Aug. 14, 1956 O. MacD. WOODWARD, JR 2,759,183

ANTENNA ARRAYS

Filed Jan. 21, 1953 3 Sheets-Sheet 1

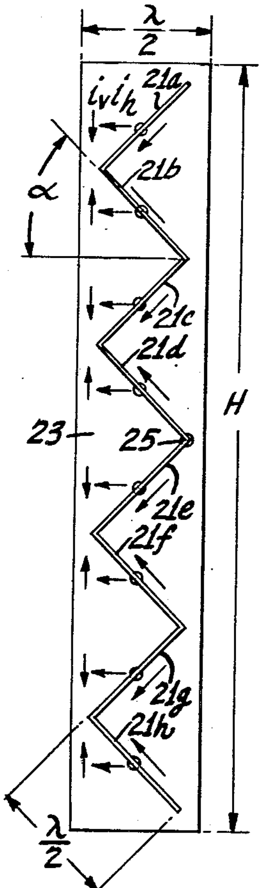


Fig_1

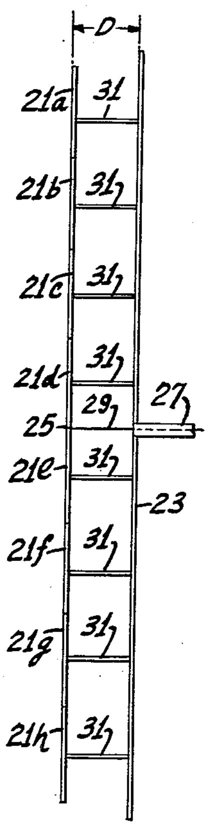


Fig_2

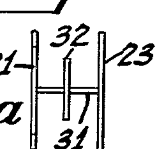


Fig_2a

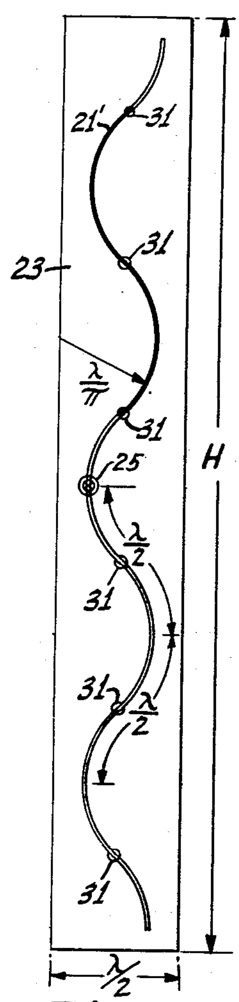


Fig_3

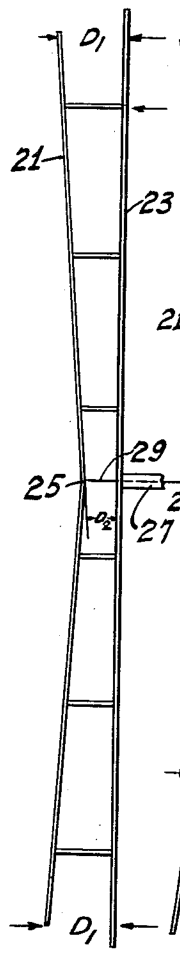


Fig_4

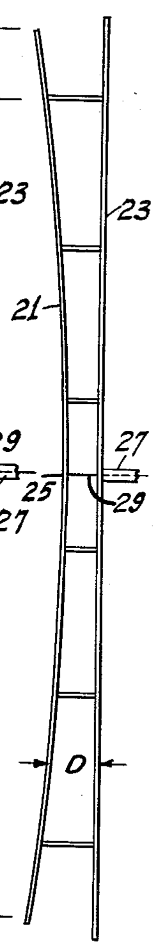


Fig_5

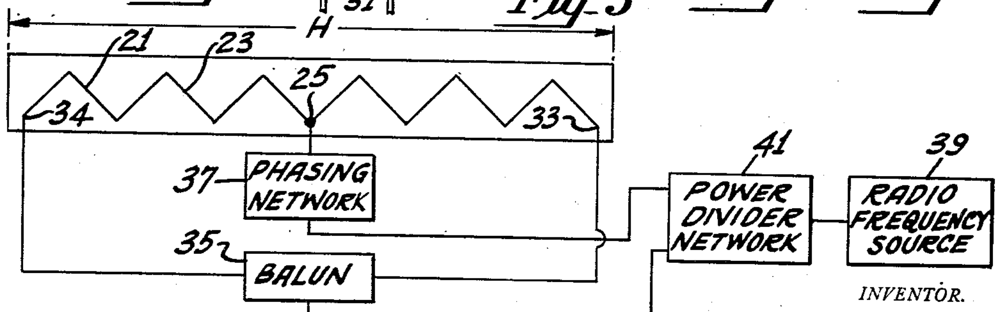


Fig_6

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ANTENNA ARRAYS

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Fig. 7

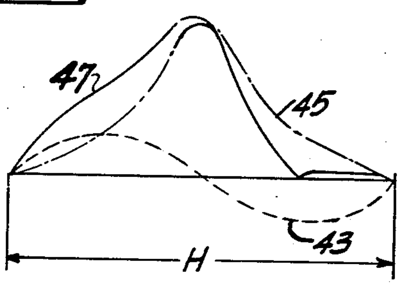



Fig. 8

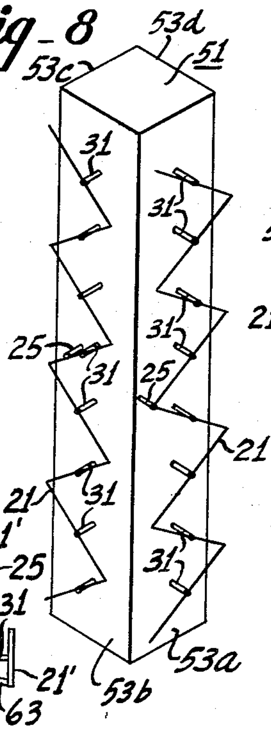



Fig. 9

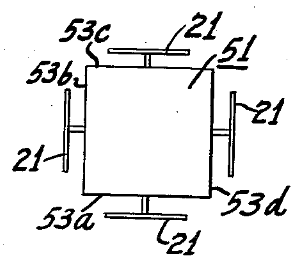
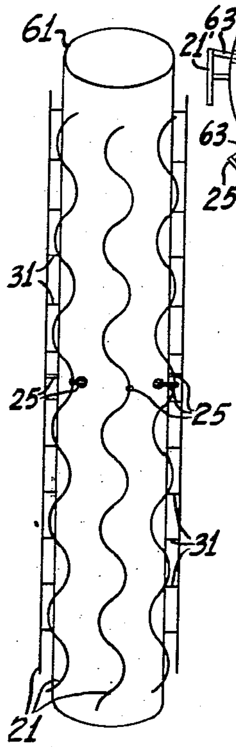



