Dec. 6, 1966 J. D. KRAUS 3,290,688

BACKWARD ANGLE TRAVELLING WAVE WIRE MESH ANTENNA ARRAY

Filed June 11, 1962 2 Sheets-Sheet 1

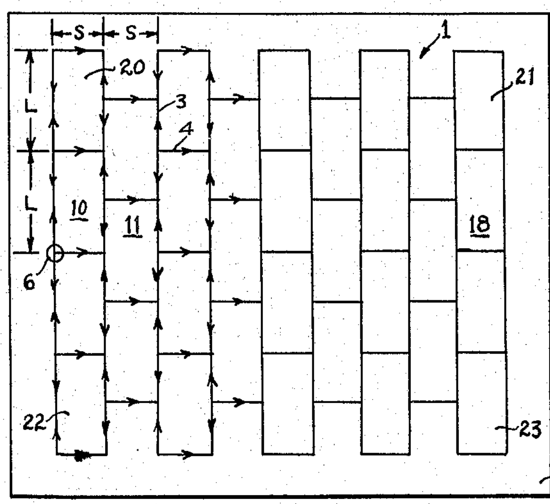

Fig. 1

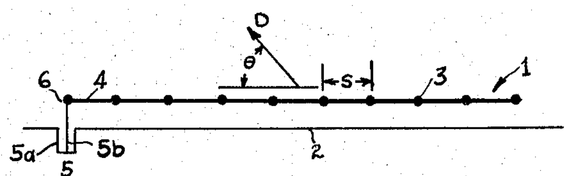

Fig. 2

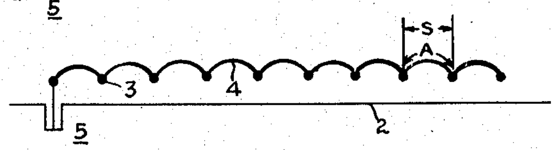

Fig. 3

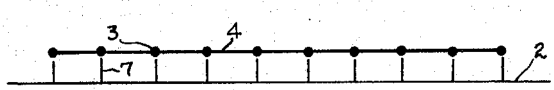

Fig. 4

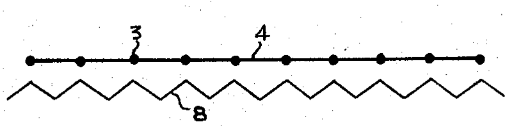

Fig. 5

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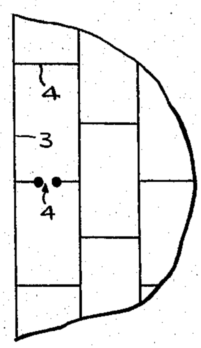

Fig. 6

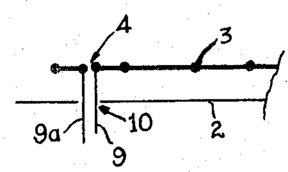

Fig. 7

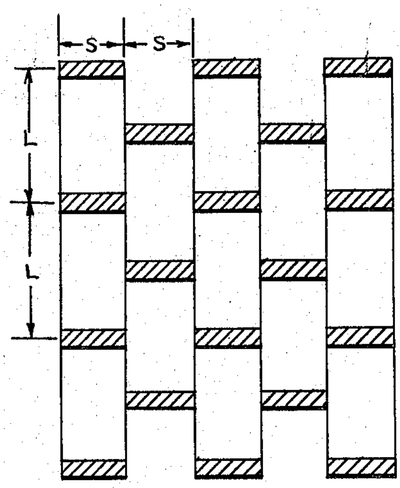

Fig. 8

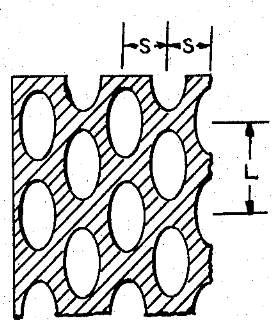

Fig. 9

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BACKWARD ANGLE TRAVELLING WAVE WIRE MESH ANTENNA ARRAY

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This invention relates to high-gain antennas and in particular to a non-resonant antenna array having an electrically controlled radiated beam.

In conventional antennas, it is necessary, to achieve high gain, to use an antenna whose dimensions are large compared to the wavelength. One form of a standard high-gain antenna consists of an array of dipole radiating elements arranged to cover a flat square or rectangular area with maximum radiation broadside to the area. Such an arrangement is usually called a broadside-type of array. In this antenna transmission lines must be provided to each radiating element. In arrays with large numbers of elements the complexity in construction and adjustment of individual elements and the losses in the transmission lines limit the effectiveness of the arrangement.

