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Coleman

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[54] **MULTIMODAL RETRODIRECTIVE ARRAY**

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[73] Assignee: **The United States of America as represented by the Secretary of the Navy,** Washington, D.C.

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[52] **U.S. Cl.** ..... **343/754,** 343/100 TD, 343/854, 343/893

[51] **Int. Cl.** **H01q 3/26**

[58] **Field of Search**..... 343/100 TD, 753, 754, 854, 343/893

[56] **References Cited**

UNITED STATES PATENTS

3,618,090 11/1971 Garrison 343/754

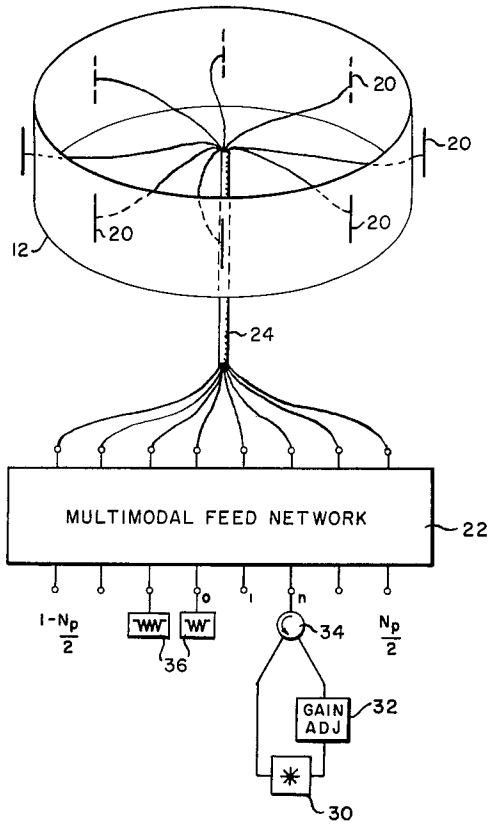
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[57] **ABSTRACT**

A technique and apparatus for obtaining automatic retro-directive performance from antennas and antenna arrays of general geometric configurations such as cones, ellipsoids, etc. The elements of the antennas or arrays are connected to multimodal feed networks. Conjugate phase circuits and gain adjustments are connected to some of the feed network terminals. The degree of retrodirectivity can be controlled by the gain adjustment and the number of conjugate phase circuits used.

8 Claims, 4 Drawing Figures



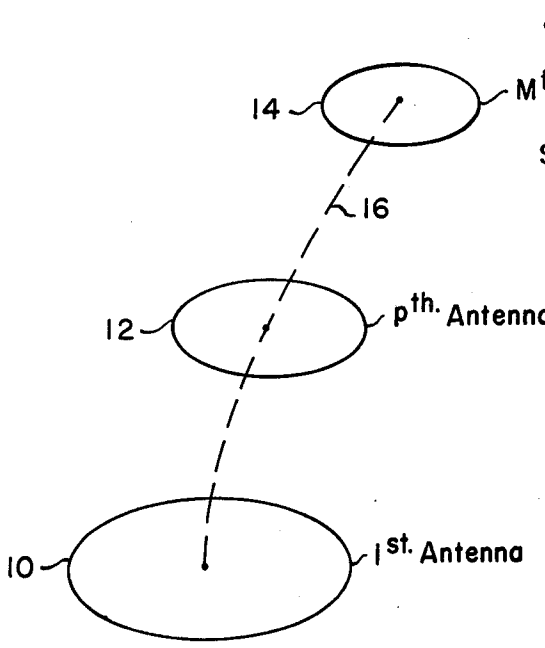


FIG. 1.