Fig. 10



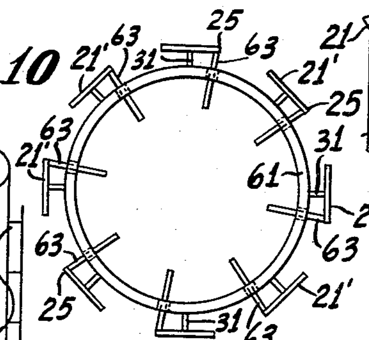
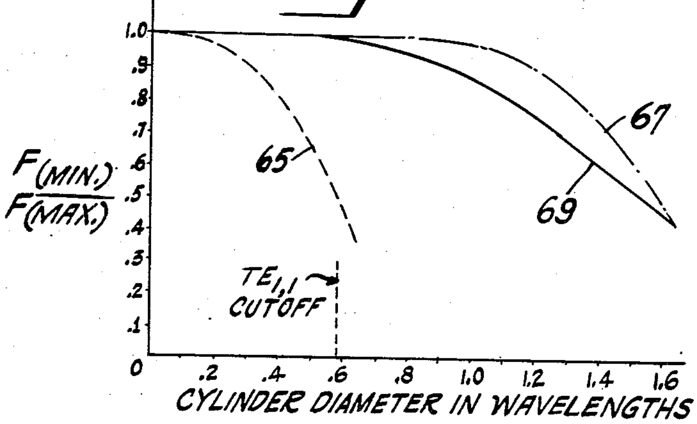




Fig. 11

Fig. 12

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ANTENNA ARRAYS

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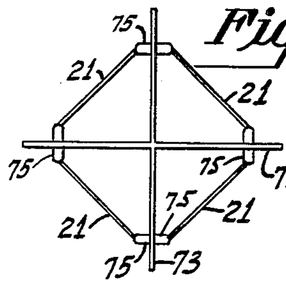


Fig_13

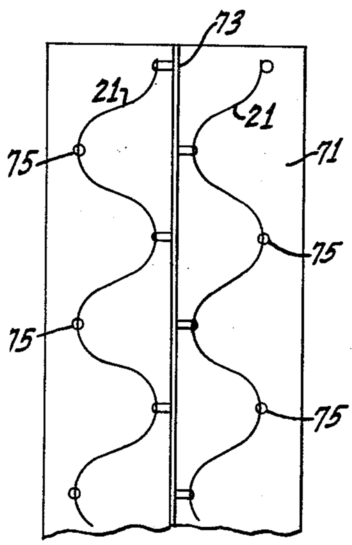


Fig_14

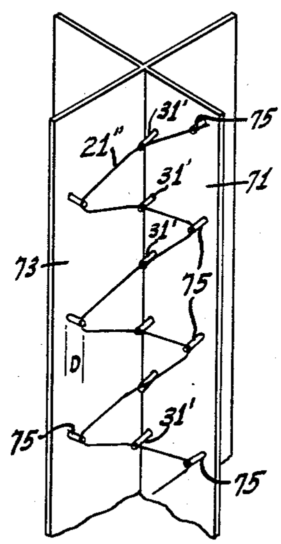


Fig 17

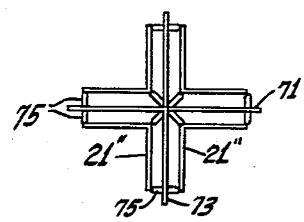


Fig_16

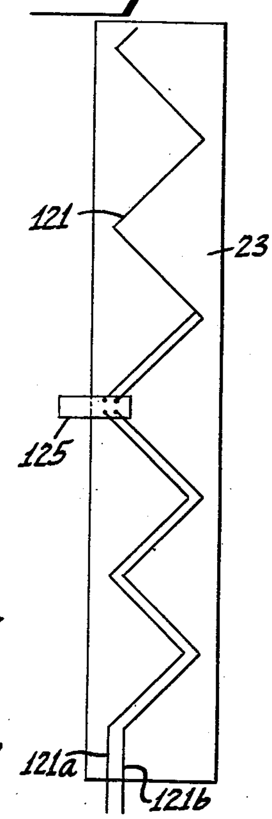


Fig_18

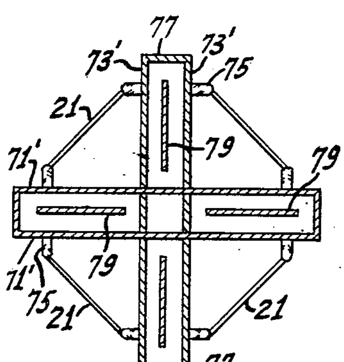


Fig_15

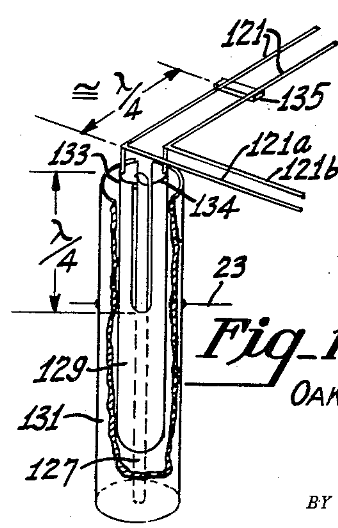


Fig_19

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United States Patent Office

2,759,183

Patented Aug. 14, 1956



2,759,183

# ANTENNA ARRAYS

Oakley MacDonald Woodward, Jr., Princeton, N. J., assignor to Radio Corporation of America, a corporation of Delaware

Application January 21, 1953, Serial No. 332,439

26 Claims. (Cl. 343—908)

This invention relates to antennas, and particularly pertains to antenna arrays especially suitable for broadcasting broadband signals, such as television picture and sound transmission.

Television broadcast transmitting antennas, especially in the ultra high frequency band between 470 and 490 megacycles, must satisfy the following requirements: provide as great a power gain in the allowed vertical aperture of the antenna as is practicable; be capable of handling power of from 200 to 1000 kilowatts of effective radiated power; be strong mechanically to minimize the effect of wind deflection; and be able to use efficiently and economically the available radio frequency energy. To achieve this last requirement, the radiation from the broadcast antenna must be primarily directed into the service area of the broadcasting establishment, and must not be wasted in undesired directions. It is also desirable that broadcast antenna systems be made up of antenna elements which may be utilized to obtain either directional or omnidirectional azimuthal pattern characteristics.