An alternative form of high-gain antenna employs a single primary antenna with a large reflecting surface, usually of parabolic shape, to focus the radiation. This form of antenna has the advantage that only a single feed point with one transmission line is required. However, the curved reflecting surface of the parabola is usually more difficult to construct and maintain than the flat geometry required in a broadside-type of array. Furthermore, the curved reflecting surface results in a larger enclosed antenna volume than required in a flat broadside-type of array.

My present invention overcomes the above-noted objections and yet provides an antenna that incorporates the features of each by providing a flat mesh of conducting elements above a ground. The mesh of elements is excited at a single point by a traveling wave, resulting in a beam having a direction less than broadside. No transmission lines are required to distribute energy over the mesh, the mesh structure having both radiating and guiding (or transmission) properties. Further, the direction of the beam may be altered or scanned electrically by varying the feed frequency.

Accordingly, it is a principal object of the present invention to provide a high-gain antenna which combines the small space volume of a flat-type array with the simplicity of a single feed point.

It is another object of the present invention to provide an antenna having the advantages of an array of elements but is fed at a single point with a single transmission line.

It is a further object of the present invention to provide an antenna with method and means of electrically controlling the angle of beam radiated therefrom without making physical changes in the structure.

Still another object of the present invention is to provide an efficient high-gain antenna that is relatively simple in construction and operation to assure reliability in manufacture.

Other objects and features of the present invention will become apparent from the following detailed description when taken in conjunction with the drawings in which:

FIG. 1 is a plan view of the basic arrangement of the antenna of my present invention;

FIG. 2 is an elevational view of the basic arrangement of the antenna of FIG. 1;

FIG. 3 is an alternative arrangement of the construction of the radiating elements in the antenna of FIG. 1;

FIG. 4 is another alternative arrangement of the construction of the radiating elements in the antenna of FIG. 1;

FIG. 5 is an arrangement for the construction of the ground plane structure of the antenna of FIG. 1;

FIG. 6 is an alternative arrangement in plan view for feeding the grid elements of the antenna of FIG. 1;

FIG. 7 is a partial elevational view of the feeding arrangement shown in FIG. 6;

FIG. 8 is an alternative construction of the grid elements per se that are shown in FIG. 1; and

FIG. 9 is still another alternative construction of the grid structure of the antenna of FIG. 1.

A preferred embodiment of the present invention very generally comprises a relatively flat mesh of conducting elements spaced a small fraction of a wavelength from a flat conducting ground plane. A single transmission line from the associated transmitter or receiver is connected to one point of the mesh. A preferred location for this connection of the feed point is at one edge of the mesh. When fed in this manner electromagnetic energy in the form of a traveling wave travels from the edge of the mesh. The resulting radiation pattern has maximum power in the direction making an angle θ with respect to the plane of the array. That is, the array is an angle-fire type. Further, the beam direction can be electrically scanned or steered over appreciable angles by shifting the frequency of the feed signal. Again, by varying the number of meshes in the grid and, hence, the over-all dimensions of the array, the beam widths and directivity of the antenna can also be controlled.

Referring now specifically to the drawings, wherein FIG. 1 is a plan view and FIG. 2 an elevation view of the antenna, in its basic form, the antenna comprises a flat mesh of conductors **1** placed parallel to and a small fraction of a wavelength from a flat conducting ground plane **2**. The grid **1** is comprised of rectangular meshes whose long sides **3** of the length L are approximately a wavelength long at the center frequency of operation. The short sides **4** of the rectangles join the long sides **3** of the adjacent rectangles, at their center points. All conductors **3** and **4** are electrically connected at the corners of the rectangles making the grid a continuous electrical structure. The electromagnetic energy is fed to the grid through feed line **5**, illustrated in FIG. 2 as a coaxial cable, having its outer conductor **5a** connected to the ground plane **2** and its inner conductor **5b** connected to the grid mesh at edge **6** thereof.

In the operation of the antenna of FIGS. 1 and 2, the radiation is essentially from the short elements **4** with the longer members **3** acting mainly as guiding or transmission line elements. The arrows on the grid elements **3** and **4** indicate assumed instantaneous current directions at the arrow locations when the sides **3** of the rectangles are about one wavelength long and sides **4** about one-half wavelength of the operating signal under assumed theoretical single frequency resonant operation. With such a current distribution, all members **4** are in phase and the maximum radiation would be broadside to the array, or the angle θ in FIG. 2 would be 90°.

