Variable Aperture Variable Polarization High Gain Antenna System for a Discrimination Radar

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FIG. 1

FIG. 2
This invention relates to an antenna system and more particularly to a system for discrimination radar having variable aperture, variable polarization and high gain.

In a discrimination radar system, there is a need for a radar system which provides for the examination of a small portion of the sky (about 6 degrees) with a high gain antenna at one time together with relatively small variation of the illumination angle to a maximum of approximately 30 degrees. Additionally, the antenna system must provide surveillance of the radar illuminated portion of the sky with a bundle of high gain narrow beam antennas. Both the receive and transmit antenna systems must be capable of providing for the use of horizontal, vertical, or circular polarized radiation.

It is, therefore, an object of this invention to provide a radar antenna system having variable aperture control. Further, it is an object of this invention to provide an antenna system having variable polarization.

Another object of this invention is to provide a variable aperture and variable polarization antenna system having high gain.

Other objects and many of the attendant advantages of this invention will be readily appreciated as the same becomes better understood by reference to the following detailed description when considered in connection with the accompanying drawing in which like reference numerals designate like parts throughout the figures. It is to be expressly understood, however, that the drawings are for the purposes of illustration and description only, and are not to be construed as defining the limits of the invention. In the drawings, FIGURE 1 is a diagrammatic view of an antenna system according to the present invention.

FIGURE 2 is a front view of a transmitting antenna showing a cut-away view of a portion of the radiating elements of the antenna.

FIGURE 3 is a schematic diagram of a transmitting antenna system according to the present invention.

FIGURE 4 is a block diagram of a microwave variable polarization control system for the transmitting antenna.

FIGURE 5 is a simplified block diagram of a polarization control system for the transmitting antenna.

In order to better understand the operation of the system described in the figures, a description of its components is first presented.

Referring now to FIGURE 1, the antenna system support control unit 5 could be a mobile unit or a fixed station unit depending upon the deployment situation. A U shaped yoke azimuth gimbal 7 supports the antenna structure so that total azimuth travel is 360 degrees. The gimbal rotates in control unit 5. The receiving lens 9, transmitting antenna 11 and associated electronics contained in the box like structure 13 are rigidly constructed with a predetermined spaced relationship of transmitting antenna 11 to lens 9 and the entire structure is pivotally mounted at two diametrically opposite points on the equator of lens 9 as shown by pivot 15. The track discriminate antenna 11 is a plane circular array. It is mounted at the top of the receiving lens antenna 9 and mechanically constrained so that its radiated beam is pointed in the same direction as that of the receiving lens antenna 9.

Referring now to FIGURE 2, there is shown transmitting antenna 11. The radiating elements 19 are arranged in 6 concentric rings of which a portion of rings 6, 7 and 8 are shown in the cut-away view. The elements 19 have both horizontal and vertical polarized transmitting elements which are separately fed. Further, the rings are fed in such a manner that when a broad beamwidth is desired, only the central group of elements are energized. As narrower beamwidths are desired, the outer rings of elements are progressively added until for the narrowest desired beamwidth, all the radiating elements are energized. The elements are positioned on a circular pan shaped structure as shown in FIGURE 1, for reflection of the radiating elements. The antenna has a cover 21 made of a material that does not restrict the radiation from the antenna but will protect the elements 19 from the weather.

Referring now to FIGURE 3, there is shown the control system for dividing power to the transmitting antenna 11 rings of feeds. Only the outputs for four rings are shown for purposes of simplifying the description. The powers to the transmitting 23, having a control unit 22 connected thereto, located in the control unit 5 (FIGURE 1), is connected to a first variable power divider 25 giving three output ratios of 1:1, 1/2:1/2, and 1:0. A first output of power divider 25 is connected to a second three ratio power divider 27. A second output of divider 25 is connected to a third three ratio power divider 29 through a 90 degree fixed phase shifter 31, the purpose of which will be explained later. A first output of power divider 27 is connected to a fourth two ratio (1:1 and 1/2:1/2) power divider 33, the output of which feeds the first rings of horizontally polarized elements 19. A second output of divider 33 feeds the second ring of vertical elements. A second output of divider 27 is connected to divider 35 which feeds vertical elements rings 3 and 4 as described above for rings 1 and 2. Power dividers 37 and 39 are connected to outputs of divider 29 and feed the first four rings of horizontally polarized elements 19 as described for the vertical polarized elements.

A second transmitter is connected to a second set of power dividers (all not shown) as described above to feed the remaining four rings of normally polarized elements.

Referring now to FIGURE 4, there is shown a variable power divider as used in the dividers discussed in FIGURE 3. The unit consists, of a first, microwave hybrid network 41 which accepts an input signal and a terminating means 43 is provided for load matching purposes. A first output of hybrid network 41 is connected directly to a second microwave hybrid network 45. A second output of hybrid 41 is connected to a second input of hybrid network 45 through a solenoid actuated phase shifter 47 which provides for the proper power output ratios as discussed above from the output hybrid network 45. The variable phase shifter is connected to and controlled by control means 22.