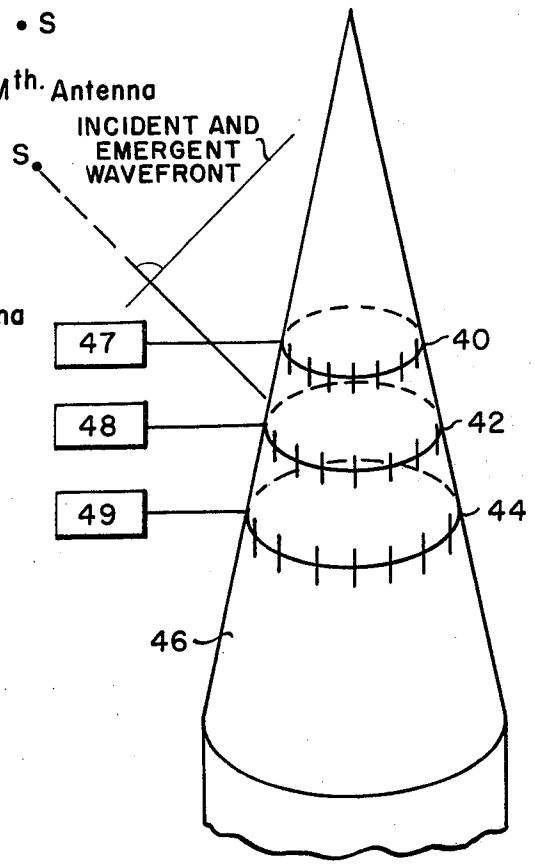


FIG. 4.

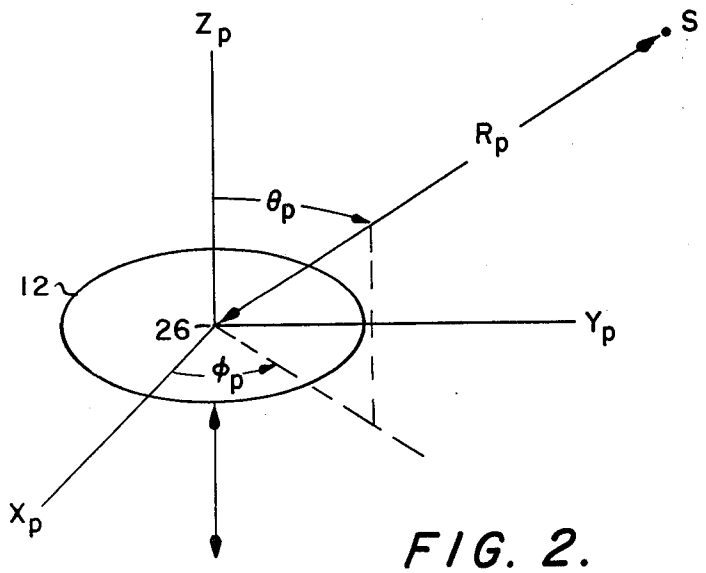


FIG. 2.