This invention is directed to antenna arrays which are composed of elements utilizable either in a directional array or as an omnidirectional array. It is expected that an important application of antenna arrays in accordance with the invention will be for ultra high frequency television broadcasting services in the frequency band between 470 and 890 megacycles.

It is an object of this invention to provide a physically simple, improved high gain antenna array for ultra high frequency services having a straightforward and uncomplicated feeding arrangement.

Another object of this invention is to provide an antenna array for horizontally polarized waves having a very large vertical aperture in wavelengths for a single feedpoint with good operating characteristics over a 6 megacycle bandwidth for broadcasting television signals.

A further object of this invention is to provide an anantenna element which serves the dual function of a transmission line and a multi-unit radiator.

Yet another object of this invention is to increase the power handling capabilities of ultra high frequency broadcast antennas.

A still further object of this invention is to provide an improved ultra high frequency antenna array which is composed of radiating elements which may be arranged to produce either directional or omnidirectional azimuthal pattern characteristics.

In accordance with this invention, these and other objects are obtained by utilizing a radiating element of elongated sinuous form. Such a sinuous radiating element may be, for example, a continuous zig-zag wire with straight portions and sharp bends or a serpentine conductor in which the arcuate portions are quadrants of a circle or half circles. This sinuous conductor is closely spaced to a sheet reflector structure, and the spacing therebetween may vary from less than ⅛ wavelength to ¼ wavelength at the mean operating frequency. The



sinuous conductor and the reflector structure serve the dual functions of a transmission line and a multi-unit radiator. The sinuous conductor radiates a certain portion of the power from each unit and at the same time serves as a transmission line for the succeeding sections farther from the feedpoint. The spacing between the continuous conductor and the sheet reflector determines whether the particular section of the sinuous conductor under consideration acts more like an antenna or like a transmission line; that is, the spacing of the sinuous conductor from the sheet reflector is utilized to determine the proportion of power radiated by each elemental section of the sinuous conductor.

A unidirectional or directional array having approximately a cosine distribution in the azimuthal plane is produced by a single reflector screen and one or more sinuous conductor radiators closely spaced thereto. Omnidirectional arrangements of the antenna array of this invention are provided which utilize an equilateral polygon as the reflector structure and, when the number of sides of the polygon is made greater than six, an arrangement using a circular cylinder as the sheet reflector structure may be used. Several feeding systems for coupling the terminals of the antenna array to suitable radio frequency apparatus are utilizable, and these include coaxial and parallel two-wire lines as well as hollow pipe wavelength guides and slab type rectangular coaxial lines.

A more detailed description follows in conjunction with the accompanying drawings, in which:

Figs. 1 and 2 show a front elevation and a side elevation, respectively, of an antenna array in accordance with this invention;

Fig. 2A is a fragmentary view of a portion of Fig. 2 illustrating a modification of one element of Fig. 2;

Fig. 3 is a front elevation of another form of the antenna array of the present invention;

Figs. 4 and 5 are side elevations of another antenna array in accordance with the invention;

Fig. 6 illustrates an alternative feeding system for an antenna array in accordance with the invention;

Fig. 7 is a graphical representation illustrating principles of the invention;

Figs. 8 and 9 are perspective and top plan views, respectively, of an omnidirectional antenna array utilizing the principles of this invention;

Figs. 10 and 11 are perspective and top plan views, respectively, of another omnidirectional array in accordance with the invention;

Fig. 12 is a graphical representation explanatory of certain principles of the invention;

Figs. 13 and 14 are top plan and elevation views, respectively, of another omnidirectional array in accordance with the invention;

Fig. 15 is a top plan view in section of a modification of the antenna array of Figs. 13 and 14;

Figs. 16 and 17 are top plan and perspective views, respectively, of another antenna array in accordance with the invention;

Fig. 18 is a schematic representation of the antenna array in accordance with this invention illustrating another antenna feed system; and

Fig. 19 is a view in perspective of a device useful in carrying out the feed system illustrated in Fig. 18.

Referring to Figs. 1 and 2, Fig. 1 shows a front elevation and Fig. 2 a side elevation of a sinuous conductor in the form of a continuous zig-zag wire denoted generally by the reference number **21**, and a conductive sheet reflector structure **23** in the near zone of the sinuous conductor **21**. The continuous zig-zag wire **21** is shown as being made up of a plurality of straight portions **21*a*** through **21*h***, each straight section of which is one-half wavelength long at the mean operating frequency and inclined at an angle $\alpha$ with respect to the horizontal. The zig-zag conductor **21** is excited with radio frequency energy at a feedpoint **25** by a coaxial transmission line having its outer conductor **27** electrically connected to the sheet reflector structure **23** and its inner conductor **29** electrically connected to the feedpoint **25**. The term "conductive sheet reflector structure" as used in this specification and the appended claims means either a solid conductive sheet reflector, a flat conductive sheet having apertures therein, a grid of conductors closely spaced together, or one composed of a network of wires such as a screen.

The zig-zag conductor **21** is spaced along its length from the conductive sheet reflector **23** by a distance D. With a constant spacing D between the conductor **21** and the reflector **23** along the entire length thereof, this spacing D may vary from one-quarter down to one-twelfth wavelength at the mean operating frequency.

When radio frequency excitation is applied between the feedpoint **25** and the sheet reflector **23**, instantaneous currents are produced in the zig-zag conductor **21**, and for one polarity of applied radio frequency excitation have the instantaneous current shown in Fig. 1 by the arrows adjacent each section of the conductors **21***a* through **21***h*. These instantaneous currents may be resolved into horizontal and vertical components of current, in which case they will have the instantaneous magnitudes in the two directions as shown to the left of the conductor sections **21***a* through **21***h*. The arrows shown at the extreme left-hand side under the heading $i_v$ indicate the magnitude and direction of the vertical components of current in each of the sections of the zig-zag conductor **21***a* through **21***h* opposite which they appear. Likewise, the arrows in the column headed $i_h$ denote the instantaneous values and direction of the horizontal components. It can be seen that any two adjacent sections of the sinuous conductor, for example sections **21***g* and **21***h*, have vertical components of current, each of which produces a vertical field which tends to cancel that of an adjacent section. On the other hand, all the horizontal components of current are in the same direction and combine additively to produce a strong horizontal field. The antenna of this invention, therefore, produces radiation which is polarized at right angles to the length of the aperture, with very little radiation polarized in the lengthwise direction.

