June 7, 1966 P. W. HANNAN 3,255,457

RETROFLECTOR HAVING MULTI-BEAM ANTENNAS WITH INDIVIDUAL PORTS FOR INDIVIDUAL BEAMS AND MEANS INTERCONNECTING PORTS OF LIKE DIRECTED BEAMS

Filed June 28, 1963 5 Sheets-Sheet 1

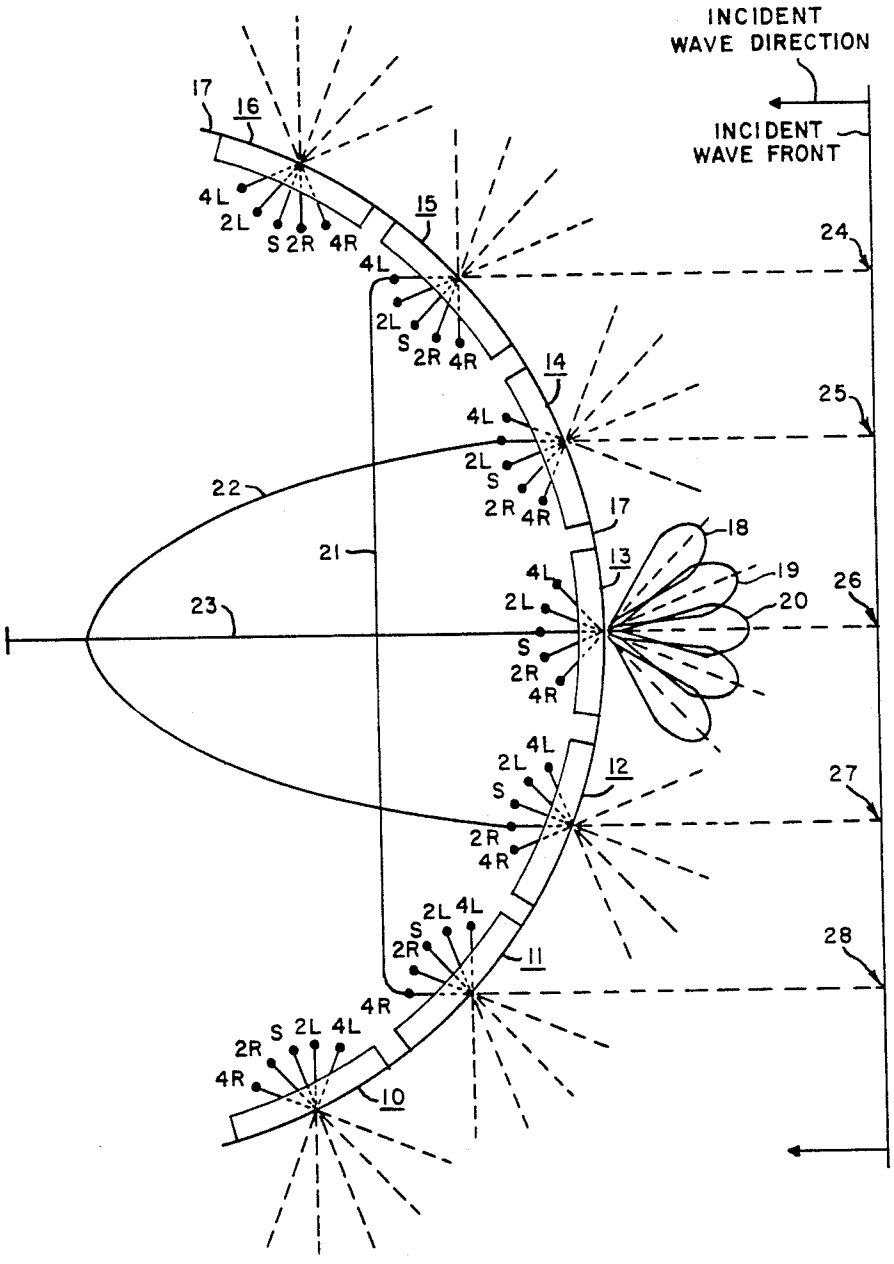


FIG. 1

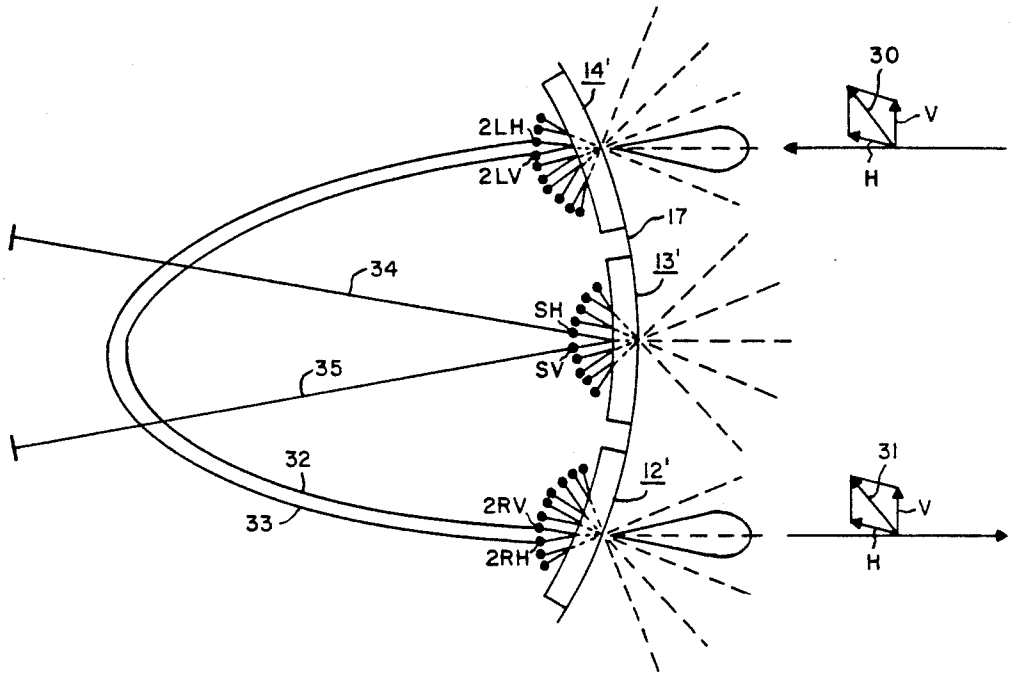