Referring now to FIGURE 5, there is shown a section of the receiving lens 9. A reference line 49 shows the fixed spaced relation of transmitting antenna 11 to receiving lens 9. Located at the rear on a 30° conical spherical segment of lens 9 is a plurality of circular wave guide feeds
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51. Only one row of feeds are shown in order to simplify the description. Connected to each of feeds 51 is a parametric amplifier and mixer 57 for changing the received frequency to a lower frequency which will allow connection to the waveguide section 59 through slip rings not shown. The receiver section also being controlled by control means 22.

Operation

The track discriminate antenna will perform two basic functions. It will provide angular resolution of the many fragments in the decay cloud 17 (FIGURE 1) and it will track the centroid of the cloud. Before either of these operations take place, the antenna system must be directed such that the coverage provided centers on the decay cloud.

The antenna system consist basically of a Luneberg lens 9 illuminated by multiple feeds 51 so that a set of high beams are produced which cover a portion of a hemisphere. This antenna will be used for receiving only and will be equipped with parametric amplifiers 57, one for each feed or angular resolution element.

The first of the basic functions, that of angular resolution of fragments covering a large solid angle is the one from which the basic information required is derived; the second function is important only in that it allows continuous surveillance of the moving cloud, keeping all important fragments within the fixed field of view. The resolution of the targets in angle becomes the first in a series of operations done on the radar returns from the fragments to distinguish the warhead 16 from tankage and other forms of decoys 18.

As mentioned previously, receiving antenna 9 is a Luneberg lens, which is a spherical dielectric having a dielectric constant (\(\varepsilon\)) or refractive index (N) varied as:

\[
\varepsilon = N^2 = 2 - \frac{2\pi}{\lambda} \sin^2 \theta
\]

where \(\theta\) is the normalized length of a radius vector from the center of the sphere to any internal point.

It is the property of such a lens 9 that it will focus a plane wave, impinging upon it to a point diametrically opposite from the point at which the wave initially contacts the lens. Two examples of this characteristic are shown in FIGURE 5: one wave by dashed lines and one by solid lines. Therefore, energy arriving from different directions is focused at different points on the lens surface. Placing many feeds 51 in close proximity on the surface of the lens then allows resolution of the particles of cloud 17 to within limits defined by the size of the lens 9 and feeds 51.

The operating frequency of the system is 8.5 kmce, corresponding to a center frequency free space wavelength of 1.39 inches. The lens 9 being 5 feet in diameter yielding a beamwidth factor of approximately 70 so that the half power beamwidth (\(\theta/2\)) is 1.63 degrees.

\[
\theta/2 = \frac{\lambda}{D} = 1.63 \text{ degrees}
\]

The gain based on an aperture effectiveness of .5 is:

\[
G = \frac{4\pi NA}{\lambda} = 9100 \text{ or } 39.6 \text{ db}
\]

In order to determine the number of feeds 51, the area of coverage and the depth of crossover between adjacent beams must be chosen system considerations and expected maximum cloud size indicate that a conical sector with a total cone angle of 50 degrees should be used as shown in FIGURE 5. In order that the gain in a given direction be close to the 39.6 db maximum at beam peaks, it would be advantageous to use a crossover of 3 db.

For a 3-db crossover, the feeds 51 must be .842 inch center-to-center. If an unmodified circular waveguide of .025 inch wall thickness is used as a feed the resulting guide is below cutoff at 8.5 kmce and thus is the system operating frequency. However, if X-band circular waveguide with a 0.938" OD is used the guide is above cutoff, and the resulting crossover is approximately 4 db down from the individual beam peaks. Such an arrangement is deemed more desirable than loading each feed with di-electric and using the closer spacing. Dielectric loading of the waveguide requires a high degree of uniformity of the dielectric comprising lens 9 if polarization integrity is to be maintained. The closer spacing also results in high mutual coupling between feeds which makes the antenna design unduly complex. The increased crossover depth is, therefore, the best compromise of the polarization characteristics are important in the discrimination process. Using open-ended circular guide feeds with 0.938" OD permits 18 feeds to be located on a diameter of the 30 degree conical surface of lens 9 as shown in FIGURE 5.