As the angle of inclination $\alpha$ of the zig-zag conductor sections **21***a* through **21***h* is increased, no great change occurs in the shape of the field patterns of the horizontally polarized components of radiation. The power efficiency, however, does change, and above about 45° begins to drop off quite rapidly because of an increase in power radiated and lost in vertically polarized fields. When the angle $\alpha$ is 30° with respect to the horizontal, the power efficiency is better than 95 percent, that is, more than 95 percent of the radiated power is present in the horizontal components of field, and less than 5 percent represents vertically polarized components. At an angle $\alpha$ of 45°, the antenna has a power efficiency of about 92 percent. When the angle $\alpha$ is increased to 60°, however, the power efficiency drops to 60 percent. A choice of the angle $\alpha$ equal to 45° provides a reasonable compromise between a minimum number of elements in an array to cover a given aperture and the maximum gain possible for the aperture.

Two characteristics of an antenna array in accordance with Figs. 1 and 2 are affected by changing the spacing between the zig-zag conductor **21** and the sheet reflector structure **23**. With relatively short apertures, that is, of the order of four wavelengths and eleven elements **21** inclined at an angle $\alpha$ equal to 45°, very little difference is found in the bandwidth characteristics for a screen spacing of D equal to one-eighth wavelength and D equal to one-quarter wavelength. On the other hand, with a larger aperture such as seven wavelengths, and the number of elements **21** increased to nineteen at an angle $\alpha$ of 45°, a greater bandwidth is obtained with one-eighth wavelength spacing. In general, the bandwidth over which the zig-zag conductor and reflector arrangement will operate efficiently is limited by the increase in magnitude of side lobes in the vertical radiation pattern for the one-eighth wavelength spacing and by a broadened main beam for the one-quarter wavelength spacing.



The zig-zag conductor **21** is maintained in spaced relation to the sheet reflector **23** by supports **31**. These supports **31** are positioned at the center of the half-wave sections of the sinuous conductor **21**. At this position which is a voltage nodal point, either metal or insulation material may be used for the supports **31**. The use of insulation material for the supports **31** has the advantage of allowing the zig-zag conductor **21** to be de-iced by passing heating currents through the zig-zag conductor, whereas the use of metal supports does provide somewhat greater mechanical strength. Although a zig-zag conductor **21** with metal supporting members **31** gives a greater frequency bandwidth, the total aperture is less efficiently utilized than is possible with insulating stand-off supports **31**. A given aperture can be more efficiently fed when metal supports **31** are used by employing circular flat metal tuning discs properly positioned on the metal support posts **31**.

Fig. 2A is a fragmentary view of a portion of Fig. 2 showing a metal support **31** having a tuning disc **32** positioned thereon. The tuning disc **32** has a diameter of the order of one-eighth wavelength and is positioned near the middle portion of the support **31**. In one embodiment, an array for television picture transmission on a frequency of 524–530 megacycles used a zig-zag conductor having cross-sectional dimensions of ⅛ x ¾ inches spaced 5⅝ inches from the reflector screen **23**. The metal supports **31** were ⅜ inch in diameter and carried flat circular discs **32** having a diameter of 3 inches. These discs were mounted on the supports **31** parallel to the reflector screen halfway between the zig-zag conductor **21** and the screen **23**.

It should be noted that although the antenna conductor **21** is shown as being excited by a single-sided radio frequency signal at the end of a half-wave unit, the conductor **21** may be excited by a balanced radio frequency signal at the midpoint of the center element of the array.

Referring now to Fig. 3, there is shown another type of sinuous conductor having sections composed of quadrants of a circle. The radius of curvature of the arcuate portions of the sinuous conductor **21'** which crosses the support elements **31** at an angle $\alpha$ of 45° is $\lambda/\pi$.

Comparing the ratio of the respective dimensions of the zig-zag conductor **21** with the sinuous element **21'**, it is found that the sinuous element **21'** composed of quadrants of a circle is 27 percent greater in length of aperture for a given number of sections and only about one-half as wide as the zig-zag element **21**. It will thus be seen that with a sinuous element **21'**, fewer individual elements are required for a given aperture array.

Fig. 4 illustrates a variation of the spacing D between the sinuous or zig-zag conductor **21** with respect to the sheet reflector **23** over the length of the aperture H. The zig-zag or sinuous conductor **21**, together with the sheet reflector structure **23**, serves two functions: first, that of a multi-unit radiator and, second, that of a transmission line to feed the sections of the zig-zag or sinuous conductor **21** remote from the feedpoint **25**.

From the transmission line viewpoint, the system may be considered as a lossy line in which the loss per unit section of line is represented by the power radiated from each zig-zag or sinuous element. The power radiated from the first few elements near the feedpoint will increase as the screen spacing D is increased, and the more distant elements from the feedpoint **25** will receive less power. Consequently, for screen-to-element spacings from more than one-eighth up to one-quarter wavelength, a symmetrical graded current distribution results with a centerfed array, giving a broader main beam and reduced side lobes.

Reduced screen spacings permit more effective use of the aperture because the initial sections function more like a transmission line with lower radiation loss per section. By varying the spacing D over the length of the array so that the screen-to-element spacing increases as the function of the distance away from the feedpoint **25**, a more uniform distribution of current to all of the elements is obtained. A center fed array of fifty half-wave sinuous elements of the form shown in Fig. 3, in which a spacing D1 at the remote ends of the array was 0.22 wavelength and the spacing D2 at the feedpoint **25** was one-eighth wavelength with a linear taper from the feedpoint to each end, gave a greater percentage bandwidth as well as a more nearly uniform distribution of current across the aperture than a similar array in which the spacing D was constant throughout the aperture.

The tapered spacing between the sinuous or zig-zag conductor **21** and the sheet reflector **23** over the length of the aperture H may, as is shown in Fig. 3, be close at the feedpoint **25**, becoming greater at the end of the aperture. Conversely, another desired current distribution may be obtained for a given aperture by a wide spacing D2 at the feedpoint **25** and a spacing narrower than D2 toward the end of the aperture.

Fig. 5 shows another arrangement in which the spacing D between the sinuous or zig-zag conductor **21** and the sheet reflector **23** is varied over the length of the aperture. Instead of a linear taper like that shown in Fig. 4, the arrangement of Fig. 5 represents an exponential taper or a parabolic, elliptical, or similar second or higher order function of the distance D relative to the spacing of any point from the feedpoint **25**. The disposition of the sinuous or zig-zag conductor **21** relative to the sheet reflector **23** of Fig. 5 is useful for obtaining other desired current distributions over the length of the aperture of the array.