FIG. 2

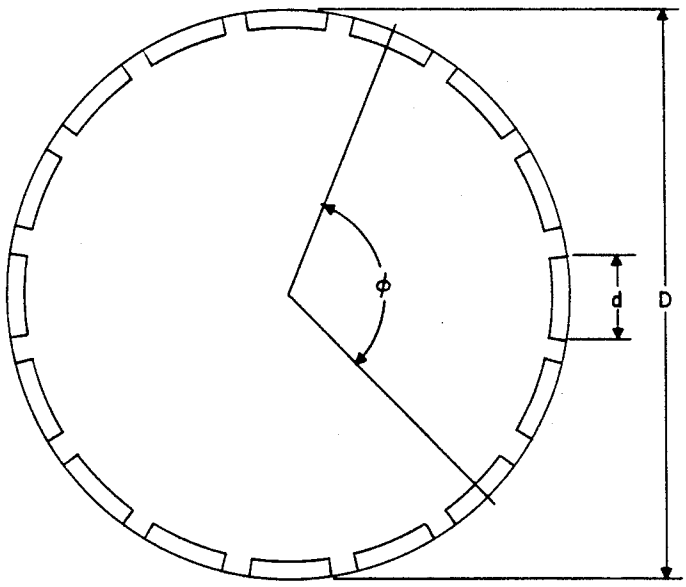


FIG. 3

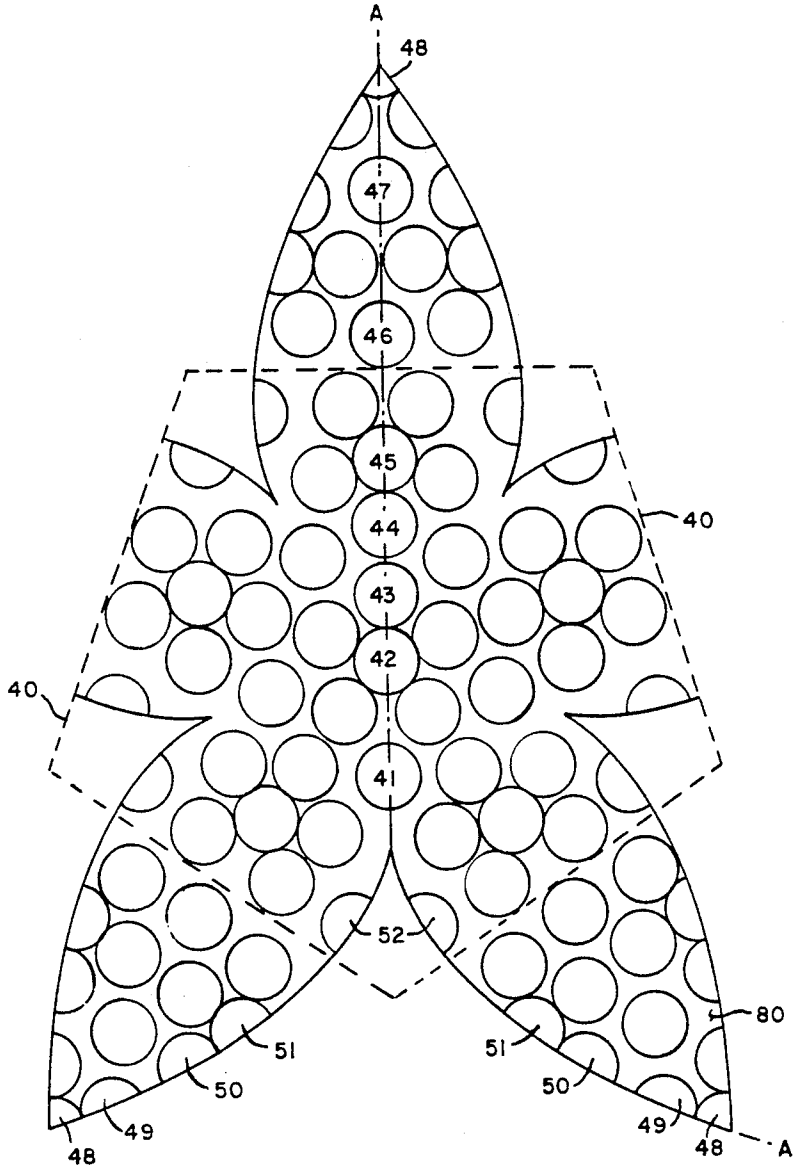


FIG. 4

June 7, 1966 P. W. HANNAN 3,255,457

RETROFLECTOR HAVING MULTI-BEAM ANTENNAS WITH INDIVIDUAL PORTS FOR INDIVIDUAL BEAMS AND MEANS INTERCONNECTING PORTS OF LIKE DIRECTED BEAMS

