

[54] **ELECTRICALLY STEERABLE
AIRCRAFT MOUNTED ANTENNA**

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[58] Field of Search.....343/705, 708, 854,
343/814

2,464,276 3/1949 Varian.....343/854

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[57]

ABSTRACT

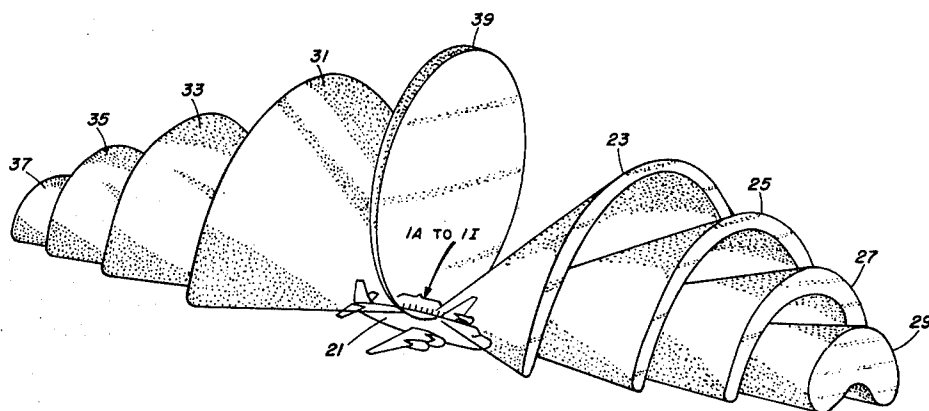
The application discloses an electronically steerable aircraft-to-satellite antenna system using a linear series of parallel dipoles fed through