In actual operation of the antenna mesh of FIGS. 1 and 2, the antenna is a non-resonant antenna operable over a wide band of frequencies and consequently the phasing of the currents is different from that indicated. That is, with a coaxial feed cable **5** connected so that the inner conductor **5*b*** is attached to the grid joint at point **6** and the outer conductor **5*a*** to the ground plane **2**, the grid, when transmitting, is excited by a traveling wave which propagates from left to right in FIGS. 1 and 2. The phasing is such that there is a progressive shift in phase from one ladder of the mesh to the next so that when the phases are added vectorally, the resulting beam direction D is at an angle θ which is less than 90°. More precisely, the maximum radiation is in a plane passing through the center of the grid parallel to a short side **4** of the rectangles and perpendicular to the plane of the array. In this way, the angle of the maximum radiation is between the broadside direction and the fed edge of the grid.

As mentioned above, the radiation from the antenna is essentially from the short elements **4** with the longer members **3** acting mainly as guiding or transmission line elements. In order to minimize the radiation from the members **3**, and enhance the radiation from the members **4**, several alternative constructed embodiments may be substituted for that shown in FIG. 1. In the first alternative embodiment, the members **4** can be curved outward from the ground plane as suggested in FIG. 3. In this way, the members **3** are closer to the ground plane **1** and, therefore, less effective as radiating elements. In this arrangement the length A measured along the curved arc of members **4** exceeds the spacing S by 25 percent or more. Another alternative arrangement for the same purpose is to keep all member **3** and **4** in a flat plane as in FIGS. 1 and 2 and to connecting conducting strips **7** to the ground plane. The strips are so placed to be perpendicular to the ground plane and parallel to the long sides **3** of the mesh as in FIG. 4. The strips extend upward to a short distance from the mesh.

Again, another alternative arrangement is to use a corrugated ground plane **8** as in FIG. 5 with the ridges of the corrugations closely adjacent and parallel to the members **3**. The ground plane **2** of FIGS. 1, 2, 3, or 4, or **8** of FIG. 5, may be of solid conducting sheet or may consist of a screen or grid with holes or perforations whose peripheral length is less than one-half wavelength and preferably much less.

The conductors of the mesh of the antenna of FIG. 1 are considered to be of a circular cross-section. However, conductors may have other shapes or forms to make the construction of the antenna conform to that of a particular manufacturing process or to adapt the antenna to a specific geometrical configuration, such as the contour of an aircraft. For example, in a stamping process, it may be more desirable that the mesh elements be made up partly of flat strip conductors. An arrangement using flat strips for the short sides of the grid rectangles, is illustrated in FIG. 8. As another example, the grid can be made entirely by an industrial stamping process. This can be acomplished by stamping out of a continuous conducting sheet holes or perforations. A mesh constructed in this manner is illustrated in FIG. 9. A wide variety of conductor shapes can be employed to form the basic periodic structure represented in its simplest form by the grid in FIG. 1. The ratio of the length L of the long sides **3** to the length S of the short sides **4** of the rectangles of the grid is shown as 2 to 1 in FIG. 1, but this ratio can be varied. Ratios may range from 1.5 (or less) to 1 to 3 (or more) to 1, with preferred values of the *L/S* ratio between 2 to 1 to 3 to 1.

To accommodate the array to a particular configuration, the array need not be square or rectangular in over-all dimensions. For example, one or more meshes **20, 21, 22, 23** may be omitted at the corners of the array so that the over-all outline approaches that of a circle or an ellipse.

Although both the grid structure and the ground plane have been described as flat, the invention is not to be so limited and both the grid and ground plane may be curved either convex or concave. The result of such curvature and its advantage is to broaden the beam width in the plane of curvature.

The feed arrangement of FIG. 1 is by way of illustration. Other arrangements for feeding the grid are possible without departing from the spirit of the invention. With reference to FIG. 6 and the partial elevation view of FIG. 7, there is shown a two-wire transmission line **9** and **9*a*** passing through opening **10** in the ground plane **2** and connecting with the opened center of a side **4** of one of the grid rectangles.