Filed June 28, 1963 5 Sheets-Sheet 4

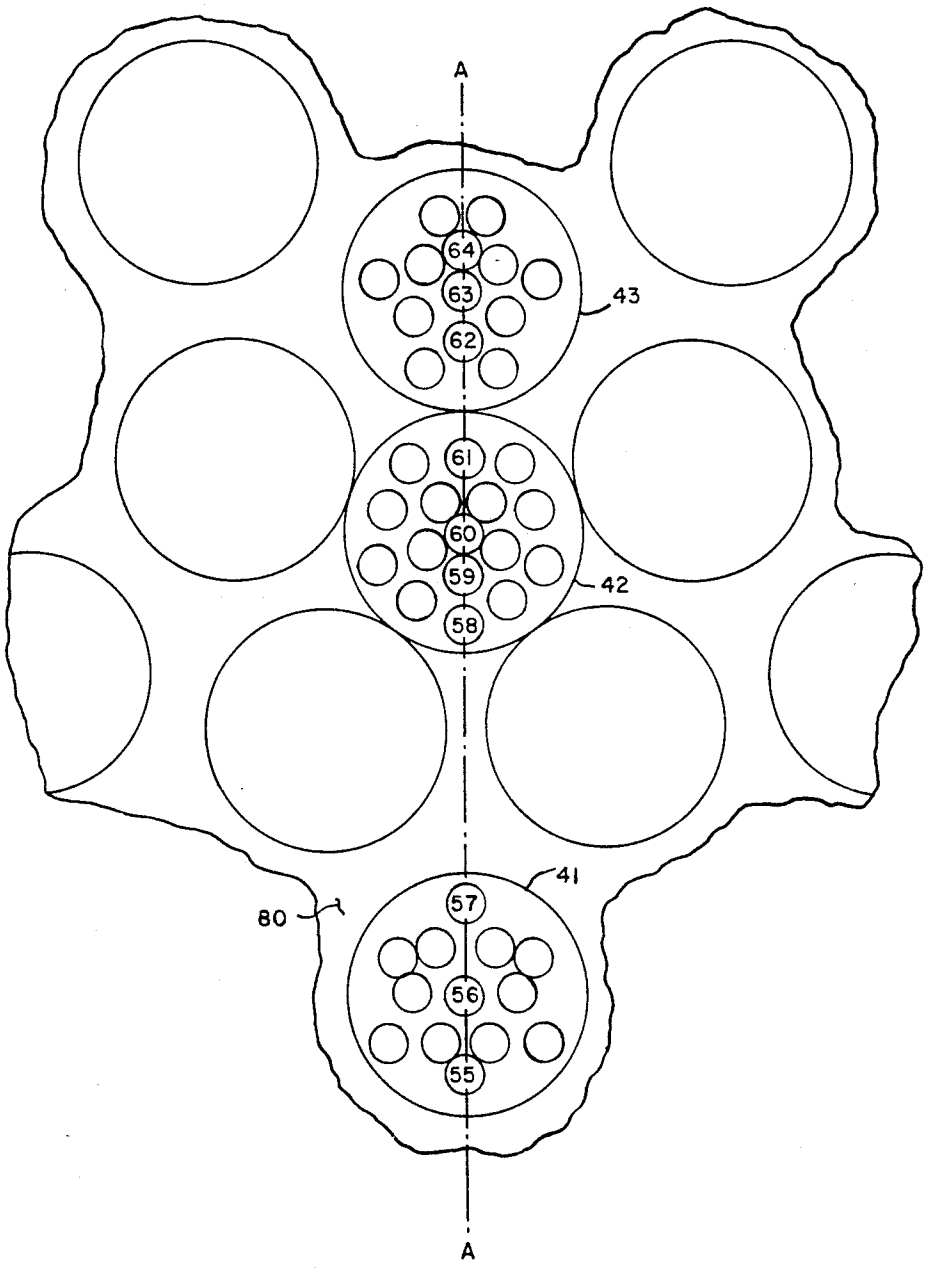


FIG. 5

June 7, 1966 P. W. HANNAN 3,255,457
RETROFLECTOR HAVING MULTI-BEAM ANTENNAS WITH INDIVIDUAL PORTS FOR INDIVIDUAL BEAMS AND MEANS INTERCONNECTING PORTS OF LIKE DIRECTED BEAMS
Filed June 28, 1963 5 Sheets-Sheet 5