Referring now to Fig. 6, there is shown a feeding system for an antenna array in accordance with the invention in which the elevation pattern may be tilted and shaped for certain applications. The zig-zag conductor **21** is fed at the two ends **33, 34** with out-of-phase (that is, push-pull) voltages which may be supplied from a single-sided (that is, unbalanced to ground) source by a balun **35**, which is an unbalanced-to-balanced converter. The midpoint **25** of the zig-zag conductor **21** is at zero potential with respect to the voltage impressed across the ends **33, 34** by the balun **35**. The midpoint may therefore be utilized as a feedpoint **25** for another source of radio frequency voltage and be completely decoupled from the voltage impressed across the ends **33, 34**. The feedpoint **25** is coupled single-sided (that is, unbalanced with respect to ground) through a phasing network **37** so that the relative phase of the two radio frequency voltages may be adjusted. Both the balanced feed of the ends **33, 34** and the single-sided feed at the midpoint **25** are conveniently supplied from the same radio frequency source **39** through a power divider network **41**. Such a power divider network allows the adjustment of the relative amplitude of the radio frequency signal supplied to each of the two feeding systems. The arrangement of Fig. 6 permits considerable latitude in tilting and shaping the vertical pattern by virtue of the separate adjustments of the relative amplitude and phase of the two voltages supplied to the antenna.

Fig. 7 shows a representative current distribution for one condition of adjustment of the antenna feed arrangement of Fig. 6. The dashed-line curve **43** illustrates a current distribution across the aperture H due to the balanced voltage fed at the ends **33, 34**. The dot-dash curve **45** shows one current distribution obtained from a single-sided signal applied to the center feedpoint **25**. The resultant distribution of radio frequency energy across the aperture is shown by the solid line curve **47**. Such a current distribution as that shown in the solid line curve **47** causes a radiation pattern in the vertical or elevation direction to have its main lobe tilted from a normal to the sheet reflector structure **23** of Fig. 6. The relative magnitude and phase of the dashed-line curve **43** and dot-dash curve **45** determine the degree and magnitude of the tilt in the vertical pattern.



Referring now to Figs. 8 and 9, Fig. 8 is a view in perspective and Fig. 9 is a top plan view of an omnidirectional antenna array in accordance with this invention. A tower, denoted generally by the reference character **51**, has a regular polygonal cross section, such as a square, the sides of which are conductive sheet reflector elements **53*a*, 53*b*, 53*c*, 53*d***. Each face **53*a*** through **53*d*** has a sinuous conductor **21** maintained in spaced relation thereto by supports **31** like those described above with respect to Figs. 1 and 2. Each face **53*a*** through **53*d*** of the tower **51** may be of solid metallic or conductive material, or may consist of a conductive screen or a grid or network of conductors electrically connected together to approximate a solid sheet reflector.

Radio frequency excitation is applied to each zig-zag conductor **21** at its feedpoint **25**, which may be at the midpoint thereof, in the same manner described above in conjunction with Figs. 1 and 2. The antenna elements **21** on the several faces **53*a*** through **53*d*** may be excited with radio frequency voltages in phase, or loop feed; or alternatively may be excited in phase rotation, also termed "turnstile" feeding. In phase rotational feeding, the antenna elements **21** on one pair of opposite faces (for example, 53*a*, 53*c*) are excited from one source of voltage while the antenna elements **21** on the other two faces (in our example, **53*b*** and **53*d***) are excited by another source of voltage of the same frequency which is displaced 90° in time relation from the first source of voltage. The radio frequency currents in the antenna elements **21** induce fields around the tower **51** which combine to produce apparent rotation of the field at radio carrier frequency. This type of feed is termed "phase rotational" or "turnstile" feed.

The conductive sheet reflector elements forming the faces **53*a*** through **53*d*** of the tower **51** have dimensions the same as the sheet reflectors **23** of Figs. 1 through 6. The sinuous conductor **21** associated with the tower faces is shown as having a zig-zag shape, but it may also be of the form shown in Fig. 3 in which the conductor **21** is made up of sections of a circle. Further, according to the particular use of the omnidirectional antenna array in accordance with Fig. 8 and the desired vertical pattern characteristic, the spacing between the sinuous conductor **21** and the tower faces **53*a*** through **53*d*** may be uniform over the entire aperture, or may be varied as explained above in the description of Figs. 4 and 5.

In Figs. 10 and 11, Fig. 10 is a view in perspective and Fig. 11 is a top plan view of another omnidirectional array in accordance with this invention. A cylindrical tower **61** forms a conductive sheet reflector surface for the sinuous conductor antenna elements **21'**. The sinuous conductor elements **21'** are maintained in spaced relation to the tower by supports **31** like those described above with respect to Figs. 1, 2 and 3. The cylinder **61** is preferably of solid metallic or conductive material for reasons to be explained below, but may consist of a conductive screen, grid, or network of conductors electrically connected together to approximate a solid sheet reflector.

Radio frequency excitation is applied to the sinuous conductors **21'** at the feedpoint **25** of each conductor **21'** in the same manner described above in conjunction with Figs. 1, 2 and 8.

As described above in conjunction with feeding the several elements **21** on the separate faces of the tower **51** of Figs. 8 and 9, the separate sinuous conductors **21'** of Figs. 10 and 11 may be excited with radio frequency voltage in the same phase, or alternatively may be fed in phase rotation.

One arrangement for feeding the separate antenna elements **21'** includes utilizing the tower **61** as a waveguide for coupling the energy between the antenna array and the radio frequency apparatus associated therewith. The arrangement shown in Figs. 10 and 11 utilizes a circular cylinder tower **61** as a circular waveguide. If all of the separate sinuous conductors **21'** are to be excited in the same phase, a mode of propagation in the circular cylinder **61** is selected which has circular symmetry (for example, $TE_{0,1}$ or $TM_{0,1}$). The radio frequency excitation is applied to the feedpoints of each of the several conductors **21'** from a probe **63** which extends into the circular guide **61**. The geometric configuration of suitable probes depends upon whether the probe is to be excited by a magnetic or an electric field within the guide **61**. Numerous suitable designs are known in the art.

To feed the separate antenna elements **21'** in phase rotational fashion utilizing the tower **61** as a circular waveguide, a circularly polarized mode or rotating polarization is employed. One method of accomplishing a rotating $TE_{1,1}$ mode in the waveguide **61** consists of exciting the waveguide **61** in two quadrature related $TE_{1,1}$ modes simultaneously. This has the effect that at any point in the waveguide **61** there exist two $TE_{1,1}$ modes of propagation which are perpendicular to one another and which are in time quadrature electrically, that is, one $TE_{1,1}$ mode leads the other by 90 electrical degrees. This produces a resultant $TE_{1,1}$ field configuration within the waveguide which appears to rotate at carrier frequency.