Although the grid is usually most conveniently placed parallel to the ground plane, the spacing can be varied in order to afford some control of the current distribution over the array. The grid may be held away from the ground plane by a plurality of insulating supports constructed of dielectric material or by other means well known to the art.

As pointed out above, the antenna structure of FIG. 1 is a broad-band antenna; that is, it is a non-resonant antenna and is operable at maximum power over a band of frequencies. It has been found that there is a direct relationship between frequency change and beam angle, the change in beam angle being approximately proportional to the frequency. It is possible to scan electrically with the present antenna, that is, without utilizing mechanical movement or physically varying the parameters.

A constructed embodiment of an antenna of the present invention comprised the same number and arrangement of rectangles as in FIG. 1. The mesh rectangle dimensions of L were approximately 0.95 wavelength, S about 0.35 wavelength, the curved members **4** (as in FIG. 3) had a length A of about 0.43 wavelength. With this physical arrangement there was produced a beam at an angle θ of about 50°. In this embodiment the mesh sides **3** were spaced approximately 0.1 wavelength from the ground plane. The ends of the short sides **4** of the rectangles were the same distance from the ground plane but the outward curvature of these members placed the center of the sides **4** about 0.2 wavelength from the ground plane. The beam width measured between half-power points was about 18° in the plane of the electric vector and about 12° in the plane of the magnetic vector. Changes in frequency of plus or minus 10 percent produced shifts in the beam direction θ of approximately plus or minus 25°, that is, from about $\theta=25°$ to $\theta=75°$.

It is understood that the beam widths set forth above are for an array having the over-all dimensions 4L by 9S. By changing the numbers of meshes and, hence, the over-all dimensions, the beam widths can be varied. Thus, the beam width of the main lobe of radiation in the plane of the magnetic vector is largely controlled by the dimension NL and the beam width in the plane of the electric vector by the dimension nS, where N is the maximum number of meshes measured in the L direction and n is the number of meshes measured in the S direction.

While the operation of the antenna of the present invention has been discussed mainly in connection with radiation from the antenna, it is apparent from the principle of reciprocity that the pattern characteristics would be the same for both transmitting and receiving. Also, by way of definition, it is understood that the term grid or mesh, as used herein, is intended to mean conductors mechanically connected and electrically bonded at intersection points.

It is apparent that the present invention provides an antenna that is useful for high-gain applications. In particular, the flat grid and ground plane arrangement occupies a minimum volume while the single feed point provides great simplicity in connecting the antenna to a receiver or transmitter. The tilt angle of the beam can be controlled without requiring any physical changes in the antenna. The grid structure is simple and easily fabricated.

Although certain specific and alternative arrangements have been shown and described, it is to be understood that modifications and departures may be had without departing from the true spirit and scope of the invention.

What is claimed is:

1. A broadband directional antenna comprising a plurality of conductors interconnected to form a rectangular mesh structure with the short sides of said rectangles essentially comprising the radiating elements and the long sides of said rectangles essentially comprising the transmission line elements; said rectangles being in parallel relationship to each other and wherein the short sides of the rectangles form a ladder connected to the centers of the long sides of adjacent rectangles in an adjacent ladder.

2. A broadband directional antenna comprising a plurality of conductors interconnected to form a rectangular mesh structure with the short sides of said rectangles essentially comprising the radiating elements and the long sides of said rectangles essentially comprising the transmission line elements; said rectangles being in parallel relationship to each other and wherein the short sides of the rectangles form a ladder connected to the centers of the long sides of rectangles in an adjacent ladder, a ground plane, and means for maintaining said mesh in fixed relation to said ground plane.

3. A broadband directional antenna structure comprising a plurality of conductors interconnected to form a rectangular mesh, the short sides of said rectangles connected to the centers of the long sides of said rectangles, said rectangles being in parallel relationship to each other and wherein the short sides of the rectangles form a ladder, a ground plane, means for maintaining said ground plane in a fixed relation from said mesh, and feed means connected to one end of said mesh and said ground plane for exciting said antenna by a travelling wave propagating from said one end to the other end of said mesh and wherein there is a progressive shift in phase from one ladder of the mesh to the next.

4. A broadband directional antenna comprising a plurality of conductors interconnected to form a rectangular mesh structure with the short sides of said rectangles connected to the centers of the long sides of said rectangles, a ground plane, and means for maintaining said mesh in fixed relation to said ground plane; and wherein the length of the long sides of the rectangles is in the order of one wavelength at the center frequency of operation and the length of the short sides of said rectangles is between one-quarter and one-half wavelength at said center frequency.