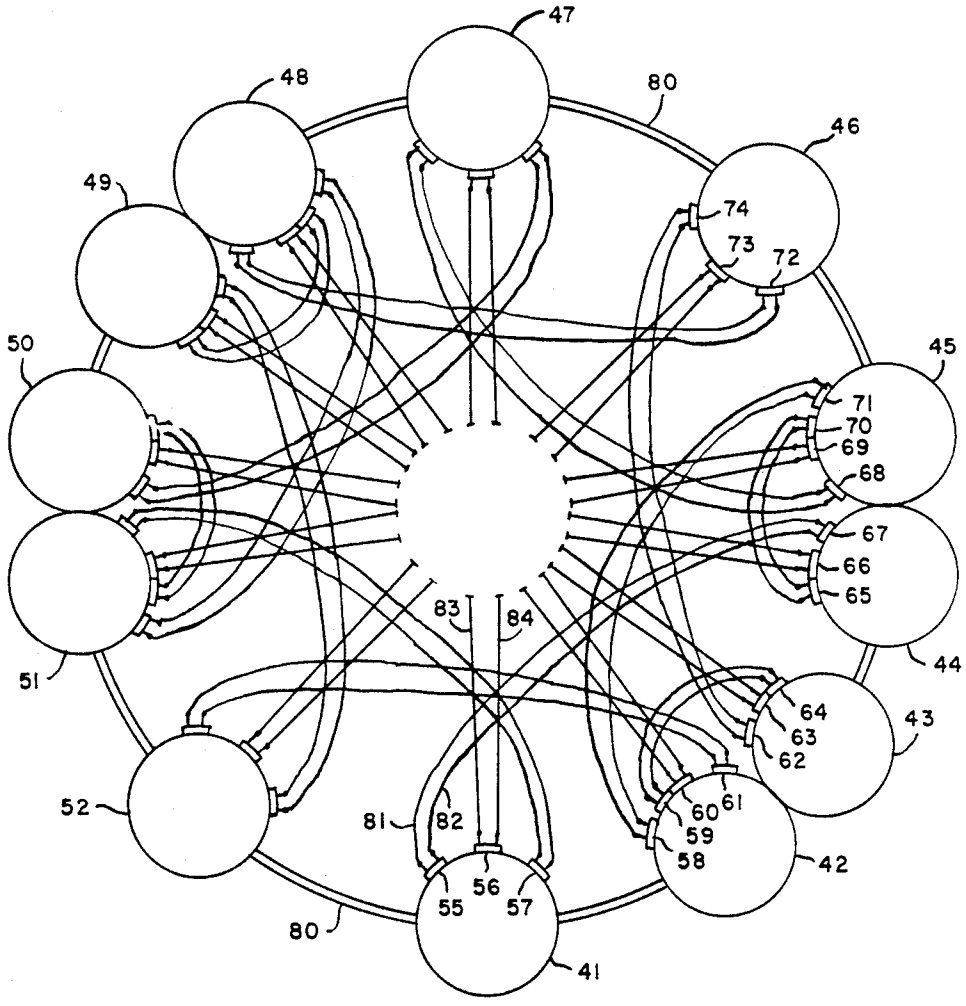


FIG. 6

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RETROFLECTOR HAVING MULTI-BEAM ANTENNAS WITH INDIVIDUAL PORTS FOR INDIVIDUAL BEAMS AND MEANS INTERCONNECTING PORTS OF LIKE DIRECTED BEAMS

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15 Claims. (Cl. 343—853)

This invention relates to reflecting antenna array systems and, more particularly, to such systems able to provide a substantially uniform high level of reflection for any incidence angle, or alternatively, for a range of incidence angles.

There exists a need for an efficient means for enhancing the reflection of a radio wave from an object. The traditional device employed for this purpose has been a corner reflector or a cluster of corner reflectors. However, the former has a limited coverage angle, while the latter has angular regions of low response and interferences.

The essential problems involved in achieving high return of the incident waves, together with complete independence of orientation of the reflecting device, may be illustrated by comparing two simple devices. One device, a flat reflecting plate many wave lengths in diameter, achieves very high return when it is broadside to the wave direction, but the return falls off rapidly with departure from the broadside condition. The other device, a reflecting sphere, yields a return which is independent of orientation, but the return is weak compared to the broadside return of the plate just described.

In recent years, two significant advances have been made in this field. In one case, a Luneberg lens coated with a partially reflecting surface achieves high returns independent of orientation. Unfortunately, when a large lens is required, the great volume and weight of dielectric material needed makes this solution unattractive. In the other case, several Van Atta arrays are grouped together, each operating over a different range of angles, so that coverage nearly independent of orientation can be obtained with a relatively lightweight structure; in addition, amplifiers or modulators may be employed to achieve some further capabilities. Unfortunately, in such arrangements, utilizing Van Atta arrays there exist interference regions at those angles where two arrays are equally effective. For such regions the reflected signal amplitude is greatly reduced.

It is an object of this invention to provide improved reflecting antenna array systems which avoid one or more disadvantages of the prior art and which allow a high level of reflection independent of incident angles.

It is an additional object of this invention to achieve a combination of the desirable performance characteristics of the Luneberg reflector with those of the Van Atta array system. More particularly, it is an object to achieve the isotropic performance of the Luneberg reflector, together with the light weight and adaptability of the Van Atta array system.

In accordance with the invention, a reflecting antenna array system for providing a substantially uniform high level of reflection for any incidence angle comprises, a plurality of multibeam antennas supported in a substantially spherical array, each antenna having a separate port for each of its beams, and a plurality of transmission lines connected to the ports of the antennas, each port being connected to the port which has the same beam direction and which occupies the symmetrical position relative to the beam direction involved; whereby incident waves in a range of frequencies are efficiently reflected back toward the source of these waves.

Also in accordance with the invention, a reflecting antenna array system for providing a substantially uniform high level of reflection for any incidence angle comprises, a plurality of Luneberg-lens antennas supported in a substantially spherical array, each antenna having a plurality of feeds each representing a separate beam, a first group of short-circuited transmission lines short circuiting each feed which corresponds to a beam direction perpendicular to the array surface and a second group of transmission lines interconnecting the remaining feeds, each individual feed of each antenna being connected to a single feed of another antenna which has the same beam direction and which occupies a symmetrical position relative to the incident wave direction involved; whereby incident waves in a range of frequencies are efficiently reflected back toward the source of those waves.

For a better understanding of the present invention, together with other and further objects thereof, reference is had to the following description taken in connection with the accompanying drawings, and its scope will be pointed out in the appended claims.

In the drawings, FIG. 1 shows a particular form of reflecting array system constructed in accordance with the invention;

FIG. 2 shows a modification of the FIG. 1 system allowing operation with any polarization;

FIG. 3 is a simplified drawing used in describing relationships between various significant parameters and dimensions of systems constructed in accordance with the invention;

FIG. 4 is a planar projection of a complete spherical reflecting antenna array system utilizing Luneberg-lens antennas (actually a complete system is not shown because two portions have been removed due to limitations in drawing size);

FIG. 5 is a detail view of a portion of the FIG. 4 system, and

FIG. 6 is a partial sectional view along a diameter of the complete spherical system of FIG. 4.

FIG. 1 system

Referring to FIG. 1, there is shown a view of a portion of a reflecting antenna array system for providing a substantially uniform level of reflection over a range of incidence angles. FIG. 1 shows a group of antennas supported in a circular array; this simple arrangement will be discussed to bring out the concepts of the invention before considering a full spherical array. For the purposes of this specification the word "port" is used as a term generic to the word "feed," both words being applied in accordance with common usage in the antenna art.

In FIG. 1 are shown seven antennas **10–16**, each of which is a multibeam antenna. Examining antenna **13**, it will be seen that this antenna has five ports labeled **4R**, **2R**, **S**, **2L** and **4L**. Each of these ports has a sep-

arate antenna pattern or beam associated therewith. Thus, beam **18** corresponds to port **4R**, beam **19** corresponds to port **2R**, beam **20** corresponds to port S, etc.; the dotted line in the center of each beam being effectively an extension of the corresponding port. It will be noted that with respect to the remaining antennas **10–12** and **14–16**, only the dotted center lines of the beams are shown without a beam contour pattern.

