Sept. 27, 1966 A. DORNE ET AL 3,276,023

GRID ARRAY ANTENNA

Filed May 21, 1963 4 Sheets-Sheet 1

Fig. 1

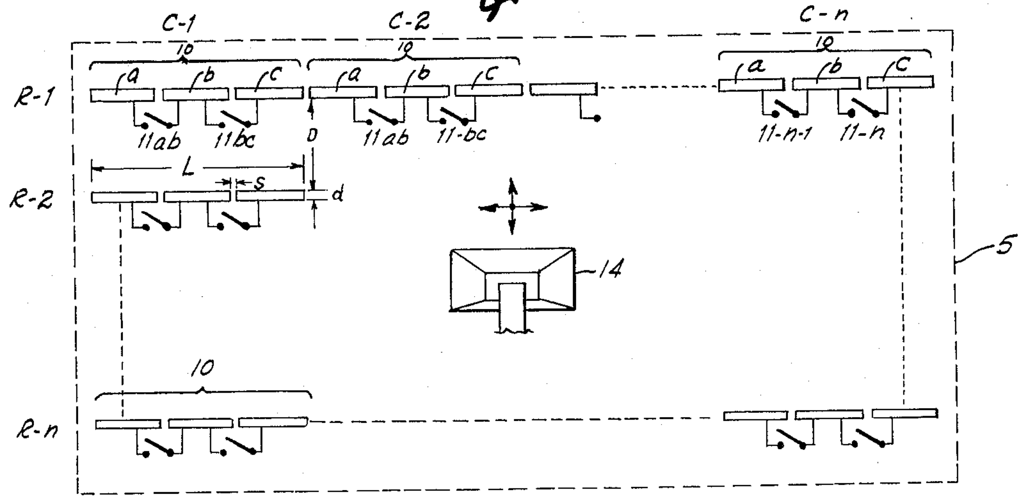
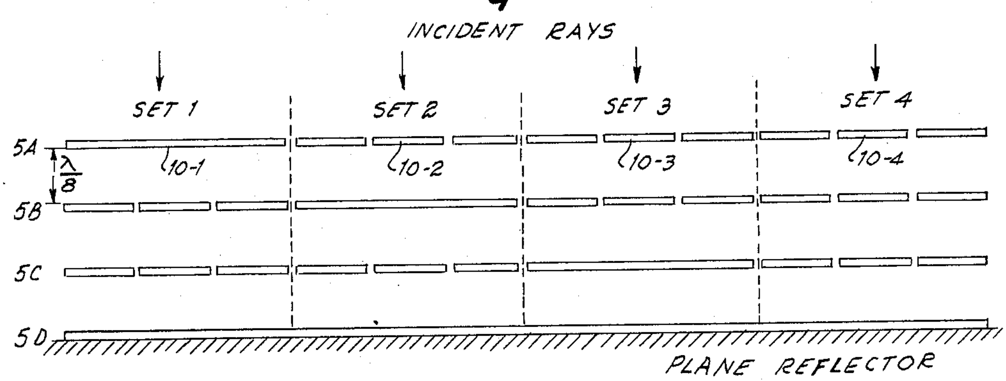


Fig. 2



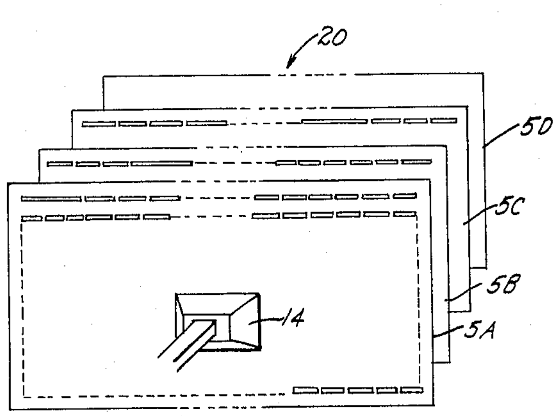


Fig. 2A

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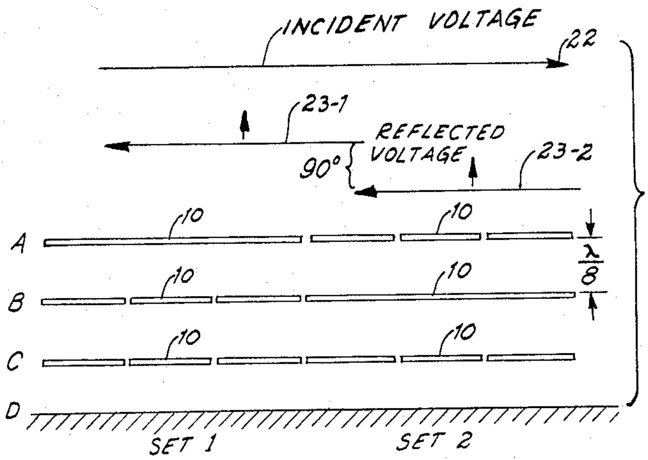

