being of a width smaller than the width of said planar conductor and lying within the confines of said planar conductor thereby providing in conjunction with said planar conductor a waveguide for propagation of radio frequency wave energy in a mode simulating substantially a TEM mode, and a junction coupling said main line conductor to said branch line conductors having a conducting portion of a width greater than the width of said main line conductor to which said branch lines are coupled to present an impedance equal to the load impedance of said branch lines in parallel and another portion interconnecting said main line conductor to said low impedance portion of greater width, said interconnecting portion being tapered and of a length equal to at least one-half guide wavelength, and said branch lines are further divided by transformer junctions into additional branch line conductors, the corresponding lengths of certain of said first mentioned branch line conductors being different by one-quarter wavelength to minimize reflections from the junctions thereof.

References Cited in the file of this patent

UNITED STATES PATENTS
2,159,648 Alford May 23, 1939
2,297,202 Dallenbach et al. Sept. 29, 1942
2,425,488 Peterson et al. Aug. 12, 1947
2,454,766 Billouin Nov. 30, 1948
2,496,643 Smith Feb. 7, 1948
2,540,839 Southworth Feb. 6, 1951
2,624,003 Iams Dec. 30, 1952
2,654,842 Engelmann Oct. 6, 1953
2,689,303 Rissler Sept. 14, 1954
2,749,545 Kostriza June 5, 1956

FOREIGN PATENTS
541,380 Great Britain Nov. 25, 1941
580,115 Great Britain Aug. 27, 1946
629,893 Great Britain Sept. 30, 1949
655,803 Great Britain Aug. 1, 1951

OTHER REFERENCES