phase-shifting controls. By variation of the phase-shift to the various dipoles, different cones of radiation (or preferred reception) are provided. The cone axes are parallel to or coincident with the longitudinal axis of the aircraft, so that aircraft roll has little effect on the orientation of the cone.

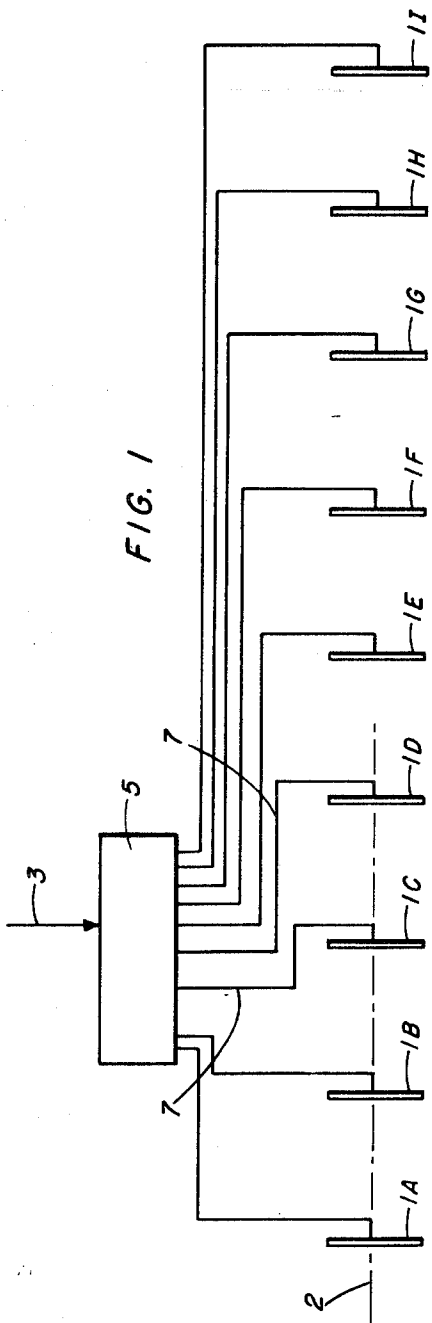
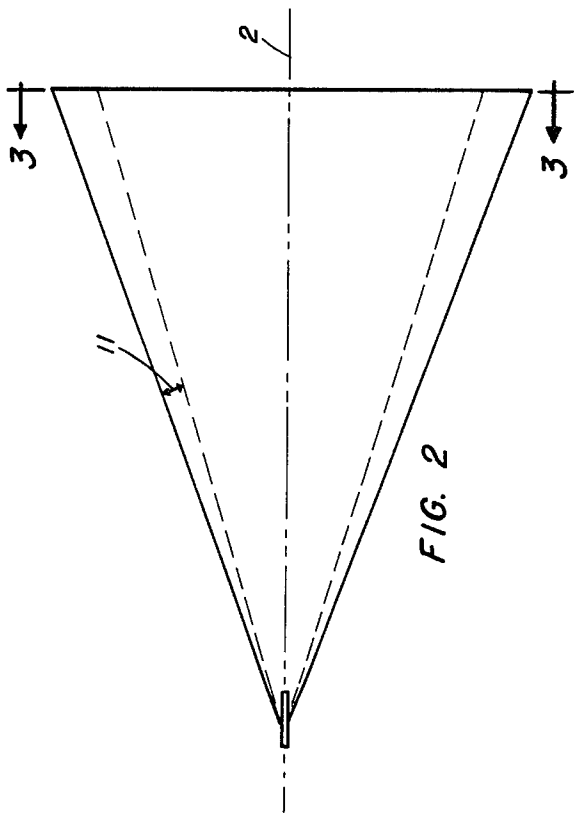
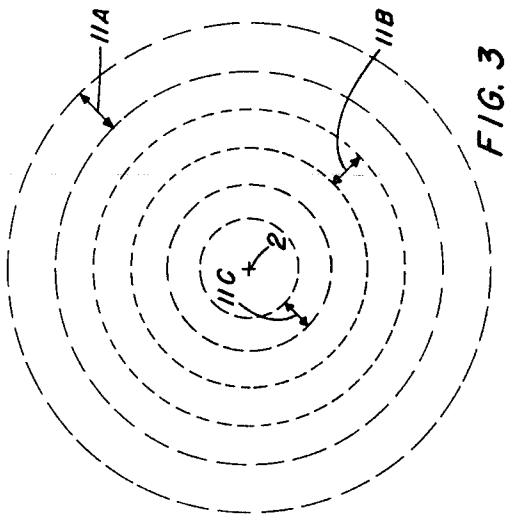
7 Claims, 6 Drawing Figures