Fig. 3

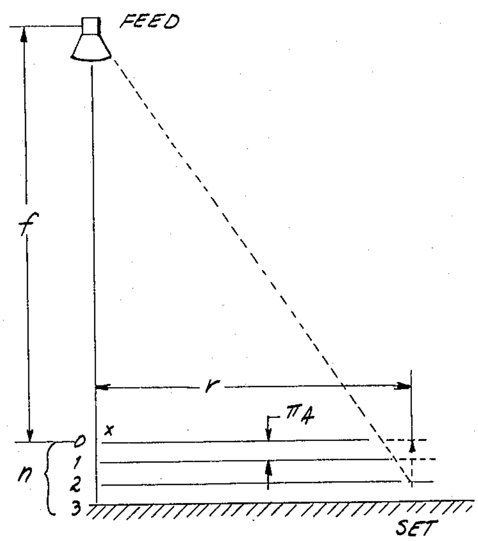

Fig. 4

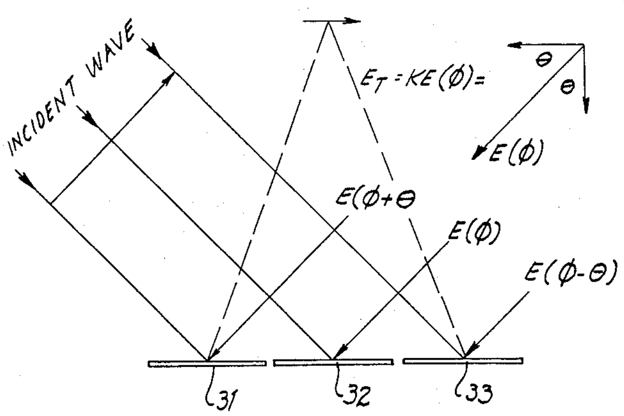

Fig. 5

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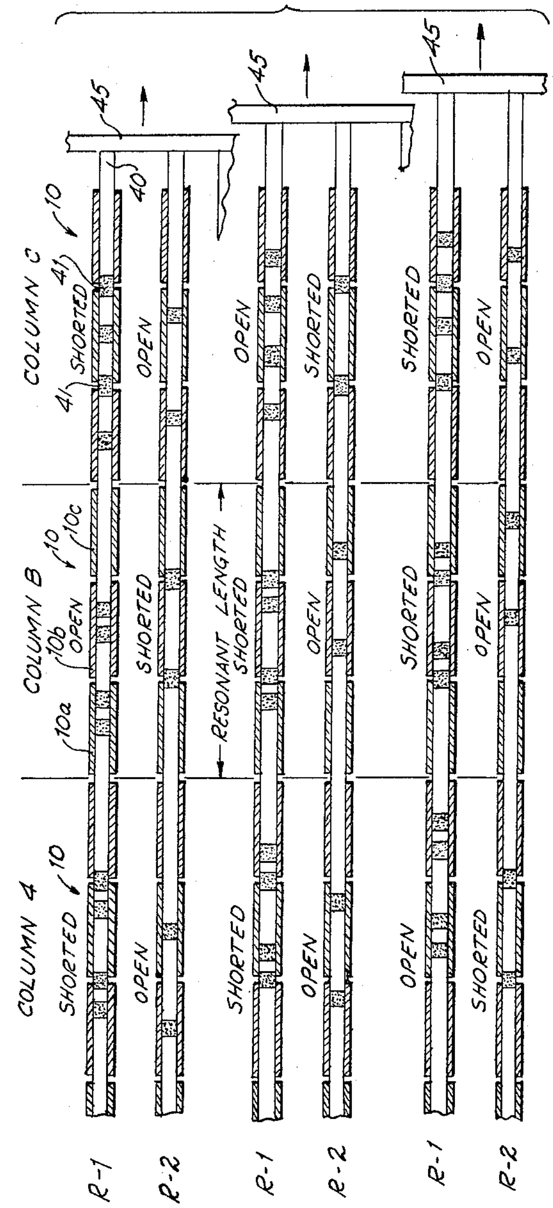
GRID ARRAY ANTENNA