5. A broadband directional antenna comprising a plurality of conductors interconnected to form a rectangular mesh structure with the short sides of said rectangles connected to the centers of the long sides of said rectangles, a ground plane, and means for maintaining said mesh in fixed relation to said ground plane; and wherein the length of the long sides of the rectangles is in the order of one wavelength at the center frequency of operation and the length of the short sides of said rectangles is between one-quarter and one-half wavelength at said center frequency and herein the short conductors of said rectangular mesh are bent outward from the plane of the mesh.

6. A broadband directional antenna comprising a plurality of conductors interconnected to form a rectangular mesh structure with the short sides of said rectangles connected to the centers of the long sides of said rectangles, a ground plane, and means for maintaining said mesh in fixed relation to said ground plane; and wherein the length of the long sides of the rectangles is in the order of one wavelength at the center frequency of operation and the length of the short sides of said rectangles is between one-quarter and one-half wavelength at said center frequency and wherein means is provided to maintain the spacing between said mesh and said ground plane in the order of one-quarter wavelength or less.

7. A broadband directional antenna as set forth in claim 3 wherein said means to maintain the spacing between said mesh and said ground plane in the order of one-quarter wavelength or less and said feed means comprises a cable having an inner conductor connected to said mesh and an outer conductor connected to said ground plane.

8. A broadband directional antenna as set forth in claim 3 wherein said feed means comprises a pair of balanced conductors connected to said mesh.

9. A broadband directional antenna comprising a plurality of conductors interconnected to form a rectangular mesh structure with the short sides of said rectangles connected to the centers of the long sides of said rectangles, a ground plane, and means for maintaining said mesh in fixed relation to said ground plane; and in which the short conductors of said rectangular mesh are bent outward from the plane of the mesh.

10. A broad band directional antenna comprising a plurality of conductors interconnected to form a rectangular mesh structure with the short sides of said rectangles connected to the centers of the long sides of said rectangles, a ground plane, and means for maintaining said mesh in fixed relation to said ground plane; and further comprising a plurality of elongated conducting strips having their short dimensions perpendicular to said ground plane and extending from said ground plane to a short distance from said mesh.

11. A broadband directional antenna as set forth in claim 2 in which said ground plane is corrugated.

12. A broadband directional antenna as set forth in claim 1 in which the plane of said mesh is relatively flat.

13. A broadband directional antenna as set forth in claim 1 in which the plane of said mesh is curved.

14. A broadband directional antenna as set forth in claim 2 in which the plane of said mesh and said ground plane is relatively flat.

15. A broadband directional antenna as set forth in claim 2 in which the plane of said mesh and said ground plane is curved.

16. A broadband directional antenna as set forth in claim 2 in which said mesh conductors are flat strips.

17. A broadband directional antenna comprising a continuous conducting sheet means for forming in said sheet a plurality of elongated slots, the spacing between the centers of the long sides of said slots being in the order of one wavelength at center frequency of operation and the spacing between the centers of the short sides of said slots being between one-quarter and one-half wavelength the material between the slots forming a plurality of side by side ladder structures, a ground plane, means for maintaining said ground plane in a fixed relation to said conducting sheet, and feed means connected to one end of said conducting sheet and said ground plane for exciting said antenna by a travelling wave propagating from said one side to the other end of said sheet and wherein there is a progressive shift in phase from one ladder of the slots to the next.

18. A broadband directional antenna as set forth in claim 2, means for feeding said antenna at one end thereof, and means for varying the frequency of operation to vary the beam angle of said antenna.

19. A broadband directional antenna as set forth in claim 2 means for feeding said antenna at one end thereof and means whereby the frequency of operation is varied to vary the beam angle of said antenna in a

range of $\theta=20°$ to $\theta=85°$ from the plane of said mesh.

20. A broadband directional antenna comprising a plurality of conductors interconnected to form a rectangular mesh structure with the short sides of said rectangles connected to the centers of the long sides of said rectangles, a ground plane, and means for maintaining said mesh in fixed relation to said ground plane; and wherein the length of the long sides of the rectangles is in the order of one wavelength at the center frequency of operation and the length of the short sides is between one-quarter and one-half wavelength at said center frequency, wherein means is provided for feeding said antenna at one end thereof and means is provided for varying the frequency of operation to vary the beam angle of said antenna in the range of $\theta=20°$ to $\theta=85°$.

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