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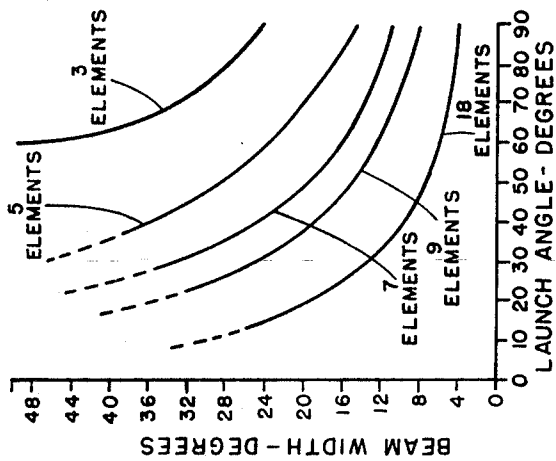


FIG. 5

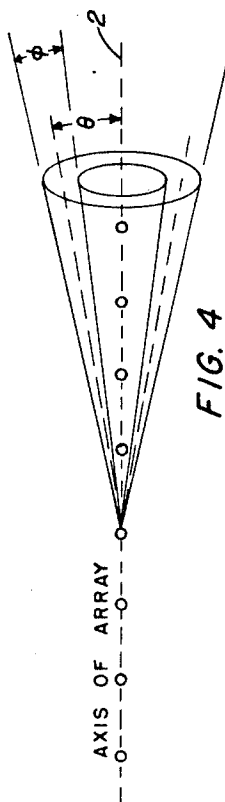


FIG. 4

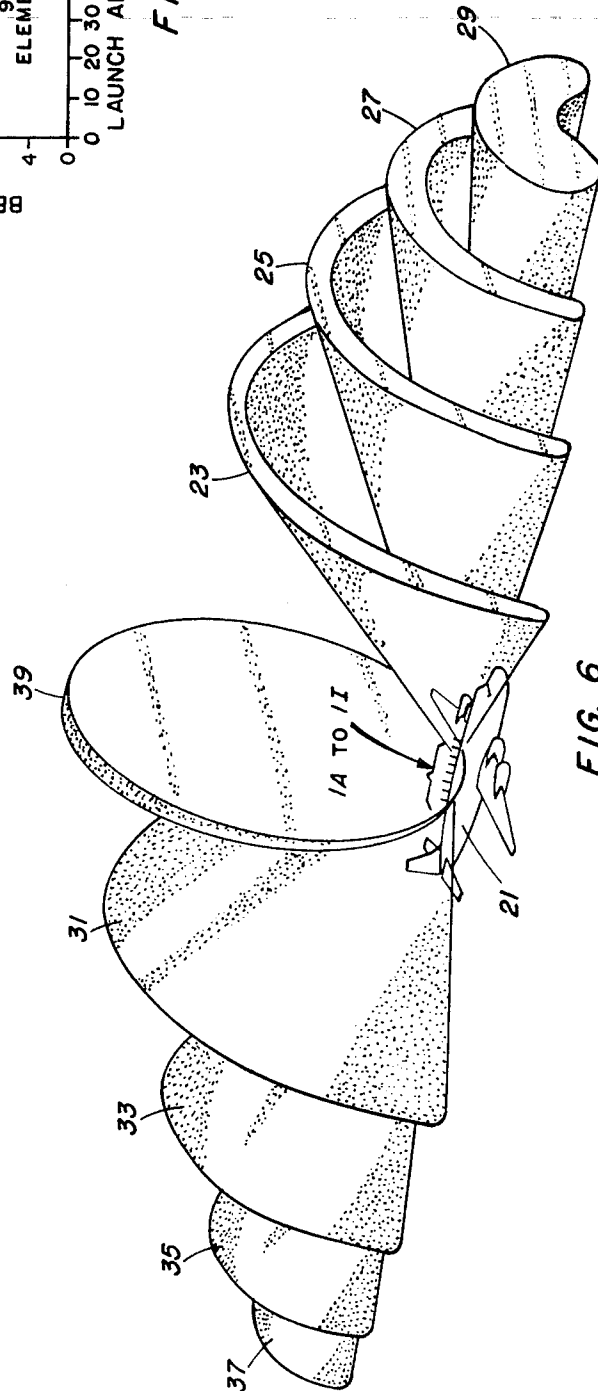


FIG. 6

ELECTRICALLY STEERABLE AIRCRAFT MOUNTED ANTENNA

STATEMENT OF GOVERNMENT INTEREST

The invention described herein may be manufactured and used by or for The Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to electrically steerable antenna systems, and finds particular application in airborne mobile communications system intended for communication with an orbiting satellite.

Use of an omni-directional antenna on a mobile platform enables communication between the mobile platform and a satellite whatever the bearing and elevation of the satellite (as long as it is radio range) but on the other hand such an antenna is inefficient as regards the transmission of energy towards the satellite and provides no rejection of signals from noise sources during reception. In order to provide an acceptable level of effectiveness, some form of directional antenna in combination with some form of steering of the antenna is necessary.

2. Description of the Prior Art

It is known to utilize for communication purposes antennas which are directional and which are physically steerable, and these are used both for UHF systems, in which arrays of dipoles are used as the antenna, and for systems for frequencies above UHF, in which latter systems sheet metal antennas are usually used. It is also known, for UHF systems, to use fixed antenna arrays of dipoles having radiation patterns which can be modified by varying the relative phases of the energizing signals applied to the different dipoles. To utilize such a system, of electronically steerable dipole arrays, for an aircraft communication system, is of great interest since the mechanical steering of antennas in this environment is difficult and sometimes impossible. In considering the airborne antenna system, a two-dimensional angular steering of a conventional phased dipole array is necessary, and the associated control circuitry is complex.

SUMMARY OF THE INVENTION

According to one aspect of the present invention, an antenna system comprises at least three doublet elements arranged coaxially and spaced apart, together with means adapted to apply a common signal to all the elements but with a progressive change in the phase of the signal as received by the elements in one sense along the length of the array, the means adapted to apply the common signal being adjustable to permit a change in the rate of the progressive change in the phase, whereby by operating the antenna system at different rates of change of the progressive change in phase, different annular conical lobes of radiation, or of selective sensitivity to radiation, are produced centered on the common axis of the elements.