Making the approximation that the 30 degree region is a planar circular region the number of feeds required is:

\[
N = \frac{X}{4(18)^2} = 253 \text{ feeds}
\]

The use of circular waveguide feeds 51 simplifies the job of providing polarization diversity. Horizontal and vertical polarization components of the return from target cloud 17 may be sequentially analyzed by including a half-wave plate of dielectric material in the circular guide. Polarization sensitivity of such a device varies as twice the angle of rotation between the horizontal and polarization vector of the output port. If circular polarization is required as another option, this can be provided by inclusion of a dielectric quarter wave plate in each feed, which may be rotated in 45 degree increments. When this device is either in line with or normal to the polarization of the output port, it has no effect upon polarization sensitivity, but at 45 degrees or 135 degrees, circular polarization sensitivity is produced (opposite sense for 45 degrees as opposed to 135 degrees). Simple solenoid actuated devices of this type are already in existence and therefore are not shown.

The parametric amplifiers and mixers 57, one for each feed, are connected directly to feeds 51 so that only IF signals must be taken off the movable part of the antenna structure through rotational joints to a mounting vehicle. In this way, only transmitter power must be taken through X-band rotary joints and the IF signals may be handled on sets of slip rings to receiver section 59 controlled by control means 22.

The lens 9 with feeds 51 and amplifiers and mixers 57 contained in box 12 is supported at two diametrically opposite points on its "equatorial" plane for elevation motion of the lens and feeds together. In this way, a given feed is always "looking" through the same portion of the lens 9 from the same aspect and imperfections in the Luneberg lens do not cause differential errors as a function of antenna motion.

Azimuth travel is accomplished by way of a pivot located under the center of the structure which supports a yoke-like azimuth gimbal 7. Total azimuth travel is 360 degrees and total elevation travel is 90 degrees, so that the whole hemisphere may be covered in such a way that the centroid of clouds of up to 30 degrees in diameter may be tracked.

The transmitting antenna 11, shown in FIGURE 2, is a plane circular array 16 inches in diameter. The radiating elements 19 of the array are arranged in 8 concentric rings and fed in such a way that when a broad beamwidth is desired, only the central group of elements is energized. As narrower beamwidths are desired, the outer rings of elements are progressively added until, for the narrowest desired beamwidth, all the rings are energized. The array is capable of stepwise beamwidth variation from a half power beamwidth of approximately 30 degrees, when only a central group of elements are excited, to approximately 6 degrees when all elements are excited. The variation of excitation of the array is accomplished by means of variable attenuators as shown in FIGURE 5 for four rings of feeds. The transmitting elements 19 are composed of linearly polarized radiating
elements. If an orthogonal sense of linear polarization is desired, it may be obtained in two ways: One, by rotating the antenna 90 degrees, second, by feeding another set of linearly polarized elements (such as dipole elements) orthogonal to the first set which is the illustrated configuration. Polarization is selected, as shown in FIGURE 3 for 4 rings, by means of variable power divider 25. The cloud coverage is then selected by power dividers 29, 37 and 39 for horizontal polarization and dividers 27, 33 and 35 for vertical polarization. Circular polarization is obtained with these groups of orthogonal linearly polarized elements by feeding them simultaneously with a 90 degree phase differential between the horizontal and vertical elements by means of fixed phase shifter 31 in FIGURE 3.

When a discrimination radar according to the present antenna system is placed into action, the antenna is positioned in azimuth and elevation by commands to control unit 5 (FIGURE 1) for cloud 17 illumination and, by analysis of the radar returns from the cloud the antenna is made to track the centroid of the target cloud. The returns from separate targets will be received in separate portions of lens 9 as shown by points 55 and 57 (FIGURE 5) for two separate returns. The returns from these particles will remain in focus and the same points due to the fact that the transmitting antenna is constrained to look at the same sky segment as the receiving lens. Therefore, it is possible to make discrimination tests on different particles, using the techniques explained above, to locate the warhead 16 from other particles 18.

While the invention has been described with reference to a particular embodiment thereof, it will be apparent that various modifications and other embodiments thereof will occur to those skilled in the art within the scope of this invention. Accordingly, it is desired that the scope of this invention be limited only by the appended claims.

What is claimed is:

1. A discrimination radar antenna system comprising:

- a transmitting antenna means;
- a receiving antenna means;
- structure means for structurally restricting said transmitting antenna means in a predetermined fixed space relationship to said receiving antenna means, so that said receiving antenna means is illuminating the same sky segment as said transmitting antenna means at all times,
- said receiving antenna means comprising a Luneburg lens having a plurality of open-ended circular waveguides positioned on a surface of said lens to define a conical circular sector of said lens diametrically opposite a portion of said lens surface exposed to impinging radiation from said sky segment; said waveguides being spaced apart predeterminately so that separate waves impinging said lens are detected separately by means of said waveguides;
- a receiver; a plurality of parametric amplifiers and mixer means connected between each of said open-ended waveguides and said receiver means;
- gimbal means supporting said antenna means so that total azimuth travel is 360 degrees; said gimbal means being defined by a U-shaped yoke pivotally connected to said structure means for positioning said antenna means in elevation; and support means for supporting said gimbal means.

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