Also shown in FIG. 1 are a plurality of transmission lines connected to ports of the antennas. Only three typical transmission line connections **21**, **22** and **23** are shown for ease of drawing and explanation. Line **21** is a section of transmission line connecting port **4L** of antenna **15** to port **4R** of antenna **11**. It can now be noted that the "4L" and "4R" designations are location codes. The **4L** port of antenna **15** is interconnected to the fourth (4) antenna to the left (L), which is antenna **11**; connection must be to port **4R** of antenna **11** because that is the port of antenna **11** which carries the fourth (4) antenna to the right (R) designation. In similar manner, port **2L** of antenna **14** is connected, via transmission line **22**, to port **2R** of antenna **12**. Port S of antenna **13** is effectively connected to itself by the transmission line **23** which is short circuited at the far end. All the connections between the antennas shown in FIG. 1 (as well as to the additional antennas which could be added to form a complete circle) can now be made following the location code designations.

Assuming now that an electromagnetic wave approaches the FIG. 1 system with a plane wave front indicated by the straight line labeled "Incident Wave Front" and a direction indicated by the arrow labeled "Incident Wave Direction." Such a wave will be intercepted by antennas having beams of direction approximately corresponding to the incident wave direction. This condition of corresponding direction is met in FIG. 1 by the beams associated with port **4L** of antenna **15**, port **2L** of antenna **14**, port S of antenna **13**, port **2R** of antenna **12** and port **4R** of antenna **11**. Signals originating from the vicinity of point **24** in the incident wave will be coupled, via the combination of port **4L** of antenna **15**, line **21** and port **4R** of antenna **11**, to the vicinity of point **28**. Similarly, signals originating near point **25** will be coupled to the vicinity of point **27**, signals originating near point **26** will be coupled back to the vicinity of point **26**, signals originating near point **27** will be coupled to the vicinity of point **25** and signals originating near point **28** will be coupled to the vicinity of point **24**. The result will be a reconstituted wave travelling away from the reflecting array system.

If the lengths of the transmission lines **21**, **22** and **23** are chosen so that the electrical path lengths from point **24** to point **28**, from point **25** to point **27** and from point **26** back to point **26**, are all substantially identical, then the reconstituted wave will have a plane wave front corresponding to the plane wave front of the incident wave. The net result will be that the incident wave is efficiently reflected back toward the original source of the waves. If desired, the incident wave can be effectively defocused prior to being reconstituted by choosing the lengths of lines **21**, **22** and **23** so that the path lengths are unequal (instead of substantially identical as just discussed). Such defocusing will cause the wave power to be returned over a solid angle centered on the original source of the wave with correspondingly reduced strength.

The arrangement as shown in FIG. 1 will be defined as one in which each port of the system is connected, via a transmission line, to the port which has the same beam direction and which occupies the symmetrical position relative to the beam direction involved. Thus, in FIG. 1, the beam direction involved is the direction corresponding to the incident wave direction. The ports corresponding to this particular beam direction are port **4L** of antenna **15**, port **2L** of antenna **14**, port S of antenna **13**, port **2R** of antenna **12** and port **4R** of antenna **11**. Each of these ports is interconnected, as shown, to the port which occupies the symmetrical postion relative to this particular beam direction. More particularly, the FIG. 1 system includes two types of transmission lines. The first group of transmission lines, of which line **23** is typical, are short circuited. The short-circuited ports are the ports which correspond to a beam direction perpendicular to the array surface. Thus, port S of antenna **13** corresponds to beam **20** which is substantially perpendicular to the array surface. With respect to port S of antenna **13**, this port itself occupies the symmetrical position and is effectively coupled back to itself via the short-circuited line **23**. The second group of transmission lines, of which lines **21** and **22** are typical, interconnect the remaining ports which are not connected to short-circuited lines. As described above, this is typically accomplished by interconnecting port **4L** of antenna **15** and port **4R** of antenna **11**, since these two ports occupy symmetrical positions relative to their beam directions.

It will be understood that any suitable type of multibeam antennas can be utilized in systems constructed in accordance with the invention. One particular type of antenna will be described in connection with the FIG. 4 arrangement.

FIG. 2 system

In the FIG. 1 arrangement each beam direction of each antenna has a single port and the system can be designed to operate for any one particular polarization. FIG. 2 shows a portion of the FIG. 1 arrangement modified for operation with any polarization. Each FIG. 2 antenna **12'**, **13'** and **14'** has five pairs of ports, each pair covering two orthogonal wave polarizations. Each antenna has a separate port for each of its beams and two beams for orthogonal polarizations for each beam direction. For example, one port of each pair may be for vertical polarization and the other for horizontal polarization. Thus, for the beam direction indicated, ports **2LH** and **2LV** of antenna **14'**, and ports **2RH** and **2RV** of antenna **12'** are involved. The beams for the vertical and horizontal polarizations are substantially identical so that only one beam contour is shown for each of these pairs of ports. These designations **2LH**, **2LV**, etc. are location codes the same as discussed above with the addition of the "V" and "H" designations corresponding to vertical and horizontal polarizations, respectively. As shown, each port will again be connected to the port which has the same beam direction and which occupies the symmetrical position relative to the beam direction involved. However, in this case two transmission lines are utilized for each beam direction so that each port is connected to the respective port of the proper polarization.

In operation, an incident wave with a linear polarization corresponding to arrow **30** will be separated into two orthogonal components with the vertical component utilizing line **32** and the horizontal component utilizing line **33** so that the reflected wave will have a polarization corresponding to arrow **31**, which is the same polarization as indicated by arrow **30**. Similarly as in FIG. 1, ports corresponding to beam directions perpendicular to the array surface will have each port short-circuited by short-circuited lines such as **34** and **35**.