According to another aspect of the invention, a method of producing an annular conical, or a part-annular-conical lobe of radiation or of selective sensitivity to radiation, comprises effecting a variable pattern of phase shifts to signals passing between an input/output lead and a coaxial array of at least three dou-

blet elements, the pattern being such that the phase shifts associated with the doublet elements vary in a progressive manner in one sense along the length of the array in such a manner as to produce the annular conical, or the part-annular-conical lobe, and the pattern being varied so as to change the half-angle of the lobe cone.

OBJECT OF THE INVENTION

10 An object of the present invention is the provision of an electronically steerable antenna system suitable for particular applications and for those applications providing a system which offers a marked reduction in both cost and complexity.

15 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 drawing.

20 BRIEF DESCRIPTION OF THE DRAWINGS

The invention will now be described, by way of example, with reference to the accompanying drawings, in which:

25 FIG. 1 is a plan view of an antenna system according to the present invention;

FIG. 2 is a side elevation of the effective radiation produced by the antenna system of FIG. 1 in free space;

30 FIG. 3 is a diagram showing the different zones of effective radiation produced at the plane III—III of FIG. 2 under different conditions of operation;

FIG. 4 is a diagram of the typical lobing structure of an array such as that shown in FIG. 1;

35 FIG. 5 is a graph showing the relationship between launch angle and beam width (in degrees) of antenna such as those shown in FIG. 1 but with varying numbers of dipole elements; and

40 FIG. 6 is a perspective drawing of an aircraft carrying an antenna array such as that shown in FIG. 2, and also shows schematically the effective lobes produced by that antenna system when operating under different conditions.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

45 Referring first to FIG. 1, the antenna system illustrated comprises nine dipoles 1A to 1I, the nine dipoles being arranged parallel and linearly on an axis 2. The spacing between adjacent dipoles is not critical, but the spacing will affect the radiation pattern obtained when the various dipoles are energized with signals from the same source but at different phases. In the example shown, the spacing between adjacent dipoles is one-half (wavelength), and each dipole has an overall length of one-half (wavelength).

50 All nine dipoles are fed from a common input/output lead 3 through a phasing unit 5. This unit introduces different delays to a common signal as it passes to leads 7 leading respectively to the various dipoles.

60 As will be appreciated by those skilled in the art, the lengths of at least most of the leads 7 will exceed one wavelength, and the lengths of the various leads will thus affect the phase of the signals actually reaching the dipoles. For any given channel, the relative phase shifts introduced by the leads must be taken into account. For an antenna system intended to operate on several channels, it may be simpler to ensure that all the leads

7 have the same length, so that phase shift in the leads 7 will be equal for all dipoles at all frequencies.

Bearing the above points in mind, the phasing unit 5 is arranged to enable the relative phases of the signals applied to the different dipoles to be varied. When the signals applied to all the different dipoles have the same phase, the overall radiation pattern of the array will have a lobe of maximum radiation extending normally from the array axis 2. According to the present invention, the signals applied to the dipoles vary progressively in phase from one end of the array to the other end, in the same sense, i.e., either with progressively increasing amounts of phase lag or with progressively increasing amounts of phase advance. In these circumstances, a lobe of maximum radiation will be produced in the form of a hollow cone with its apex at the array and with its axis colinear with the axis of the array, as indicated in FIG. 2 by the hollow cone 11.

By using the phasing unit 5 to vary the amount of phase lag or phase advance along the array from dipole to dipole, the cone half-angled (see FIG. 4) can be varied. Thus, by changing the phase shifts involved, it is possible to obtain different hollow cones of effective coverage by the antenna system. FIG. 3 indicates this point, and shows the annular form of three different lobes designated 11A, 11B and 11C, obtained in this manner.

A partial set of beams generated by a linear array of $\lambda/4$ dipoles mounted on the surface of an aircraft 21 may look somewhat like that shown in FIG. 6. In this case, only the upper half-cones 23, 25, 27, 29, 31, 33, 35 and 37 and the central disc 39 are present because of the shadowing effect of the aircraft.