Probes **63** extending into the interior of the waveguide **61** pick up the energy from the rotating or circularly polarized mode of propagation in the guide **61** and apply this energy to the feed-points of the antenna elements **21'**.

Referring now to Fig. 12, there is shown a graphical representation of the horizontal field pattern variation as it varies with the cylinder diameter for three different antenna arrangements. The dashed line curve **65** shows the ratio of minimum to maximum field of four axial slots around a waveguide cylinder with phase rotational feeding. The dot-dash curve **67** represents the minimum to maximum field variation with cylinder diameter with eight axial slots around a cylinder fed in a phase rotational fashion. The solid line curve **69** represents the ratio of minimum to maximum field for eight horizontal dipoles or eight sinuous conductor elements spaced one-eighth wavelength from the outer surface of the cylinder and fed in phase rotation. Along the abscissa of the graph of Fig. 12 will be seen a vertical dashed line marked $TE_{1,1}$ cut-off at approximately $.586\lambda$.

A useful range of cylinder diameters for feeding eight sinuous conductors **21** spaced around the cylinder in the frequency band from 470 to 890 megacycles for ultra high frequency television broadcast purposes is from about 15 inches at the lower frequency to about 8 inches at the upper end of the band. For the reason that undesired higher order modes may be set up in the waveguide **16**, a maximum cylinder diameter slightly less than one wavelength should be observed, since with a diameter of $.97\lambda$ and smaller, the $TE_{2,1}$, $TE_{0,1}$, $TM_{1,1}$ and other modes of higher order cannot be propagated since the guide is below cut-off for these modes at the desired frequency of operation.

It will be seen from the solid line curve **69** of Fig. 12 that in the desirable operating range of cylinder diameter (from $0.6\lambda$ to $0.97\lambda$) utilizing eight sinuous elements around a cylinder with phase rotational excitation, the minimum field is always more than nine-tenths of the maximum field, yielding a broadcast antenna of extremely good omnidirectional pattern characteristics.

Fig. 13 is a top plan view and Fig. 14 is an elevation of an omnidirectional array in accordance with this invention in which the reflector structure is formed of two intersecting planes. The reflector structure has two plane sheets of conductive material **71**, **73** intersecting each other at right angles and electrically connected at their midpoint. A sinuous conductor **21** (which may be, for example, like the zig-zag conductor **21** of Fig. 1 or the arcuate sinuous conductor **21'** of Fig. 3) is arranged in each 90° corner between the intersecting sheet reflectors **71**, **73**, and makes an acute angle (preferably 45°) with each of them.

The sinuous conductor **21** is maintained in insulated spaced relationship from the sheet reflector structure **71**, **73** by stand-off insulators **75**. The stand-off insulators **75** are placed for convenience at the nearest points at which the sinuous conductor **21** approaches the sheet reflectors **71**, **73**. The placing of the insulators as shown in Figs. 13 and 14 has the advantage that the mechanical strength of the entire structure is considerably increased, but on the other hand, these points of support are points of high voltage at the frequency of operation, a drawback not found in the arrangement shown in Figs. 1 through 5 and 8 through 10.

The antenna array of Figs. 13 and 14 may be fed with in-phase voltages or with voltages in phase rotational or "turn-stile" relation.

Fig. 15 shows a top plan view in section of a modification of the antenna array of Figs. 13 and 14 which includes very high power transmission lines within the reflector structure for interchanging energy between the antenna and an associated radio frequency apparatus. Four slab-type coaxial transmission lines are provided. The transmission lines have broad walls which are formed by the reflector surfaces **71'** or **73'**. Narrow end walls **77** of the same sheet conductive material as the reflector surfaces **71**, **73** close the rectangle forming the exterior conductor. The center coaxial conductor is a flat slab of conductive material **79** which is parallel to the outside walls **71'** or **73'** and **77**.

These transmission lines internal to the antenna array structure may be interconnected with the antenna elements **21** in several different ways, depending upon the type of excitation to be employed. For example, if a single feedpoint is to be used to feed the total aperture with in-phase or quadrature-displaced radio frequency voltages, each slab-type coaxial line **71'**, **77**, **79** or **73'**, **77**, **79** is directly connected to the antenna element **21** with which it is associated at the feedpoint thereof by a conductive metallic bonding strip from the center slab conductor **79** through an aperture in the reflector **71'** or **73'** to the feedpoint of the antenna conductor **21**. The separate transmission lines are then connected to a single source of voltage with equal length lines for in-phase excitation or with suitable phasing harness to produce the quadrature-displaced voltages in a manner well-known in the art. Further, if two or more feedpoints are necessary for an array because of its exceedingly long aperture, the four separate transmission lines thus provided may be utilized to excite the several bays separately. An apparatus for accomplishing the division of radio frequency power between the several bays in the total array may be located at the base of the antenna within the associated tower or within the building or other structure upon which the antenna array is erected.

Referring to Figs. 16 and 17, there is shown another arrangement in accordance with this invention of which Fig. 16 is a top plan view and Fig. 17 is a view in perspective. The reflector structure has two plane sheets of conductive material **71**, **73** intersecting each other at right angles and electrically connected at their midpoint. A sinuous conductor **21''** is bent to a right angle along its lengthwise axis and is arranged in each 90 degree corner between the intersecting sheet reflectors **71**, **73**. The portions of the sinuous conductor **21''** adjacent the sheet reflector **71** is parallel thereto and those portions of the sinuous conductor **21''** adjacent the other sheet reflector 73 is parallel to this other sheet reflector 73. Before being bent along its lengthwise center axis to form the 90° corner, the sinuous conductor 21″ may be like the zig-zag conductor 21 of Fig. 1 or the arcuate sinuous conductor 21′ of Fig. 3.

The sinuous conductor 21″ is spaced from each of the two sheet reflectors 71, 73 by a distance D which may be uniform throughout the aperture of the array as described in connection with Figs. 1 and 2 above, or which may vary over the length of the aperture as described in conjunction with Figs. 4 and 5. The sinuous conductor 21″ is maintained in insulated spaced relationship to each of the two sheet reflectors 71, 73 by insulating spacers 75 at the sharp bends of the zig-zag or the maximum deviation of the conductor 21″ from its lengthwise axis. Also, for added rigidity, a plurality of supports 31′ may be used at the center of the half-wave sections of the sinuous conductor 21″, as explained above in conjunction with Figs. 1 and 2. These supports 31′ may be either metal or of insulation material.