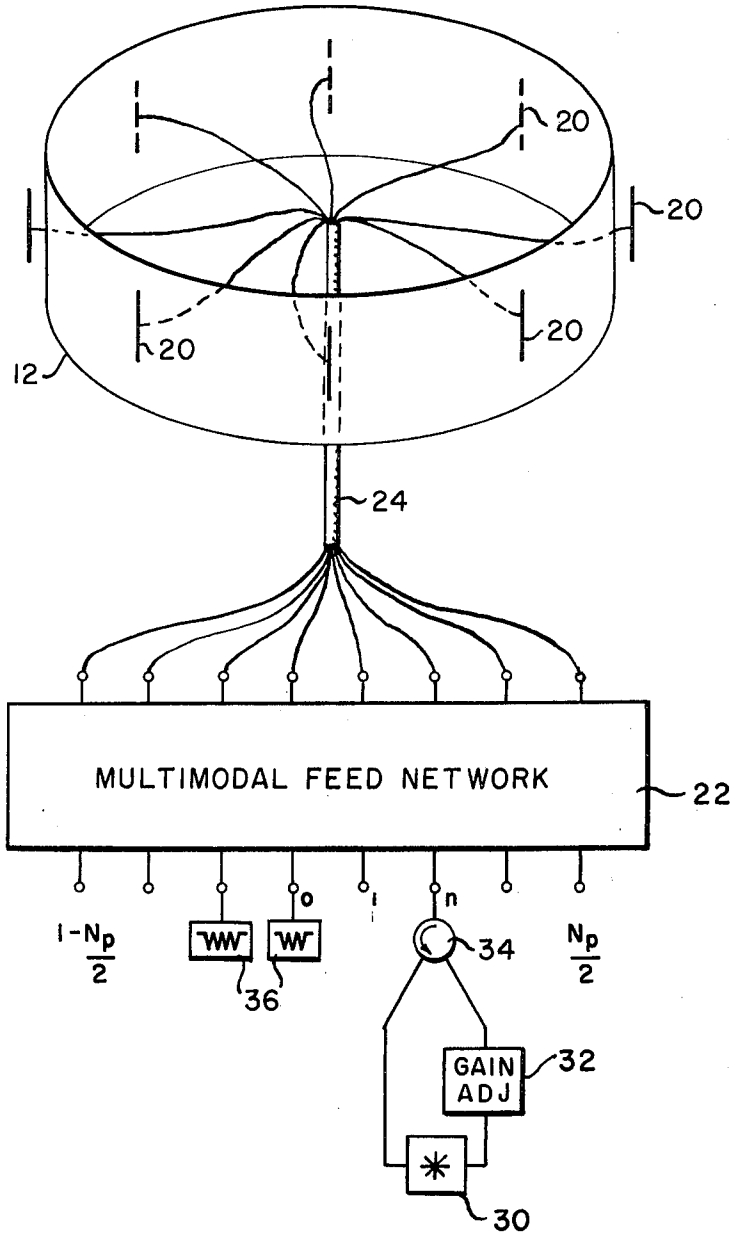

20
20
20
20
12
24
MULTIMODAL FEED NETWORK
22
1-Np/2
o
i
n
34
Np/2
36
GAIN ADJ
32
30

FIG. 3.

MULTIMODAL RETRODIRECTIVE ARRAY

BACKGROUND OF THE INVENTION

The best known method of obtaining retrodirective beam radiation capability is that disclosed by Van Atta in U. S. Pat. No. 2,908,002. Van Atta shows a passive linear array of elements, interconnected in such a way that an electromagnetic beam is redirected from the array at substantially the same angle from which it came. It has become possible to construct an active Van Atta array, and thus the use of such an array has been found to be an effective and practical way to obtain retrodirectivity. However, the Van Atta array is basically limited to the linear or planar discrete arrays. Therefore, it lacks the capability of operating with a circularly symmetric array and is unable to provide 360° coverage. Also, it is not capable of being designed for use in other geometric configurations.

Another method of obtaining retrodirectivity is the fitting of conjugate phase circuits to elements of a linear or circular array. This method is applicable to a general array but is limited in its application because relatively complex circuitry myst be provided for each element of the array. Furthermore, an effort must be made to assume that all the individual conjugate phase circuits are identical so as to provide the desired symmetrical response. This method is expensive and difficult to use in a practical application.

A modified Van Atta arrangement has been suggested by Davies in *Proceedings of the IEEE*, March 1963. Here, isotropic elements are arranged in a circularly symmetric manner. Although 360° retrodirectivity is possible, problems such as the control of sidelobe level and the system's size and weight limit the usefulness of this array. Furthermore, this system is not adaptable to a general array.

Considering such drawbacks, the present invention provides a retrodirective antenna system which is adaptable to a general array and which displays none of the disadvantages set forth above.

SUMMARY OF THE INVENTION

The present invention involves an extension of the principles set forth in the Applicant's copending application Ser. No. 220,663, filed Jan. 25, 1972, for Circularly Symmetric Retrodirective Array. In that application, retrodirective performance from circularly symmetric arrays is obtained by connecting the elements of the array to a multimodal feed network. Phased mode sets are provided by interconnecting the network terminals in a predetermined manner. All modes in a particular mode set become in-phase in the direction of an incoming signal and, as a result, a beam is made to reradiate in that direction. This technique can be used with cylindrical arrays but not with a general array.