While an incident wave of any linear polarization will be reflected as a wave of the same polarization by the FIG. 2 arrangement, an incident wave of circular polarization will be reflected as a wave of the opposite circular polarization. This is the well known reversal which occurs with any single simple reflection of a circularly-polarized wave. It might be desired that an incident circularly polarized wave be returned without polarization reversal. This can be accomplished in the FIG. 2 arrangement merely by interchanging the interconnections between the two ports of each beam direction. That is by connecting the lower end of line **32**

to port 2RH of antenna 12' and the lower end of line 33 to port 2RV of antenna 12'. Also, the lines 34 and 35 will be connected together at the free ends instead of being individually short circuited. This interchanging of the port connections would, of course, have the additional effect of rotating the polarization of any linearly polarized wave by 90°. An alternate way to achieve the results described would employ ports corresponding to circularly-polarized waves. In this case the rules for interchanging connections are opposite to those with linear polarization.

FIG. 3 system

In FIG. 3 and below are indicated various significant parameters and dimensions associated with systems constructed in accordance with the present invention:

D=sphere diameter
d=antenna aperture diameter
λ=design wavelength
β=half-power beamwidth of an antenna aperture
ϕ=angle of effective antennas on sphere
n=number of beams per aperture beamwidth
P=number of antennas on sphere
Q=number of beams in one antenna; Q also equals the number of active antennas
S=total number of feeds
k=ratio of highest usable frequency to lowest usable frequency

The following are certain important relationships between the above parameters and dimensions:

$$\frac{d}{\lambda}\approx\sqrt{\frac{1}{2n}\cdot\frac{D}{\lambda}}\approx\frac{1}{\beta} \quad (1)$$

$$\frac{D}{d}\approx\sqrt{2n\frac{D}{\lambda}} \quad (2)$$

$$P\approx 8n\frac{D}{\lambda} \quad (3)$$

$$Q\approx 8n\sin^2\left(\frac{\phi}{4}\right)\frac{D}{\lambda} \quad (4)$$

$$S\approx\left[8n\sin\left(\frac{\phi}{4}\right)\frac{D}{\lambda}\right]^2 \quad (5)$$

$$k\approx\frac{\phi^2}{20}\cdot\frac{D}{\lambda} \quad (6)$$

The above relationships are based on the assumption of a sphere many wavelengths in diameter, which is the condition for efficient and useful operation of the invention. It can be seen that the diameter of the individual antennas is proportional to the geometric mean of the design wavelength and the sphere diameter. Also, the total number of transmission lines is proportional to the square of the ratio of sphere diameter to design wavelength (this is similar to the result for a Van Atta array). Although wavelength appears as a parameter in the formulas, the system is not necessarily narrow band. As wavelength is varied in a given system, the number (n) of ports per antenna beamwidth varies. As long as the ports per beamwidth is one or more, and the beamwidth (β) is small compared with the sphere surface angle (ϕ), the system will perform well; i.e., a sphere diameter very large in wavelengths permits operation over a wide frequency band.

As described, the system provides a high return which is independent of polarization. When all the ports corresponding to all the beam directions are connected up, and when a sufficiently large number of antennas and beams are employed, the return is essentially independent of orientation of the system, and exhibits no significant interferences. The resulting performance is thus similar to that of the isotropic Luneberg reflector. However, since each antenna may be relatively small and light, and since the antennas are connected with transmission lines, those advantages associated with the Van Atta array are also achieved.

System of FIGS. 4, 5 and 6

FIGS. 4, 5 and 6 show a specific design of an array system constructed in accordance with the invention utilizing a large number of Luneberg-lens antennas. FIG .4 is a projection of the complete surface of a spherical reflecting antenna array system (actually two portions are missing, as will be noted below). FIG. 4 may be likened to a type of polar projection of the surface of the earth relied upon in certain maps. It will be appreciated that no planar representation of a spherical surface will be completely accurate. The surface of one hemisphere of the spherical array system is included within the pentagon labeled 40. The other hemisphere comprises five identical, approximately pie-shaped pieces, of which three are shown and two have been omitted to avoid crowding in the drawing. The dot-dash line labeled A—A represents a diameter of the complete spherical array system.

The array system illustrated in FIG. 4 includes three slightly different types of antennas: antennas such as 41, which are spaced away from all other antennas; antennas such as 42, which are surrounded by a cluster of five other antennas in close proximity; and antennas such as 43, five of which cluster around each type 42 antenna. The whole spherical array comprises a regular pattern of these three types of antennas. The complete group of antennas lying along the diameter A—A are labeled 41–52, inclusive. FIG. 5 is an enlarged view of antennas 41, 42 and 43 and a few neighboring antennas. Each Luneberg-lens antenna is shown as being optically transparent and having a plurality of feeds coupled to its far surface. In each antenna 41, 42 and 43, the feeds which lie along the diameter A—A are numbered. Thus, of the thirteen feeds of antenna 41, the three lying along diameter A—A are labeled 55, 56 and 57. Of the sixteen feeds of antenna 42, the four lying along diameter A—A are labeled 58, 59, 60 and 61. Of the thirteen feeds of antenna 43, the three lying along the diameter A—A are labeled 62, 63 and 64. In FIG. 6 is shown a side sectional view of the antennas 41–52 which lie along diameter A—A. In FIG. 6, diameter A—A is represented by means 80 which is the mechanical structure which supports the antennas in the spherical configuration; any appropriate physical arrangement can be utilized to support the antennas as described.

Considering FIGS. 4, 5 and 6 together, there is shown a reflecting antenna array system for providing a substantially uniform high level of reflection for any incidence angle. As illustrated, the system includes a plurality of multibeam antennas, shown as Luneberg-lens antennas of which 41, 42 and 43 are typical, supported in a substantially spherical array. Each antenna has a separate feed (such as feeds 55–74, for example) for each of its beams, and each feed is shown as having two ports for orthogonal polarizations. As illustrated, the system further includes a plurality of transmission lines (four representative lines are labeled 81–84) connected to the feeds of the antennas, each feed being connected to the feed which occupies the symmetrical position relative to the beam direction involved (in the manner discussed more fully with reference to FIG. 1). More particularly, there are shown a first group of short-circuited transmission lines, of which lines 83 and 84 are examples, short circuiting each port of each feed which corresponds to a beam direction perpendicular to the array surface. Also included are a second group of transmission lines, of which lines 81 and 82 are examples, interconnecting the ports of the remaining feeds.