It should also be noted that the doubly bent sinuous conductor 21″ of Figs. 16 and 17 may be employed with the reflector structure 71′, 73′ of Fig. 15 which includes therein the slab-type coaxial transmission lines 71′, 77, 79 and 73′, 77, 79.

Referring now to Fig. 18, there is shown a single unit of a zig-zag conductor and reflector antenna array which includes a modification of the antenna feed system. The antenna conductor is composed of two halves. The upper half, or portion farthest removed from the associated radio frequency apparatus to which the antenna array is to be coupled is designated by the reference character 121 and is of the form shown and described above in Figs. 1 and 2. The lower half, or portion closer to the radio frequency apparatus is composed of two parallel conductors 121*a* and 121*b*. The parallel conductor section 121*a*, 121*b* forms a balanced two-conductor open wire line. The spacing between the two conductors and the two-wire line 121*a* and 121*b* is made as small as possible with respect to a wavelength at the operating frequency to prevent extraneous radiation from the balanced two-wire section. This lower two-wire section is excited with radio frequency voltage in push-pull relation, that is, balanced with respect to a point of fixed reference potential, such as ground. By using small spacing between the two conductors 121*a* and 121*b* and taking care to insure the physical symmetry of each conductor with respect to ground and the reflector structure, radio frequency energy is transmitted along the two-wire section without radiation. At a feedpoint along the zig-zag conductor arrangement, a balanced-to-unbalanced transformer or balun 125 is employed to convert the balanced radio frequency energy appearing across the two-wire line 121*a* and 121*b* to a single-sided voltage, one which is unbalanced with respect to ground. This single-sided voltage is applied between the reflector screen 23 and both halves of the antenna (which appear in parallel with respect to the feedpoint) including the upper half 121 and the lower half consisting of the two-wire line 121*a*, 121*b*. At the feedpoint of the antenna, the entire zig-zag or sinuous conductors 121, 121*a* and 121*b* are excited by the unbalanced voltage in the same manner as the feeding system shown in Figs. 1, 2 and 3 and subsequent figures.

The two-wire section 121*a* and 121*b* therefore is excited in two modes of propagation: the balanced (non-radiating) mode by which the energy is brought from the associated radio frequency apparatus to the balun 125, and the unbalanced or single-sided voltage between the feedpoint and the reflector screen 23 which produces the antenna currents causing the zig-zag conductor to radiate.

Fig. 19 shows one type of balun which may be used in conjunction with the system of Fig. 18 to convert the balanced energy in the two-wire transmission line 121*a*, 121*b* to single-sided energy for exciting the entire antenna 121, 121*a*, 121*b*. A balun of the split-drum type is employed in which a first or inner conductor 127 is coaxial with a surrounding conductive sleeve 129. The cylindrical sleeve 129 is bifurcated at one end for a distance of approximately one-quarter wavelength at the operating frequency. The inner conductor 127 is electrically connected to one side of the bifurcated portion and is maintained in insulated spaced relationship from the other side of the bifurcated portion. This entire assembly is enclosed in a surrounding cylinder 131 which is coaxial with the inner conductor 127 and the bifurcated sleeve 129. The balanced voltage to be converted to an unbalanced or single-sided voltage is applied between the ends 133, 134 of the bifurcated sleeve 129. The applied voltage is converted to single sided by the balanced-to-unbalanced converter 125 and appears between the inner conductor 127 and the sleeve 129. The inner conductor 127 is connected to the surrounding cylinder 131 which in turn is electrically and mechanically bonded to the sheet reflector structure 23. Considered in one way, a portion of the balun 125 is in effect a folded coaxial line; the sleeve 129 forms the inner conductor and is connected to both sides of the two-wire line 121*a*, 121*b* and the surrounding cylinder 131 is the outer conductor. The cylinder 131 is electrically a continuation of the first conductor 127 and is folded back over the sleeve 129 to return to the sheet reflector structure 23. The single-sided voltage is therefore applied between the two-wire line 121*a*, 121*b* (by the sleeve 129) and the reflector structure 23 (by the cylinder 131).

The two-wire line is made to continue beyond the balun structure for a distance, although it does not function as a two-wire balanced transmission line but rather as a single conductor 121. A metallic shorting block 135 may be used to electrically connect the two conductors together approximately one-quarter wavelength beyond the point of connection to the ends of the bifurcated sleeve 133, 134. This shorting block 135 serves two purposes: first, it prevents the balanced radio frequency energy from being propagated farther; and second, the proper impedance matching of the balun structure to the two-wire line 121*a*, 121*b* may be provided by varying the position of the block 135.

What is claimed is:

1. An antenna array comprising a sinuous conductor antenna element a plurality of wavelengths long having a component of direction transverse to the length of said conductor which reverses every half wavelength at the operating frequency, a sheet reflector structure in the near zone of said sinuous conductor having a length longer than said sinuous conductor and an effective width substantially one-half wavelength at said operating frequency, a feed terminal at a point on said antenna element intermediate the ends thereof, and another feed terminal at an adjacent point on said reflector structure.

2. An antenna array comprising a sheet reflector structure having an effective width of substantially one-half wavelength and a length of a plurality of wavelengths at the operating frequency, a sinuous conductor antenna element a plurality of wavelengths long having a component of direction in a direction transverse to the length of said reflector structure and said antenna which reverses every half wavelength at said operating frequency, means spacing said sinuous conductor from said sheet reflector along the length thereof, and feed terminals for said antenna at the electrical center thereof, one of said terminals being on said antenna element and the other of said terminals being on said reflector structure.

3. An antenna array comprising a sheet reflector structure having an effective width of substantially one-half wavelength and a length of a plurality of wavelengths at the operating frequency, said sheet reflector having a linear lengthwise axis, a sinuous conductor element a

plurality of wavelengths long having a component of direction transverse to the length thereof which reverses every half wavelength at said operating frequency, said sinuous conductor element having a lengthwise axis substantially parallel to said lengthwise axis of said reflector structure along the length thereof, means spacing said sinuous conductor from said sheet reflector structure, a feed terminal at a point on said antenna element intermediate the ends thereof, and another feed terminal at an adjacent point on said reflector structure.