Filed May 21, 1963 4 Sheets-Sheet 3

Fig. 7



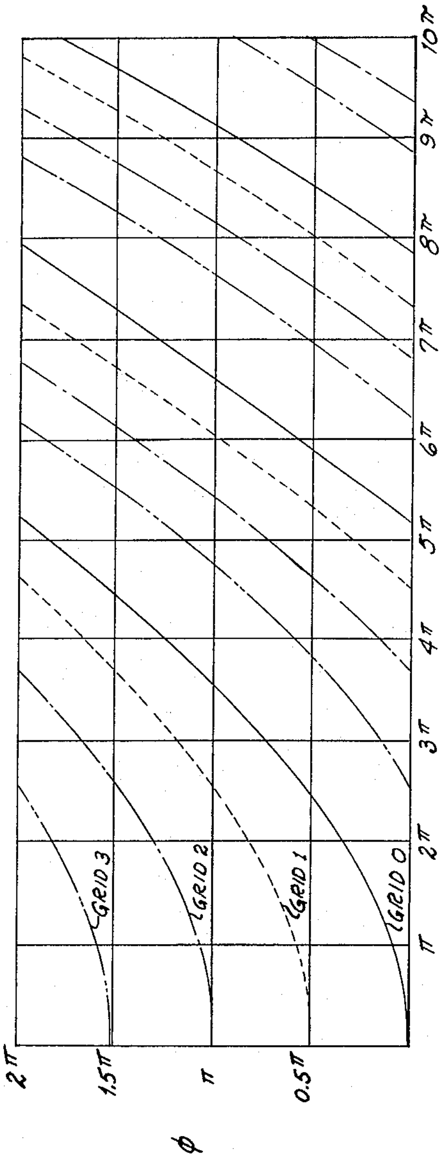


Fig. 6

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Fig. 8

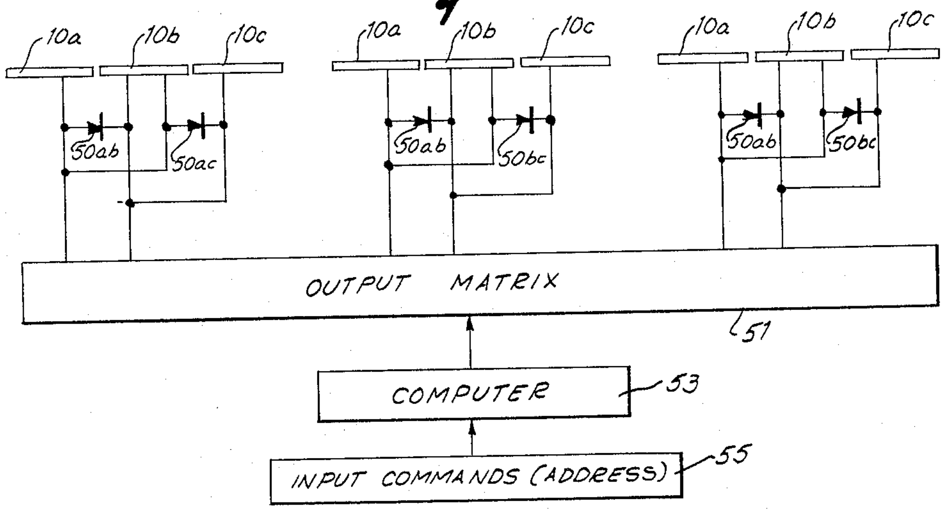
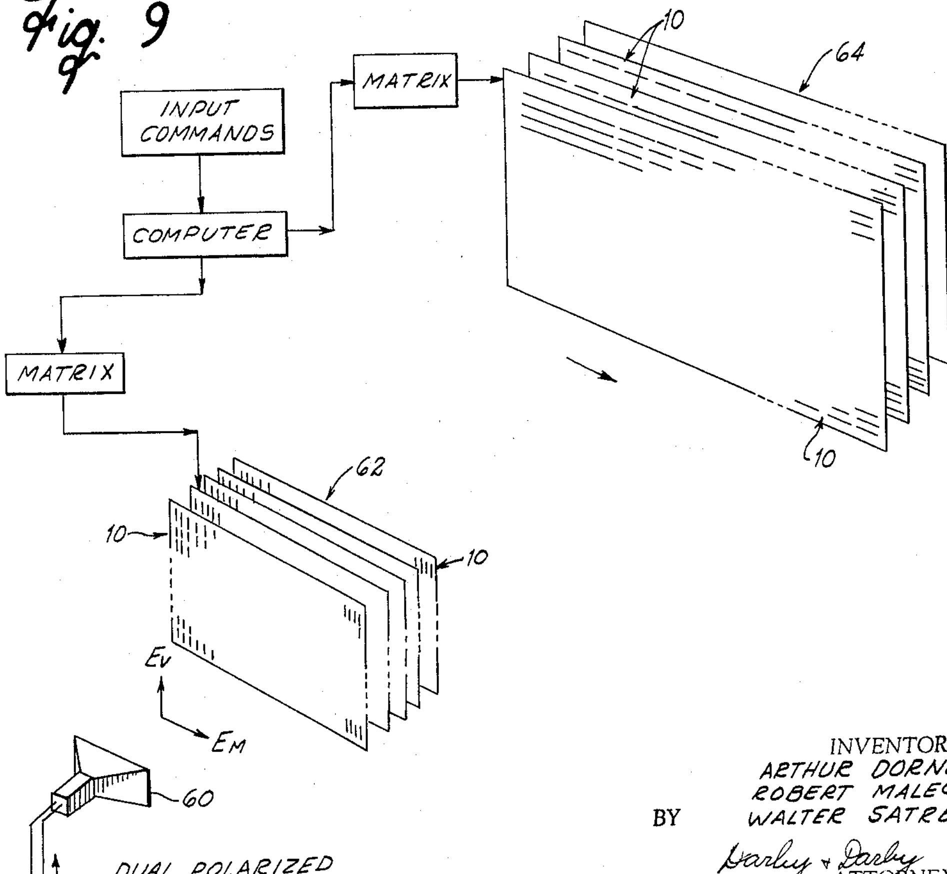


Fig. 9



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GRID ARRAY ANTENNA

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19 Claims. (Cl. 343—754)

This invention relates to antennas and more particularly to an antenna having a grid-like reflector structure.

In the co-pending application of Robert G. Malech, Serial No. 143,276, filed on October 4, 1961, entitled Antenna With Electrically Variable Reflector, and assigned to the same assignee, an antenna structure is disclosed which is disclosed which is formed by a number of waveguide sections or transmission lines which are arranged in a predetermined pattern or array. Each of the waveguide sections or transmission lines is terminated in a short circuit placed at a predetermined point thereon so that incident energy to the array will be reflected with an amount of phase shift corresponding to the placement of the short circuit. Each waveguide section or transmission line is also preferably provided with an amplifier or an attenuator so that the amplitude of the reflected energy could also be controlled. This array is capable of producing a pattern of energy having both predetermined amplitude and phase characteristics by reflection of the incident energy. The described arrangement is used for both transmission and reception of energy since all antennas are reciprocal devices.

In the aforesaid device, the segments of the incident rays of energy are bound to the particular waveguide section or transmission line back to the short. In some cases, using a device of this type is not wholly desirable.

The present invention is directed to a reflector array for use with an antenna which does not make use of the waveguide sections or transmission lines. In accordance with the invention a reflector array is provided which has a number of grids placed in a stacked arrangement. Each of the grids in the array is formed by a plurality of conductive elements. The elements each have a number of component parts and when the parts of an element are all connected together (called the shorted condition) that element effectively acts as a dipole reflector to the incident energy. When the parts of an element are left unconnected (called the open condition) that element becomes effectively transparent and allows the incident energy to pass therethrough.

By stacking a number of these grids in a predetermined relationship and selecting which of the elements of each grid are to be left in an open or shorted condition, a reflector array is formed which is capable of modifying the phase distribution of an incident wave of energy in a desired manner. This reflector array can be used either for antenna transmitting or receiving purposes.

By providing the array with mechanical, electro-mechanical or electronic switching capabilities to connect or disconnect the parts of selected elements of the array in a predetermined manner, the array can be made to produce a reflected beam of energy which scans in space. The array of the present invention can be constructed in a relatively simple manner to produce scanning as compared to other prior art devices for performing similar functions. Further, the grid array structure of the present invention possesses many of the desirable characteristics of both straight reflector type antennas and straight active antenna arrays.

It is therefore an object of this invention to provide a novel grid structure for use as a portion of an antenna reflector array.

A further object of the invention is to provide a reflector array formed by a number of grids, portions of which are either reflective or transparent to incident energy.

Yet another object of the invention is to provide a reflector array formed by a number of grids which can produce a reflected beam of energy having desired phase characteristics.

Still a further object of the invention is to provide a grid structure formed by a number of separate elements, each of the elements in turn being formed by a number of parts, and providing means to connect or disconnect the individual elements into a reflective or transparent state with respect to incident energy.

Another object of the invention is to provide a stacked array of grids formed by a number of elements and having certain of the elements in the array placed in a condition to give a desired phase shift to a reflected ray of incident energy.