In the system shown, an over-all spherical diameter (D) of about twelve wavelengths, a Luneberg-lens antenna diameter (d) of about two wavelengths and an average sphere-surface angle (ϕ) of about 90° were chosen. The total number of individual antennas utilized in this arrangement is ninety-two, which is sufficient to yield a strong return and nearly isotropic coverage. The total number of feeds in this arrangement as shown is 1,232, which amounts to approximately one feed per antenna

beamwidth for this system. The resulting system will provide a high level of reflection from a light-weight and versatile device, independent of incidence angle.

In accordance with the invention, reflecting array systems can be constructed in a substantially spherical configuration or in a partial spherical configuration (for example, a hemispherical configuration) for providing a substantially uniform high level of reflection over a range of incidence angles rather than for all incidence angles.

While there have been described what are at present considered to be the preferred embodiments of this invention, it will be obvious to those skilled in the art that various changes and modifications may be made therein without departing from the invention, and it is, therefore, aimed to cover all such changes and modifications as fall within the true spirit and scope of the invention.

What is claimed is:

1. A reflecting antenna array system for providing a substantially uniform high level of reflection for any incidence angle, comprising:
- a plurality of multibeam antennas supported in a substantially spherical array, each antenna having a separate port for each of its beams;
- and a plurality of transmission lines connected to said ports of said antennas, each port being connected to that port which has the same beam direction and which occupies the symmetrical position relative to the beam direction involved;
- whereby incident waves in a range of frequencies are efficiently reflected back toward the source of said waves.

2. A reflecting antenna array system for providing a substantially uniform high level of reflection over a range of incidence angles, comprising:
- a plurality of multibeam antennas supported in a partial spherical array, each antenna having a separate port for each of its beams;
- and a plurality of transmission lines connected to said ports of said antennas, each port being connected to the port which has the same beam direction and which occupies the symmetrical position relative to the beam direction involved;
- whereby incident waves in a range of frequencies are efficiently reflected back toward the source of said waves.

3. A reflecting antenna array system for providing a substantially uniform high level of reflection for any incidence angle, comprising:
- a plurality of multibeam antennas supported in a substantially spherical array, each antenna having a separate port for each of its beams;
- a first group of short-circuited transmission lines short circuiting each port which corresponds to a beam direction perpendicular to the array surface;
- and a second group of transmission lines interconnecting the remaining ports, each individual port of each antenna being connected to a single port of another antenna which has the same beam direction and which occupies the symmetrical position relative to the incident wave direction involved;
- whereby incident waves in a range of frequencies are efficiently reflected back toward the source of said waves.

4. A reflecting multibeam antenna array system for providing a substantially uniform high level of reflection for any incidence angle, comprising:
- a plurality of multibeam antennas supported in a substantially spherical array, each antenna having a separate port for each of its beams;
- a first group of short-circuited transmission lines short circuiting each port which corresponds to a beam direction perpendicular to the array surface;
- and a second group of transmission lines interconnecting the remaining ports, each individual port of each antenna being connected to a single port of another antenna which has the same beam direction and which occupies the symmetrical position relative to the incident wave direction involved;
- the lengths of said transmission lines of said first and second groups being such that the electrical path length from an incident plane wave front, through the array and back to the wave front is approximately identical for all paths corresponding to a beam direction substantially perpendicular to said wave front;
- whereby incident waves in a range of frequencies are efficiently reflected back toward the source of said waves.

5. A reflecting multibeam antenna array system for providing a substantially uniform level of reflection over a range of incidence angles, comprising:
- a plurality of multibeam antennas supported in a partial spherical array, each antenna having a separate port for each of its beams;
- and a first group of short-circuited transmission lines short circuiting each port which corresponds to a beam direction perpendicular to the array surface;
- and a second group of transmission lines interconnecting the remaining ports, each individual port of each antenna being connected to a single port of another antenna which has the same beam direction and which occupies the symmetrical position relative to the incident wave direction involved;
- the lengths of said transmission lines of said first and second groups being such that the electrical path length from an incident plane wave front, through the array and back to the wave front is approximately identical for all paths corresponding to a beam direction substantially perpendicular to said wave front;
- whereby incident waves in a range of frequencies are efficiently reflected back toward the source of said waves.

6. A reflecting multibeam antenna array system for providing a substantially uniform high level of reflection for any incidence angle, comprising:
- a plurality of multibeam antennas supported in a substantially spherical array, each antenna having a separate port for each of its beams and two beams for orthogonal polarizations for each beam direction;
- a first group of short-circuited transmission lines short circuiting each port which corresponds to a beam direction perpendicular to the array surface;
- and a second group of transmission lines interconnecting the remaining ports, each individual port of each antenna being connected to a single port of another antenna which has the same beam direction and which occupies the symmetrical position relative to the incident wave direction involved;
- whereby incident waves in a range of frequencies are efficiently reflected back toward the source of said waves.

7. A reflecting antenna array system for providing a substantially uniform level of reflection over a range of incidence angles, comprising:
- a plurality of multibeam antennas supported in a partial spherical array, each antenna having a separate port for each of its beams and two beams for orthogonal polarizations for each beam direction;
- a first group of short-circuited transmission lines short circuiting each port which corresponds to a beam direction perpendicular to the array surface;
- and a second group of transmission lines interconnecting the remaining ports, each individual port of each antenna being connected to a single port of another antenna which has the same beam direction and which occupies the symmetrical position relative to the incident wave direction involved;
- whereby incident waves in a range of frequencies are

efficiently reflected back toward the source of said waves.