The present invention utilizes the multimodal antenna system which is the basis of the previously disclosed technique but, by the use of conjugate phase circuitry, allows the generalization of the antenna configuration to include surfaces other than cylindrical, such as cones and ellipsoids. The system of the present invention consists of a number of multimodal antennas, directly similar to the circular multimodal antenna systems described in the aforementioned copending application, arranged along an arbitrary locus in space. However, instead of interconnecting the mode terminals, a conjugate phase circuit and a gain adjustment

network are connected to a number of the mode terminals. This results in proper phasing between the modes of the number of circular multimodal antennas so that retrodirectivity occurs even if the circular arrays have different axes, diameters, or number of elements.

OBJECTS OF THE INVENTION

An object of the invention is to provide a retrodirective antenna system of general configuration.

Another object of the present invention is to control the properties of a reradiated beam by a simple and versatile technique.

A further object of the present invention is to provide a retrodirective antenna system capable of conformal mounting on surfaces of general configuration.

Other objects, advantages and novel features of the invention will become apparent from the following detailed description of the invention when considered in conjunction with the accompanying drawings wherein:

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows a number of multimodal antennas arranged around an arbitrary locus.

FIG. 2 shows the relationship of the source to the p^{th} antenna.

FIG. 3 shows how the p^{th} antenna is electrically connected to obtain retrodirectivity.

FIG. 4 shows one possible conformal mounting arrangement.

DESCRIPTION OF THE PREFERRED EMBODIMENT

FIG. 1 shows a plurality of circularly symmetric multimodal antennas **10, 12** and **14,** arranged along an arbitrary locus represented by dashed line **16.** The antennas are directly similar to those disclosed in copending application Ser. No. 220,663. An arbitrary number M of these antennas may be used. The antennas need not be disposed along a common axis nor have the same number of elements. The system of antennas is disposed in relation to far field source of radiation S.

FIGS. **2** and **3** focus on p^{th} antenna **12** for purposes of illustrating the operation of the invention. The p^{th} antenna represents any of the individual multimodal antennas in the system. The antenna consists of a circular array of radiating elements **20** connected to multimodal feed network **22** by transmission lines **24.** Typically the array consists of 2 Np elements and the network is a Butler-Shelton matrix. With respect to the phase reference point **26** of the array, the distant source point S is at a distance R*p*. The direction of the point S relative to phase reference point **26** is given by angles θp and ϕp.

Consider a unit amplitude RF signal applied to the n^{th} mode terminal of antenna **12.** The signal at the terminal of the antenna at the point S is of the form:

$$\vec{E}_{n,p} = K\, A_{n,p}\,(\theta_p)\, e^{j\,\omega\, t}\, e^{-j\,\psi}\quad n,p \qquad \text{Eq. 1}$$

Also,

$$\psi_{n,p} = \beta R_p + F_n(\theta_p) - n\,\phi_p \qquad \text{Eq. 2}$$

where $\beta = 2\pi/\lambda$ and λ is the wavelength. Similarly, for a unit amplitude source at the point S, the signal appearing at the n^{th} mode terminals of the p^{th} antenna is of the form given by Eq. 1. As can be seen from these equations, the phase of the returned signal is dependent on n,p, and the distance of the source from the antenna. Therefore, the signals returned from a plurality of multimodal antennas will not, generally, be of proper phase relative to each other to be retrodirective.

This problem is solved by connecting conjugate phase circuitry and a gain adjustment network to a number of the mode terminals. Referring to FIG. 3, conjugate phase circuit **30** and gain adjustment network **32** (such as an amplifier and/or an attenuator) are connected to the n^{th} terminals of multimodal feed network **22** by means of a conventional circulator **34.** The phase-conjugate circuits have the property that for an incident signal of the form:

$$\vec{E}_1 = C\, e^{j\omega t} e^{-j\alpha}$$

Eq. 3

the output is the form:

$$\vec{E}_2 = C\, e^{j\omega t} e^{j\alpha}$$

Eq. 4

Suitable phase-conjugate circuitry is described in an article by Skolnik and King entitled *Self-Phasing Array Antennas* published in IEEE Transactions on Antennas and Propagation, March 1964. As will be shown below, the addition of these circuits results in a general retrodirective antenna system.