A further object of the invention is to provide a stacked array of grids formed by a number of elements and having means for selectively varying the condition of various elements in the stacked grids to produce a reflected beam of energy having predetermined phase characteristics which scans in space.

Other objects and advantages of the present invention will become more apparent upon reference to the following specification and annexed drawings in which:

FIGURE 1 is a plan elevational view of a grid shown partially in diagrammatic form;

FIGURE 2 is a top view of several sets of elements in the reflector array;

FIGURE 2A is a perspective view of the reflector array formed by a number of grids;

FIGURES 3, 4 and 5 are diagrams used to illustrate certain operating and design principles of the invention;

FIGURE 6 is a graph illustrating certain characteristics of one embodiment of the antenna;

FIGURE 7 is a sectional view of a portion of a grid with a switching arrangement;

FIGURE 8 is a schematic diagram of another type of switching arrangement; and

FIGURE 9 is a diagram showing the use of two grid arrays to produce a predetermined scanning pattern.

FIGURE 1 shows a grid **5** having a plurality of conductive elements **10**. The elements are arranged in a plurality of rows R–1, R–2 . . . R–*n* and a plurality of columns C–1, C–2 . . . *C–n*. Although only a few of the elements of the various rows and columns are shown for the sake of clarity it should be understood that there are as many elements **10** in a row and as many rows and columns are provided as is consistent with the design characteristics of the antenna.

Each element **10** is of similar construction and is illustratively shown as being formed by three parts **10***a*, **10***b* and **10***c*. Of course, the elements may be formed by as many parts as is consistent with the antenna characteristics desired. The three parts **10***a*, **10***b* and **10***c* are made of electrically conductive material, such as a solid or hollow tube of any desired shape, for example, cylindrical, polygonal, etc. The element parts **10***a*, **10***b* and **10***c* may also be made of strips of conductive material and, for example, may be printed on a printed circuit type board. The respective parts **10***a*, **10***b* and **10***c* are separated from each other by insulating spacers (not shown) of a suitable material such as phenolic plastics, Teflon, etc.

As shown in FIGURE 1, the rows R–1, R–2 . . . R–*n* are each separated from each other by a distance D and the conducting portion of each element has a respective thickness *d*. Also, the length of an element **10** is given by the distance L and the space between two adjacent parts of an element by the distance *s*. Each part of an element **10** is considered to be approximately L/X units long, where X is an integer representing the number of parts into which the element is divided. In FIGURE 1 each part of an element would be approximately *L*/3 units long.

Each element **10** is provided with two switches respectively designated **11***ab* and **11***bc*, to indicate the connections between element parts **10***a* and **10***b* and **10***b* and **10***c*, respectively. When both switches **11** of an element are closed, the element **10** has the collective length L of its component parts *a*, *b* and *c*. In this condition the element is said to be shorted. When both switches **11** of an element are open, the element is effectively divided into its three component parts. In this condition the element is said to be open.

It has been found that the grid of FIGURE 1 has special properties with respect to incident energy from a suitable source. The source is illustratively shown as a feed horn **14** which supplies radio frequency energy produced by a device such as a radio frequency oscillator, magnetron, klystron, traveling wave tube, etc. Neither the energy producing device nor the feed source, in themselves, are part of the present invention and any suitable component may be used as desired. As is shown by the arrows the feed horn **14** can be adjusted in any direction either up, down, towards or away from the grid array **5**. Also, the feed horn can be tilted and, if desired, suitable means such as attenuators may be provided to adjust the amplitude and/or phase of the pattern of radiated energy supplied to the grid from the horn.

When the lengths L of the individual elements **10** and their component parts **10***a*, **10***b* and **10***c* are properly selected, the elements of the grid **5** will have predetermined characteristics for energy incident to the array within a certain range of frequencies. For a certain range of frequencies, each full length element **10** will act as a half-wave reflecting dipole to its incidence energy. Thus, if all switches **11***ab* and **11***bc* of the grid **5** are closed, thereby making all elements have their maximum length L, the whole array will effectively be a plurality of reflecting dipoles. This arrangement of dipoles would have the property of reflecting substantially all of the incident energy in a manner similar to a plane reflector. In this state the whole grid is said to be reflective.

If the switches **11***ab* and **11***bc* of an element are opened, then the element **10** is respectively divided into its three component parts **10***a*, **10***b* and **10***c*. In this condition the element will not reflect the incident energy but will instead permit it to pass. Thus, when all of the switches **11***ab* and **11***bc* for all of the elements are left open the incident energy from the horn **14** will pass through all of the elements **10** so that the whole grid **5** will effectively be transparent to the incident energy. The grid is said to be transparent or transmissive in this state.

It should be understood that the terms "reflective" and "transparent" are relative in the sense that neither one of the array structures is completely transparent or completely reflective. However, the so-called reflective grid structure has a relatively reflective characteristic, so that the incident energy will be reflected from the array, while the so-called transparent grid structure has a relatively transmissive characteristic so that energy will pass therethrough.

It should be recognized that by selectively making certain of the elements of grid **5** have the shorted condition, where they have the maximum length L, or the open condition, where they are broken into the component parts **10***a*, **10***b* and **10***c*, that various portions of the grid may be made either reflective or transparent. In fact, any portion of the grid may be made reflective or transparent as desired. Where the reflective and transparent portions of a grid are to be fixed permanently, then the switches **11** may be eliminated and the individual elements **10** permanently placed in the open or shorted condition in accordance with the design of the grid and the rest of the array.

FIGURE 2 is a top view and FIGURE 2A is a perspective view of an array **20** formed by a number of grids 5A, 5B, 5C and 5D. Each of these grids is similar in construction to the grid **5** of FIGURE 1, and these four grids are placed in a stacked or sandwich arrangement to form the array **20**. Only a portion of one of the rows of each of the grids is shown in FIGURE 2 for the sake of clarity. The elements **10** of the respective grids 5A, 5B, 5C and 5D which are in the same column and row are placed approximately behind one another and spaced by a predetermined distance, as shown in FIGURE 2. Each set of four elements **10**, which are stacked from the front to the back of the array, is called a Set. Only Sets **1**, **2** and **3** are shown for the sake of clarity but the other Sets formed by the other elements not shown would be the same. The last grid 5D in the array **20** is constructed to be a reflector so it is illustratively shown as being a plane metallic reflector, which has substantially the same properties as a grid formed by a number of individual elements **10** in the shorted condition.