The power gain G_A of such an array will be approximated by

$$G_A = N G_R \quad (1)$$

where N = the number of elements in the array and G_R is the gain of a single element. This only holds, of course, provided that the effective apertures of the array elements are not overlapping and no serious interaction is occurring.

It is interesting to note that such an array is capable of scanning a complete hemisphere by varying the single parameter θ , the half-angle of the cone apex, (see FIG. 4).

The approximate power gain of an array of isotropic radiators G_i is given by

$$G_i = \frac{\text{solid angular area of sphere}}{\text{solid angular area of array beam (or beams)}} = \frac{4\pi}{\text{solid angular area of array beam (or beams)}}$$

when the beamwidths are measured at the -3 db points. The angular area A_x of cone with apex half-angle $\theta - \phi/2$ is given by

$$A_x = \pi [\theta - (\phi/2)]^2$$

The angular area A_y of cone with apex half-angle $\theta + (\phi/2)$ is given by $A_y = \pi [\theta + (\phi/2)]^2$

The angular area A_1 of radiated beam A_1 is given by

$$\begin{aligned} A_1 &= A_y - A_x \\ &= \pi [\theta + (\phi/2)]^2 - \pi [\theta - (\phi/2)]^2 \\ A_1 &= 2\pi\theta\phi \end{aligned}$$

So for the case of a single conical beam

$$G = (4\pi)/A_1 = 2/(\theta\phi)$$

and for several equal amplitude conical beams

$$G = 4\pi/(A_1 + A_2 + \dots) = 2/(\theta_1\phi_1 + \theta_2\phi_2 + \dots)$$

EXAMPLE

Consider the case where $N = 9$

$$n = 1$$

$$\theta = 60^\circ = 0.954 \text{ rad.}$$

$$G = N = 9$$

$$\therefore G = 9 = 2/(\theta\phi) = 2/(0.954\phi)$$

$$\phi = 2/(0.954 \times 9) = 0.233 \text{ rad.} = 13.33^\circ$$

The measured beamwidth from a synthesized pattern was 10.5° at -3 dB. For an end-launched beam, $\theta = \phi/2$ and therefore

$$G = 9 = 2/(\theta\phi) = 4/(\phi^2)$$

$$\phi^2 = 4/9$$

$$\phi = 2/3 = 38.2^\circ$$

FIG. 5 shows curves relating beamwidth to launch angle for arrays with 3, 5, 7, 9 and 18 elements. A single quadrant is plotted since quadrant symmetry exists.

In the U.H.F. band, fairly large effective apertures can be achieved using only a few elements. For example, an array of nine $\lambda/4$ dipoles will provide an effective aperture of about 1.5 square meters and a gain of about 13 db/iso at 250 MHz.

The minimum azimuthal beamwidth for such an array occurs broadside i.e., at 39 and equals about 8° .

Only a few (≈ 12) sets of lobes generated by such an array will suffice to complete hemispherical coverage, and therefore the technique is well suited to a switched-array antenna system.

It is common practice to utilize a single antenna array both to transmit a signal and to receive a signal. The above description has, for the sake of simplicity, dealt basically with the transmission of a signal, the antenna array being effective to produce an annular conical radiation lobe, or a part-annular-conical radiation lobe.

When such an antenna array is used to receive a signal, all the dipoles will receive the signal and the signal will be transmitted through the leads 7 to the phasing unit 5, where the signals from the various leads 7 will be phase shifted by varying amounts before being fed to the input/output lead 3. The net result is that for a phase shift arrangement which would give the radiation lobe 11 of FIG. 2 during transmission, the lobe 11 will be a lobe of selective sensitivity to radiation coming to the antenna array.

In the specific embodiment of the invention described above, the elements of the antenna system have been described as dipoles. It will be appreciated that a variety of radiating elements, including doublets, may be used, the distinction being that a dipole is a doublet which has a length so related to the frequency at which it is used that the overall length of the doublet is a half-wavelength at that frequency.