Taking the system with these networks and again considering a unit amplitude source at the point S, the signal entering the n^{th} network on the p^{th} antenna (ref. equation 1) is:

$$\vec{E}_{n,p,1} = K\, A_{n,p}\, e^{j\omega t} e^{-j\psi\, n,p}$$

Eq. 5

The network output is then:

$$\vec{E}_{n,p,2} = K\, A_{n,p}\, G_{n,p}\, e^{j\omega t} e^{j\psi\, n,p}$$

Eq. 6

The signal appearing back at the source is then:

$$\vec{E}_{n,p,3} = K^2\, A_{n,p}^2\, G_{n,p}\, e^{j\omega t} e^{j\psi\, n,p}\, e^{-j\psi\, n,p}$$

Eq. 7

(See Equation 1)
and rewriting Eq. 7:

$$\vec{E}_{n,p,3} = K^2\, A_{n,p}^2\, G_{n,p}\, e^{j\omega t}$$

Eq. 8

An examination of Eq. 8 shows the retrodirective properties of the system since the phase of the returned signal at S is independent of n and p, and the location of the point S with respect to any of the antennas. K and A are constant and $G_{n,p}$ is controlled by gain adjust network **32.** The choice of which mode terminals to terminate in conjugate circuitry and the adjustment of the parameter G allows the characteristics of the returned beam to be controlled. For example, the beamwidth of the antenna can be changed by terminating, more or less, of the multimodal feed network terminals in conjugate phase circuitry. Unused mode terminals are terminated in matched loads such as **36.**

FIG. 4 is a simple example of one conformal retrodirective antenna system according to the present invention. Here three circular antenna arrays **40, 42** and **44** are conformally mounted on conical structure **46.** The antennas may have the same or differing numbers of elements. They need not be the same type of antenna as long as each is circularly symmetric. Each antenna is connected to its own multimodal feed network and conjugate phase circuitry represented by boxes **47, 48** and **49** in FIG. **4.** An incident wavefront from a distant source S will be received by the three antennas and an emergent wavefront will be retrodirected back toward S.

In practicing the present invention, continuous aperture antennas can be utilized as well as circular arrays and networks other than the Butler-Shelton can be used.

Obviously many modifications and variations of the present invention are possible in light of the above teachings. It is therefore to be understood that within the scope of the appended claims the invention may be practiced otherwise than as specifically described.

What is claimed and desired to be secured by letters patent of the United States is:

1. A retrodirective antenna system of general geometric configuration comprising:

a plurality of stacked circularly symmetric antennas;

a like plurality of multimodal feed networks having antenna terminals and mode terminals, each symmetric antenna being associated with one of said multimodal networks;

means for connecting each individual antenna in each symmetric antenna to the antenna terminals of the associated network; and,

means connected to the mode terminals of said networks for receiving a signal from a terminal and returning to the terminal the phase conjugate of said signal.

2. The retrodirective antenna system of claim **1** wherein said circularly symmetric antennas are circular arrays.

3. The retrodirective antenna system of claim **1** wherein said circularly symmetric antennas are continuous aperture antennas.

4. The retrodirective antenna system of claim **1** wherein each of said multimodal feed networks is a Butler-Shelton matrix.

5. The retrodirective antenna system of claim **1** wherein each of said circularly symmetric antennas has a different axis.

6. The retrodirective antenna system of claim **2** wherein each of said circular arrays has a different number of elements.

7. The retrodirective antenna system of claim **1** wherein said signal receiving and returning means includes at least one conjugate phase circuit and one gain adjustment circuit.

8. The retrodirective antenna system of claim **7** wherein those mode terminals which are not connected to a conjugate phase circuit and gain adjustment circuit are terminated in matched loads.

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