The grid array **20** shown in FIGURES 2 and 2A may be used to produce any given phase distribution for a wave of energy conveyed to the array by the feed horn **14**. It has been determined by previous investigations with different types of antennas that a given continuous phase distribution function for a wave can be satisfactorily synthesized by a distribution containing only the discrete phase quantities 0°, 90°, 180° and 270°. This implies that a plus or minus 45° phase tolerance on a given distribution can be accepted in many cases, provided the phase errors are distributed randomly across the aperture of the antenna so as to tend to neutralize themselves and not significantly degrade the radiation pattern. In the present invention, phase control of a wave of energy is accomplished in discrete steps through the use of the grids in a manner described below.

When the respective elements of the grids 5A, 5B, 5C and 5D of FIGURE 2 are spaced apart by a distance $\lambda/8$, where λ is the wavelength of the incident energy within a given range, each one of the Sets **1**, **2** and **3** of elements of FIGURE 2 will produce a different discrete phase delay with respect to its incident energy. For example, the voltage component of a wave impinging upon Set **1** will be reflected by the element **10** in the front grid 5A, since this element is in a shorted condition. Therefore, the reflected voltage wave component from Set **1** will have a phase shift of 180°, the 180° shift being inherent in the reflection of the voltage wave. The incident wave on Set **2** will pass through element **10** of grid 5A since this element is in an open condition and be reflected by element **10** of grid 5B of Set **2** which is in a shorted condition. Since the grid 5B is spaced from grid 5A by a distance of $\lambda/8$, the reflected wave at the front of Set **2** has a phase with respect to the incident wave of 180° plus 90°, or 90° from the wave reflected from Set **1**. Similarly, the incident wave on Set **3** is reflected by the shorted element **10** in the third grid 5C of the sandwich and has a phase shift of 180° plus 180° at the front of Set **3**, while the incident wave on Set **4** is reflected by the last grid 5D and has a phase shift of 180° plus 270° at the front of Set 4. Therefore, at the front of the array the reflected wave has the respective phase shifts, going from Set **1** to Set 4, of 0°, 90°, 180° and 270°, using the reflected wave from Set **1** as the phase reference.

It should be clear that by using the stacked array of FIGURES 2 and 2A that any desired phase distribution of the reflected wave can be obtained at the front of the array merely by opening or shortening the proper ones of the elements **10** in the respective sets of elements formed by the four grids. While a typical grid spacing of $\lambda/8$ has been shown it should be recognized that other spacings may be used as well as other numbers of grids, instead of the four shown, to obtain other discrete phase shift quantities.

In order to illustrate certain operating principles of the invention, reference is made to FIGURE 3 which shows Sets **1** and **2** of elements of a four grid array, the grids being labelled A, B, C and D. The two sets of elements are adjacent each other in the overall array. When an incident voltage wave from the feed (not shown) is reflected from the same element of the same grid of each set, for example the elements **10** in grid A of Sets **1** and **2**, the reflected wave will be in phase and at a maximum perpendicular to the center of the two sets. If, however, as shown in FIGURE 3, an incident voltage wave **22** is reflected from two different elements such as the element **10** in grid A of Set **1** and the element **10** in grid B of Set **2**, at any point perpendicular to the center of the two sets the two reflected components will be 90° out of phase. This is shown in FIGURE 3 by the reflected voltage wave **23–1**, from Set **1** and reflected wave **23–2** from Set **2**, where the former leads the latter by 90°. The basic 180° phase shift of the incident wave is indicated by the reversal of the direction of the arrow heads on the incident voltage wave **22** and the reflected voltage waves **23**. In the case illustrated in FIGURE 3, the maximum addition of the two reflected voltage waves will occur at some other angle where the two components are in phase.

If the incident wave **22** has a 90° phase differential when impinging on Set **1** and Set **2** of the array, which effect is produced for example by offsetting the feed element **14** from the central position or modifying its beam, the effect of reflecting from the element in grid A of Set **1** an element in grid B of Set **2** would be to produce two reflected components which are in phase perpendicularly to the center of the two sets in a broadside antenna pattern.

For an incident wave with a 180° phase differential between Set **1** and Set 2, a broadside maximum can be obtained by reflecting the incident wave off the element in grid A of Set **1** and the element in grid C of Set **2**. Thus, various phase distributions of the reflected waves can be obtained not only by selecting the element in the various grids A, B, C and D which is to be shorted but also by varying the phase of the incident energy on the grid structures at adjacent Sets of elements.

FIGURES 4 and 5 illustrate the principles of a general method for selecting the open and short settings of the various elements of an array to obtain the desired phase distribution of the reflected wave.

FIGURE 4 shows a two-dimensional view of the feed **14** and one set of an *n* grid (designated **0**, **1**, **2** and **3**) set of elements which is offset from a line perpendicular to the feed. The distance *f* denotes the perpendicular distance from the phase center of the feed to the plane defined by the first grid **0**. The distance *r* denotes the radial distance between the center of the element being considered and the point X at which the line *f* intersects the plane of the first grid. This diagram forms the basis for design curves whose object is to present the phase of the field in the plane of the first grid, relative to the phase of the field at point X, as a function of radial distance *r* and grid number *n*. As will be shown, one such curve may be generated for each of the grid surfaces and for the ground plane formed by grid **3**. For purposes of explanation a relative phase is assumed which is the difference in path length between a ray reflected from a given element and a ray reflected from an element at point X. There may actually be no element at point X, but one may be assumed since this is a convenient reference point. The ray path chosen is as shown in FIGURE 4, and is at an angle θ with respect to the center of the feed.