4. An antenna array comprising a sheet reflector structure having an effective width of substantially one-half wavelength and a length of a plurality of wavelengths at the operating frequency, said sheet reflector having a linear lengthwise axis, a sinuous conductor element a plurality of wavelengths long having a component of direction transverse to the length thereof which reverses every half wavelength at said operating frequency, said sinuous conductor element extending collaterally and spaced from said lengthwise axis of said reflector structure along the length thereof, means spacing said sinuous conductor from said sheet reflector structure, a feed terminal at a point on said antenna element intermediate the ends thereof, and another feed terminal at an adjacent point on said reflector structure.

5. An antenna array comprising a sheet reflector structure having an effective width of substantially one-half wavelength and a length of a plurality of wavelengths at the operating frequency, said sheet reflector having a linear lengthwise axis, a sinuous conductor element a plurality of wavelengths long having a component of direction transverse to the length thereof which reverses every half wavelength at said operating frequency, said sinuous conductor element being substantially parallel to said reflector structure in a direction transverse to the length of said reflector structure and extending collaterally with said lengthwise axis of said reflector structure, means spacing said sinuous conductor from said sheet reflector structure by a distance of $\frac{1}{12}$ to $\frac{1}{4}$ wavelength at said operating frequency a feed terminal at a point on said conductive element intermediate the ends thereof, and another feed terminal at an adjacent point on said sheet reflector.

6. An antenna array as defined in claim 5 wherein said sinuous conductor element lies in a plane parallel to the lengthwise axis of said sheet reflector structure.

7. An antenna array as defined in claim 5 wherein said sheet reflector structure is a plane surface.

8. An antenna array as defined in claim 1 wherein said sinuous conductor element comprises a zig-zag conductor having straight portions substantially $\frac{1}{2}$ wavelength long at said operating frequency.

9. An antenna array as defined in claim 3 wherein said sinuous conductor element comprises a zig-zag conductor having straight portions substantially $\frac{1}{2}$ wavelength long at said operating frequency, said straight portions forming an angle of between 30° and 60° with said lengthwise axis of said reflector structure.

10. An antenna array as defined in claim 1 wherein said sinuous conductor element is composed of arcs of a circle.

11. An antenna array as defined in claim 2 wherein said sinuous conductor element is composed of alternately positioned arcuate portions.

12. An antenna array as defined in claim 2 wherein the spacing between said sinuous conductor and said sheet reflector along the length thereof varies as a function of the distance from said feed terminals.

13. An antenna array as defined in claim 2 wherein the spacing between said sinuous conductor and said sheet reflector along the length thereof varies as an exponential function of the distance from said feed terminals.

14. An antenna array as defined in claim 2 wherein the spacing between said sinuous conductor and said sheet reflector along the length thereof varies as a linear function of the distance from said feed terminals.

15. An antenna array as defined in claim 2 wherein the spacing between said sinuous conductor and said sheet reflector along the length thereof varies as a second order function of the distance from said feed terminals.

16. An antenna array comprising a sinuous conductor antenna element a plurality of wavelengths long having a component of direction transverse to the length of said conductor which reverses every half wavelength at the operating frequency, a sheet reflector structure composed of a plurality of plane conductive sheet members in the near zone of said sinuous conductor and extending collaterally with and spaced from said sinuous conductor along the length thereof, means spacing said sinuous conductor from said sheet reflector structure, a feed terminal at a point on said antenna element intermediate the ends thereof, and another feed terminal at an adjacent point on said reflector structure.

17. An antenna array as defined in claim 16 wherein said sinuous conductor is a zig-zag with straight portions $\frac{1}{2}$ wavelength long at said operating frequency.

18. The combination as defined in claim 17 wherein said zig-zag conductor is substantially parallel to an adjacent plane sheet reflector.

19. An antenna array as defined in claim 2 wherein said sheet reflector structure is a conductive cylinder.

20. An antenna array as defined in claim 4 wherein said sheet reflector structure is a right circular cylinder having a diameter of between .6 and 1 wavelength at the operating frequency.

21. An antenna array comprising a sheet reflector structure in the form of a right circular conductive cylinder having a diameter of from 0.6 to 0.97 wavelength at the operating frequency and a length of a plurality of wavelengths at said operating frequency, a sinuous conductive element a plurality of wavelengths long having a component of direction transverse to the lengthwise axis of said cylinder which reverses every half wavelength along said conductor at said operating frequency, means spacing said sinuous conductor from said cylinder along the length thereof by a distance of from $\frac{1}{12}$ to $\frac{1}{4}$ wavelength, and feed terminals from said antenna intermediate the ends of said sinuous conductor elements, one of said terminals being on said conductive element and the other of said terminals being on said reflector structure.

22. An antenna array as defined in claim 21 wherein said sinuous conductor element is composed of a continuous conductor having alternately disposed arcuate portions.

23. An antenna array comprising a sheet reflector structure having a length of a plurality of wavelengths at the operating frequency, a sinuous conductor antenna element a plurality of wavelengths long having a component of direction in a direction transverse to the length of said reflector structure and said antenna which reverses every half wavelength at said operating frequency, means spacing said sinuous conductor from said sheet reflector along the length thereof, and feed terminals for said antenna at the electrical center thereof, one of said terminals being on said antenna element and the other of said terminals being on said reflector structure.

24. An antenna array comprising a sinuous conductor antenna element a plurality of wavelengths long having a component of direction transverse to the length of said conductor which reverses every half wavelength at the operating frequency, a sheet reflector structure in the near zone of said sinuous conductor having a length longer than said sinuous conductor, a first feed point including a terminal at an intermediate point on said antenna element and a terminal at an adjacent point on said reflector structure, and a second feed point including a terminal at one end of said antenna element and a terminal at an adjacent point on said reflector.

25. An antenna array comprising a sinuous conductor

antenna element a plurality of wavelengths long having a component of direction transverse to the length of said conductor which reverses every half wavelength at the operating frequency, a sheet reflector structure in the near zone of said sinuous conductor having a length longer than said sinuous conductor, a first feed point including a terminal at an intermediate point on said antenna element and a terminal at an adjacent point on said reflector structure, and a second feed point including a terminal at one end of said antenna element and a terminal at an adjacent point on said reflector, and a third feed point including a terminal at the other end of said antenna element and a terminal at an adjacent point on said reflector.

26. An antenna array comprising a sinuous conductor antenna element a plurality of wavelengths long at the operating frequency and having a component of direction transverse to the length of said conductor which reverses every half wavelength, a sheet reflector structure, said



antenna element and said sheet reflector structure lying in generally parallel planes spaced apart, and means to feed said antenna array including one terminal at an intermediate point on said antenna element and another terminal at an adjacent point on said reflector structure.


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