Although it will usually be simpler to effect the change, in the rate of change in phase along the array, in a step like manner to produce in sequence a number of different annular conical, or different part-annular-conical, lobes of radiation, or of selective sensitivity to radiation, the different lobes overlapping one another, the present invention includes in its scope the concept of changing the rate of change in phase along the array in a progressive manner. The effect then produced will be of the nature of a radiation lobe which has a progressively changing cone half-angle.

It will be seen that in the arrangement shown in FIG. 6 two sets of half-cones are shown, one extending forwardly of the aircraft and one extending rearwardly from the aircraft. This change in direction is effected by changing the sense in which the signal phases change along the length of the array. Thus, during transmission in one instance the signals on the forward elements of the array will lag the signals on the rearward elements of the array; while in the other instance the signals on the rearward elements of the array will lag the signals on the forward elements of the array. The exact manner in which this will be done is largely a matter of design. If it is desired to make use only of devices which introduce a lagging phase shift in the phasing unit 5, this is readily achieved by the use of such devices in conjunction with each of the leads 7. When it is desired to produce a forwardly directed lobe, then these devices can be adjusted to produce zero phase lag at one end of the antenna array and a progressively increasing phase lag along the series of elements, while when it is desired to produce a rearwardly directed lobe, then these devices can be adjusted to produce zero phase lag at the other end of the antenna array, and a progressively increasing phase lag along the series of elements.

It will be appreciated that the antenna array described above has many advantages, the most important of which may be summarized as follows:

1. Such an array is capable of complete hemispherical coverage by varying a single array parameter, i.e., the cone angle. In the conventional 2-dimensional arrays, two angular parameters must be varied to allow complete hemispherical coverage.

2. The simple steering technique results in drastically simplified phase control networks.

3. The most rapid angular maneuver, in large, transport type aircraft, is that of bank or roll. If the linear array is spaced along, or parallel to the roll axis of the aircraft, no beam change or little beam change is required to maintain communication with a satellite.

4. This technique is particularly appropriate at UHF, where the angular thickness of the conical beam structure is several degrees.

With the arrangement of doublets shown in FIG. 1, a radiation pattern "hole" exists in that no effective radiation can be produced vertically (assuming the aircraft is flying horizontally). In the unusual case of the

aircraft flying under the satellite, this could create a problem. If such conditions are anticipated, the elements used can be so-called "bent-monopole" elements. These elements are commercially available.

What is claimed is:

1. An electrically steerable antenna system for use in an airborne communications system to provide communications between an aircraft and an orbiting satellite comprising:

an antenna comprising a fixed linear array of dipole elements mounted on the upper parts of the aircraft on a common axis parallel to the longitudinal axis of the aircraft;

phase shifting means connected to the array of dipole elements for introducing into a signal to be communicated a predetermined phase shift between adjacent dipole elements to produce an annular lobe of maximum radiation in the form of a hollow cone with its apex at the array and its axis collinear with the axis of the array;

means for applying the signal to be communicated to the phase shifting means; and,

means for varying the apex angle of the cone of radiation to include the orbiting satellite within the lobe of maximum radiation regardless of the relative orientations of the aircraft and satellite.

2. The antenna system of claim 1 wherein the means for varying the apex angle of the cone of radiation comprises means for varying the phase shift introduced between adjacent dipole elements.

3. The antenna system of claim 2 wherein said array of dipole elements comprises at least three elements.

4. An antenna system as claimed in claim 1 wherein the number of elements in the array is nine.

5. A method of communication between an in-flight aircraft having a fixed linear dipole array antenna mounted on the upper parts of the aircraft on a common axis parallel to the longitudinal axis of the aircraft and an orbiting satellite which comprises:

radiating from the antenna the signal to be communicated as an annular lobe of maximum radiation in the form of a hollow cone with its apex at the array and its axis parallel to the longitudinal axis of the aircraft; and

adjusting the apex angle of the cone to include the orbiting satellite within the lobe of maximum radiation.

6. The method of claim 5 wherein the step of radiating the signal comprises:

applying the signal to one end of the linear array; and,

shifting the phase of the signal between adjacent dipoles as it passes to the other end of the array.

7. The method of claim 6 wherein the step of adjusting the apex angle of the cone comprises varying the phase shift between adjacent dipoles.

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