8. A reflecting antenna array system for providing a substantially uniform high level of reflection for any incidence angle, comprising:
a plurality of Luneberg-lens antennas supported in a substantially spherical array, each antenna having a purality of feeds each representing a separate beam;
and a plurality of transmission lines connected to said feeds of said antennas, each feed being connected to the feed which has the same beam direction and which occupies the symmetrical position relative to the beam direction involved;
whereby incident waves in a range of frequencies are efficiently reflected back toward the source of said waves.

9. A reflecting antenna array system for providing a substantially uniform high level of reflection for any incidence angle, comprising:
a plurality of Luneberg-lens antennas supported in a substantially spherical array, each antenna having a plurality of feeds each representing a separate beam;
a first group of short-circuited transmission lines short circuiting each feed which corresponds to a beam direction perpendicular to the array surface;
and a second group of transmission lines interconnecting the remaining feeds, each individual feed of each antenna being connected to a single feed of another antenna which has the same beam direction and which occupies the symmetrical position relative to the incident wave direction involved;
whereby incident waves in a range of frequencies are efficiently reflected back toward the source of said waves.

10. A reflecting antenna array system for providing a substantially uniform high level of reflection for any incidence angle, comprising:
a plurality of Luneberg-lens antennas supported in a substantially spherical array, each antenna having a plurality of feeds each representing a separate beam;
a first group of short-circuited transmission lines short circuiting each feed which corresponds to a beam direction perpendicular to the array surface;
and a second group of transmission lines interconnecting the remaining feeds, each individual feed of each antenna being connected to a single feed of another antenna which has the same beam direction and which occupies the symmetrical position relative to the incident wave direction involved;
the lengths of said transmission lines of said first and second groups being such that the electrical path length from an incident plane wave front through the array back to the wave front is approximately identical for all paths corresponding to a beam direction substantially perpendicular to said wave front;
whereby incident waves in a range of frequencies are efficiently reflected back toward the source of said waves.

11. A reflecting antenna array system for providing a substantially uniform high level of reflection for any incidence angle, comprising:
a plurality of Luneberg-lens antennas supported in a substantially spherical array, each antenna having a plurality of feeds each representing a separate beam and two beams for orthogonal polarizations for each beam direction;
and a plurality of transmission lines connected to said feeds of said antennas, each feed being connected to the feed which has the same beam direction and which occupies the symmetrical position relative to the beam direction involved;
whereby incident waves in a range of frequencies are efficiently reflected back toward the source of said waves.

12. A reflecting antenna array system for providing a substantially uniform high level of reflection for any incidence angle, comprising:
a plurality of Luneberg-lens antennas supported in a substantially spherical array, each antenna having a plurality of feeds each representing a separate beam and two beams for orthogonal polarizations for each beam direction;
a first group of short-circuited transmission lines short circuiting each feed which correspond to a beam direction perpendicular to the array surface;
and a second group of transmission lines interconnecting the remaining feeds, each individual feed of each antenna being connected to a single feed of another antenna which has the same beam direction and which occupies the symmetrical position relative to the incident wave direction involved;
the lengths of said transmission lines of said first and second groups being such that the electrical path length from an incident plane wave front, through the array and back to the wave front is approximately identical for all paths corresponding to a beam direction substantially perpendicular to said wave front;
whereby incident waves in a range of frequencies are efficiently reflected back toward the source of said waves.

13. A polarization changing reflecting antenna array system for providing a substantially uniform high level of reflection for any incidence angle, comprising:
a plurality of multibeam antennas supported in a substantially spherical array, each antenna having a separate port for each of its beams and two beams for orthogonal polarizations for each beam direction;
and a plurality of transmission lines connected to said ports of said antennas, each port being connected to the port which has the same beam direction and which occupies the symmetrical position relative to the beam direction involved with the port connections interchanged to produce a change in polarization between incident and reflected waves;
whereby incident waves in a range of frequencies are efficiently reflected back toward the source of said waves with a change in polarization so that incident waves of one linear polarization are reflected as waves of an orthogonal linear polarization and waves of a first circular polarization are reflected as waves of the same circular polarization.

14. A polarization changing reflecting antenna array system for providing a substantially uniform high level of reflection for any incidence angle, comprising:
a plurality of Luneberg-lens antennas supported in a substantially spherical array, each antenna having a plurality of feeds each representing a separate beam and two beams for orthogonal polarizations for each beam direction;
and a plurality of transmission lines connected to said feeds of said antennas, each feed being connected to the feed which has the same beam direction and which occupies the symmetrical position relative to the beam direction involved with the feed connections interchanged to produce a change in polarization between incident and reflected waves;
whereby incident waves in a range of frequencies are efficiently reflected back toward the source of said waves with a change in polarization so that incident waves of one linear polarization are reflected as waves of an orthogonal linear poralization and waves of a first circular polarization are reflected as waves of the same circular polarization.

15. A polarization changing reflecting antenna array system for providing a substantially uniform high level of reflection for any incidence angle, comprising:
a plurality of Luneberg-lens antennas supported in a substantially spherical array, each antenna having

a plurality of feeds each representing a separate beam and two beams for orthogonal polarizations for each beam direction;

and a plurality of transmission lines connected to said feed of said antennas, each feed being connected to the feed which has the same beam direction and which occupies the symmetrical position relative to the beam direction involved with the feed connections interchanged to produce a change in polarization between incident and reflected waves;

the lengths of said transmission lines being such that the electrical path length from an incident plane wave front, through the array and back to the wave front is approximately identical for all paths corresponding to a beam direction substantially perpendicular to said wave front;

whereby incident waves in a range of frequencies are efficiently reflected back toward the source of said wave with a change in polarization so that incident waves of one linear polarization are reflected as waves of an orthogonal linear polarization and waves of a first circular polarization are reflected as waves of the same circular polarization.

References Cited by the Examiner

UNITED STATES PATENTS

2,566,703	9/1951	Iams	343—753
2,908,002	10/1959	Van Atta	343—776

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