Since the array is formed by a number of discrete elements, the properties of the individual elements must be examined when considering the physical relationship covering the reflector-like properties of the elements. As explained before, the elements **10** are half wavelength dipoles which re-radiate energy received from the primary feed. FIGURE 5 shows three adjacent elements **31**, **32** and **33** which are in the same plane. The rays illuminating all three elements are almost parallel and their amplitudes substantially equal. In front of and perpendicular to element **32** the reflected phase contributions from elements **31** and **33** essentially combine in the same phase as the reflected wave from **32**. Contributions from other elements (not shown) in the same plane are small, so the phase in front of element **32** is that given by the ray path shown in FIGURE 4.

Therefore, the relative phase due to any element in any grid may be given as the path length discussed above minus the path length to point X which is by definition *f*. By trigonometry:

$$\Phi=\sqrt{\left(f+\frac{n\pi}{4}\right)^2=r^2}+\frac{n\pi}{4}-f \quad (1)$$

where

Φ is the phase in the plane of the first grid relative to point X, given in radians (2π radians=360°).
f is the path length from the feed **14** to point X in radians,
n is the grid numbers shown (**0**, **1**, **2**, **3**), and
r is the radial distance from point X to any element in radians.

Graphs may be plotted for the function of Equation 1 for various values of *f* to give the relative phase Φ in radians for each element as a function of the distance *r* in radians to the point X. The function may be held to values between 0 and 2π since integral multiples of 2π can be subtracted from any point in the phase front, or in general for any traveling wave,

$$E(\Phi)=E(\Phi+2\pi n) \quad n=0,\ 1,\ 2,\ 3 \quad (2)$$

where Φ is the instantaneous phase angle at any point in space.

In the case where four grids are used and the four curves of Equation 1 are plotted for a value *f*, at a given radius *r*, the relative phase Φ of an element may be set at any of four angles given by the four curves. If some particular phase is required, the grid element giving the phase angle nearest the required angle is set shorted. The information required to obtain the correct element setting from the plotted curves are (1) the distance *r* for every set of elements and (2) the theoretical phase front for the beam required.

The theoretical phase distribution is calculated as in linear array theory for the beam conditions wanted. A simple case would be a broadside beam, which requires a uniform phase front across the entire array. The phase at point X is the reference designated, so the relative phase that must be approached at every point on the first grid surface is zero in order to produce the broadside pattern. FIGURE 6 shows a set of curves plotted for a particular feed distance $f=5.75$ radians. The Φ equals zero line is zero axis of the graph. All the radii of the elements are plotted as points along this horizontal axis and labeled as to row and column in the array. The correct setting for each row and column number is the number of the curve closest in the vertical direction to the point. If the set of curves is to be used repeatedly, the radii may be plotted on a transparent overlay having identical coordinates and the curves seen through the vellum.

By using this graphical method, the open and shorted settings of the elements for a four grid array may be determined for desired feed distances *f* and different number of rows and columns of elements in the array. It should be understood that the graphical design technique discussed above is only illustrative and that other techniques may be used to achieve a desired radiation pattern. Of course, the graphical technique may be extended to design any type of pattern for any shape of grid array.

In one form of antenna made according to the present invention, the following parameters were utilized for a design frequency of 3.5 gc./s. Here, the dimension chosen for L, the length of one element, was 0.5 wavelength. The spacing D between adjacent rows of elements was selected at 0.33 wavelength. At the design frequency the diameters *d* of the elements was 0.071 inch and the end to end spacing *s* of the various parts was one thirty-second of an inch. Using the dimensions specified at the design frequency of 3.5 gc./s., when all the elements of a grid 5 are in the open condition the transmission of energy through the grid varied from −0.5 db to −25 db as compared to all of the elements in a shorted condition. The latter figure of −25 db transmission is comparable to a plane reflector's reflecting properties. For this reason, a plane reflector may be substituted when a completely reflective grid is needed. Of course, the transmission characteristics set forth above will vary as the various elements of the grid are opened and shorted.

Different dimensions of the elements and grids are of course selected for different frequencies but one set of parameters will normally hold to within a range of up to 15% or more of the design frequency. With respect to the spacing D between adjacent rows of elements, in general a closer spacing leads to lower reflective properties of the grid and the grid in the transparent state also requires more than three parts per element for sufficiently high transmission.

It should be understood that each grid may be constructed in a substantially flat form or the grid structure can be curved as desired to obtain additional modifications of the phase of the reflected wave. For example, rather than making each of the grids A, B, C and D flat they may be curved to any suitable shape, for example, parabolic. When this is done, an additional phase shift is introduced into the reflected wave depending upon the physical phase difference introduced by reason of the physical placement of adjacent sets of elements. Also, the grids do not have to be rectangular in shape but may be of a configuration to more closely match either the shape of the incident energy beam or the shape of the desired reflected beam. Thus, the grids may be circular, square, rectangular, etc. Also, portions thereof may be left open to provide complete transparency or made as a solid reflector to provide complete reflectance.

FIGURE 7 shows a switching arrangement which may be used with the present invention in order to switch the various elements from the open to the shorted condition. Here, only two rows R–1 and R–2 of a grid, and only three elements of a respective row are shown for the sake of clarity. Three separate conditions of operation are shown for the various elements.

In FIGURE 7, the elements **10** are made of electrically conductive tubing through which passes an insulating rod **40** having conductive portions **41** thereon. These conductive portions may either be bands placed on the rod or conductive paint placed thereover. The rods **40** through the respective elements on R–1 and R–2 are moved simultaneously by a handle **45**. With the rods shown in position 1, the element in Column A of R–1 is shorted, the element in Column B of R–1 is open, and the element in Column C, R–1 is shorted. The element in Column A R–2 is open, Column B R–2 shorted, and Column C open.

With the rods **40** moved into position 2, as shown in the center of the figure, the conductive pieces on the rods **41** are moved accordingly thereby opening and shorting different elements as shown in the diagram. Similarly, when the rods **40** are moved to position 3, the state of the various elements on R–1 and R–2 are also changed.

It should be understood, that the conductive portions **41** on the rods **40** are arranged so that as the rods are moved the phase front of the reflected energy from the grid is changed in a predetermined manner.

By providing each of the grids in the array with a suitable switching device and controlling all of these devices, the reflected beam of energy can be made to have variably selective characteristics. For example, the reflected beam can be scanned to a desired angle, thereby providing a scanned to a desired angle, thereby providing a scanning

antenna pattern from the array as the switching is changed. While the switching of the elements by the rods is shown to be manually controlled in FIGURE 7, it should be obvious that they may be operated by suitable devices such as motors, solenoids, etc. In general, an array is designed to produce a particular type of beam scanning pattern so that a fixed function mechanical switch can be provided to scan the wave reflected from the array in a predetermined manner.

FIGURE 8 shows an arrangement by which the elements of the array grids are opened or shorted electronically in response to a series of input commands. Here, a few elements of one of the grids of the array are shown and the parts of each element **10***a*, **10***b* and **10***c* are bridged by the diodes **50***ab* and **50***bc*. When both of its diodes are in the non-conducting condition, at the element is open. When both of the diodes of an element are conducting, the three parts **10***a*, **10***b* and **10***c* ar electrically connected together. Operation of the elements of the various sets of the array to the incident energy is as described above.

The necessary biasing voltages to render the diodes **50** conductive are supplied from the output matrix **51** of a computer **53** which receives input commands from the addressing device **55**. The matrix has output lines connected to diodes on all of the grids of the array. Of course, if the last grid is to be completely reflective, then a solid plane reflector may be used thereby effecting a considerable saving on both the matrix and number of diodes needed. The components for performing these functions are conventional and well known in the art and no further description thereof need be given. By providing the proper addressing commands, for example by punched cards, magnetic tape, etc., to the computer the output matrix can produce pulses of a given duration to make any selected diodes conductive. Therefore, the phase front of the beam reflected from the array can be modified in a step type fashion in a desired manner merely by changing the input commands to the computer. For example, the beam can be made narrow and long, such as produced by a parabolic reflector, to track a long range target, and then made elliptical and short to track a close range target. Also, the same shape beam can be scanned in space in accordance with the input commands.

It should be understood that the switching for the elements may be accomplished by other suitable means such as electromechanical relays, reed type relays, etc.

The grid array reflector of the present invention only affects the phase of the reflected wave and not the amplitude. Therefore, to change the amplitude characteristics of the reflected wave some other means must be utilized. This can be done most readily by varying the amplitude of the incident energy on the various sets of elements. To do this, it is only necessary to modify the type of feed horn, use beam pattern attenuators, etc.; all of these techniques are well known in the art.

While the grid array has been described primarily as a transmitting device, it should be understood that all antennas are reciprocal devices. Thus, the incident energy referred to in the specification and claims which impinges upon the array may be from a feed source, so that the array will be in the transmitting antenna mode or from another transmitter, so that the array will be in the antenna receiving mode. In the latter case the feed device **14** would act as a pickup device to convey the energy focussed onto it by the reflecting properties of the array to a suitable receiver.

FIGURE 9 shows an arrangement wherein two grid arrays are used to produce a higher beam scan rate than is used for the array which is actually scanned. Here a dual polarized feed **60** provides energy of both horizontal and vertical polarization to a first grid array **62**. This array is relatively small and a relatively wide beam, say perhaps 10° by 10° is formed to pass therethrough. The array **62** is placed close to the feed and its elements are all vertically polarized as shown. The back plate of the array **62** is made of a grid rather than a solid conducting plate so that the desired beam of orthogonally polarized energy will pass through to a second array **64** located further from the feed **60**. The second array **64** is formed by horizontally polarized elements and is substantially larger but forms a narrower beam, say 1° by 1°, which is horizontally polarized.

The first array **62** is programmed to switch the various elements so that a desired scanning pattern is produced for its beam in a number of steps. Similarly, the larger array **64** is programmed to scan its beam for a number of steps during each scanning step of the smaller array. Thus, by using two scanning arrays, the scanning rate of the larger array **64** will be the product of the scanning arrays of both arrays.

In practice, the small reflector **62** operates on a programmed raster scan of the maximum antenna coverage. This would be a single beam requiring for example 81 steps. The large reflector **64** could be a tracking antenna, fed monopulse, which would search only in an area covered by one step of the smaller reflector, say in 100 steps. The particular area to be searched by the large aperture array **64** would be based on target information fed back from the small aperture array **62**. The two arrays are isolated by polarization in the feed.

While preferred embodiments of the invention have been described above, it will be understood that these are illustrative only, and the invention is limited solely by the appended claims.

What is claimed is:

1. An array for reflecting a beam of incident radio frequency energy from a source outside of the confines of said array and changing the phase of the reflected energy with respect to the incident energy comprising a plurality of grid members for reflecting incident energy, each of said grid members having a predetermined shape, said grid members being placed in a predetermined relationship with a predetermined spacing between each grid member of the array, selected ones of said grid members having portions thereof for transmitting the incident energy therethrough, the energy transmitted through one grid member being incident on and reflected by another grid member in the array whereby the respective segments of the reflected beam of energy in front of the array have predetermined phase characteristics as determined by the grid member from which each segment was reflected.

2. An array as set forth in claim **1** wherein means are provided adjacent the outermost grid member for producing a beam of incident energy to be reflected from said array with predetermined amplitude and phase characteristics.

3. An array for reflecting incident radio frequency energy from a source outside of the confines of said array comprising a plurality of grids, each of said grids being formed by a number of conductive elements, selected elements on each said grid constructed to be either relatively transparent or reflective to the incident energy with a predetermined pattern of elements of the various grids selected to be reflective so that substantially all of the incident energy is reflected, and said grids being spaced a predetermined distance apart.

4. An array for transposing a beam of incident radio frequency energy into a beam of reflected energy having predetermined phase characteristics comprising four grid members, each of said four grid members being formed of a number of conductive elements, selected elements on each said grid constructed to be either relatively transparent or reflective to the incident energy, said grid members being spaced one behind another a distance of substantially $\lambda/8$ apart, wherein λ is the wavelength of the incident energy.

5. An array as set forth in claim **4** wherein the last grid in the array is a complete plane reflector.

6. An array as set forth in claim **4** wherein the elements for reflecting the incident energy are substantially $\lambda/2$ long and the elements which are transparent to the incident energy have a number of parts which are less than $\lambda/2$ long.

7. An array for transposing a beam of incident radio frequency energy from a source outside of the confines of said array into a beam of reflected energy comprising a plurality of grid members spaced a predetermined distance apart, each of said grid members being formed by a number of conductive elements arrayed on two major axes, means for making selected elements on each said grid either relatively transparent or reflective to the incident radiated energy to produce a reflected beam of energy oriented with respect to said two major axes.

8. An array for transposing a beam of incident radio frequency energy from a source outside of the confines of said array into a beam of reflected energy having predetermined phase characteristics comprising a plurality of grid members spaced a predetermined distance apart, each grid member being formed by a plurality of conductive elements arrayed on two major axes, each element in turn formed by at least two conductive parts, means for electrically connecting the parts of selected elements of each grid, the element having their parts so connected being reflective to the incident radiated energy to produce a reflected beam of energy oriented with respect to said major axes and having predetermined phase characteristics.

9. An array for producing a scanning beam of radio frequency energy from a source outside of the confines of said array in response to an incident beam of energy comprising a plurality of grid members spaced a predetermined distance apart, each grid member being formed by a plurality of conductive elements which are selectively either reflective or transmissive to the incident energy, and means for selectively making certain of the elements in each grid member transmissive or reflective in predetermined steps.

10. An array for producing a scanning beam of radio frequency energy in response to an incident beam of energy which is transposed by the array into a beam of reflected energy having predetermined phase characteristics comprising a plurality of grid members, each grid member being formed by a plurality of conductive elements which are selectively either transparent or reflective to the incident energy, said grid members being spaced apart by a distance of $\lambda/8$, where λ is substantially the wavelength of the incident energy, and means for selectively making certain of the elements in each grid member transmissive or reflective in predetermined steps to vary the phase characteristics of the reflected beam in accordance with the elements of each grid selectively made reflective during each step thereby scanning the reflected beam.

11. An array as set forth in claim **10** wherein four grids are provided.

12. A structure for producing a scanning beam of radio frequency energy in response to a beam of energy produced by an external source comprising, a first array for receiving and reflecting said beam of energy, said first array including a plurality of grid members, each grid member being formed by a plurality of conductive elements which are selectively either reflective or transmissive to the incident energy, said grid members of said first array being spaced a predetermined distance apart, means for making certain of the elements in each grid member of the first array transmissive or reflective to produce a first beam of energy having predetermined phase characteristics, a second array for receiving said first beam and forming a second beam, said second array including a plurality of grid members each of which is formed by a number of conductive elements which are selectively either reflective or transmissive to said first beam of energy, said grid members of said second array being spaced a predetermined distance apart, and means for selectively making certain of the elements in each grid member of the second array transmissive or reflective to the first reflected beam of energy to produce the second beam of energy.

13. Apparatus as set forth in claim **12** wherein the elements of the grids of the first and second arrays are polarized in different directions.

14. Apparatus as set forth in claim **12** wherein the means provided for selecting the elements of the grids of the first array to be transmissive or reflective operate in a number of steps and the means for selecting the elements of the grids of the second array to be transmissive or reflective operate in a number of steps during each step of said first-named means.

15. An array for reflecting incident radio frequency energy from a source outside of the confines of the array comprising a plurality of grids spaced a predetermined distance apart from each other, the last grid of the array furthest from the source being totally reflective to the incident energy, a plurality of conductive elements on each of said other grids, and means for making selected ones of said elements on each of said other grids reflective to the incident energy.

16. An array for transposing a beam of incident radio frequency energy from a source outside of the confines of said array into a beam of reflected energy comprising a plurality of grid members spaced a predetermined distance apart, the last grid member of said array spaced furthest from the source being totally reflective to the incident energy, each of the other grid members including a number of conductive elements arrayed on two major axes, and means for making selected elements on each of said other grid members reflective to the incident energy to produce a reflected beam of energy oriented with respect to said two major axes.

17. An array for reflecting a beam of incident radio frequency energy from a source and changing the phase of the reflected energy with respect to the incident energy comprising a plurality of grid members for reflecting incident energy, each of said grid members having a predetermined shape, said grid members being placed in a predetermined relationship with a predetermined spacing of approximately n times $\lambda/8$ apart between each grid member of the array, wherein as an integer, portions of selected ones of said grid members being reflective to the incident energy and portions of selected grid members being transparent to transmit the incident energy therethrough so that at least a portion of the energy transmitted through a transparent portion of one or more grid members is incident on the reflective portion of another grid member of the array and is reflected to produce a reflected beam of energy whose segments have predetermined phase characteristics in accordance with the grid member from which each said segment of the reflected beam was reflected.

18. An array for reflecting incident radio frequency from a source comprising a plurality of grids having portions stacked one behind the other and spaced a predetermined distance apart, selected portions of each of said grids having means thereon which are reflective to the incident energy, the reflective portions of the last grid of the array located at least in the path of energy which has passed through all of the other grids of the array in front of the last grid, the energy impinging on a nonreflective portion of a grid passing therethrough to another grid in the array and any energy reaching the last grid being reflected therefrom so that substantially all of the impinging energy is reflected from the array.

19. An array for transposing a beam of incident radio frequency energy from a source into a beam of reflected energy comprising a plurality of grid members spaced a predetermined distance apart, the last grid member of said array spaced furthest from the source being totally reflective to the incident energy, each of the other grid members having means arrayed on two major axes making selected portions of each of said other grid members reflective to the incident energy to produce a reflected beam of energy oriented with respect to said two major axes whose segments are shifted in phase in a manner determined by which grid reflected the segment.

References Cited by the Examiner

UNITED STATES PATENTS

1,869,123 5/1932 Yagi ------------ 343—837 X

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UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 3,276,023 September 27, 1966

Arthur Dorne et al.

It is hereby certified that error appears in the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 6, lines 12 to 14, for that portion of the equation reading "$=r^2$", in italics, read -- $+r^2$ --, in italics; column 11 line 44, for "wherein as an integer" read -- where n is an integer --.

Signed and sealed this 29th day of August 1967.

(SEAL)

Attest:

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