United States Patent [19]

Ohm

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[54] **MULTIPLE-BEAM CASSEGRAINIAN ANTENNA**

[75] Inventor: **Edward Allen Ohm,** Holmdel, N.J.

[73] Assignee: **Bell Telephone Laboratories, Incorporated,** Murray Hill, N.J.

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[52] **U.S. Cl.** **343/779;** 343/781; 343/837

[51] **Int. Cl.** **H01q 19/14**

[58] **Field of Search** 343/781, 837, 840, 779

[56] **References Cited**

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Primary Examiner—Eli Lieberman
Attorney, Agent, or Firm—David L. Hurewitz; Daniel D. Dubosky

[57] **ABSTRACT**

A multiple-beam Cassegrainian antenna configuration is disclosed which supports a plurality of angularly displaced but well-isolated beams and exhibits essentially zero aperture blockage. A plurality of feed horns are clustered about the on-axis focal point of an offset Cassegrainian antenna in which the subreflector is displaced from the aperture to avoid blockage. This subreflector is sized and shaped to accommodate the plurality of beams, and the feeds are individually aimed toward the subreflector so that all of the beam centers impinge upon the common effective center of the main reflector. The antenna is well-suited for earth stations and satellites.

9 Claims, 8 Drawing Figures

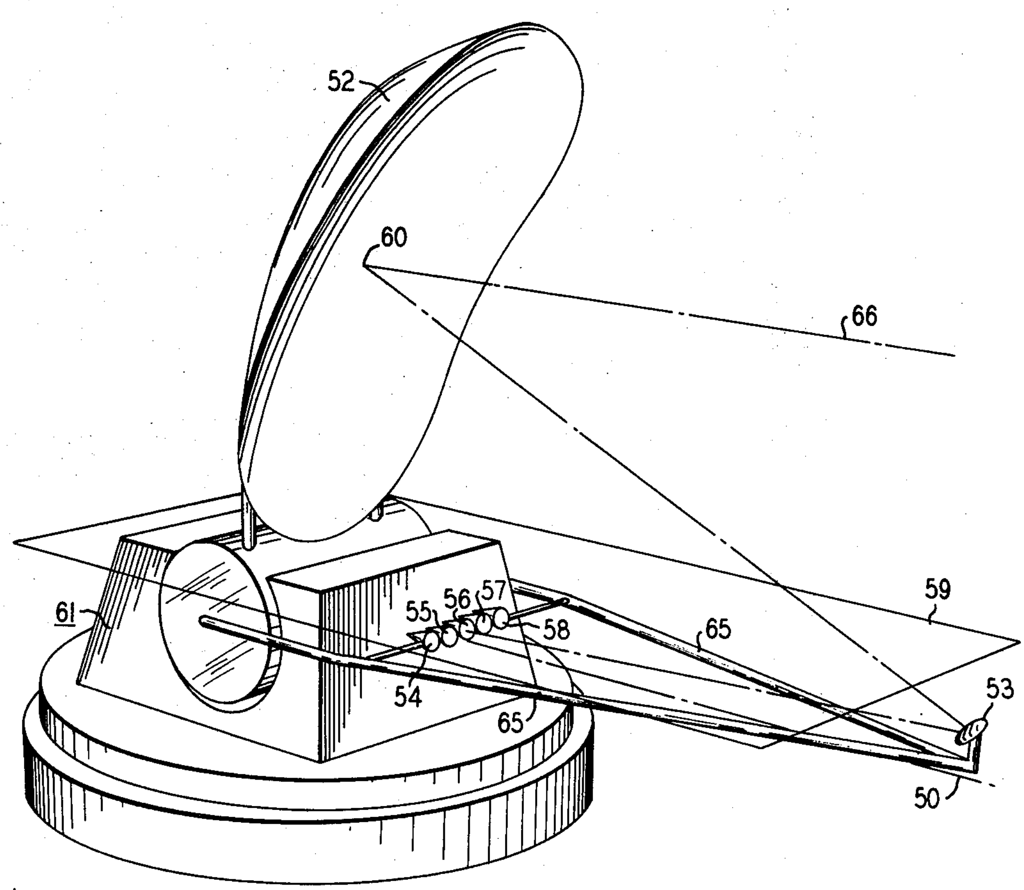


FIG. 1
PRIOR ART

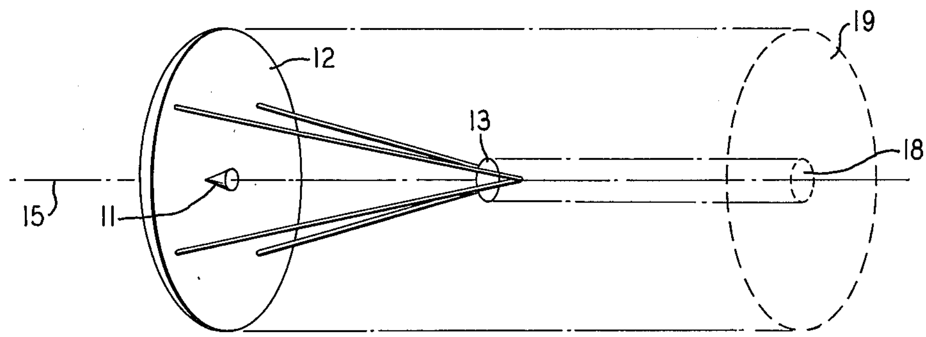


FIG. 2
PRIOR ART

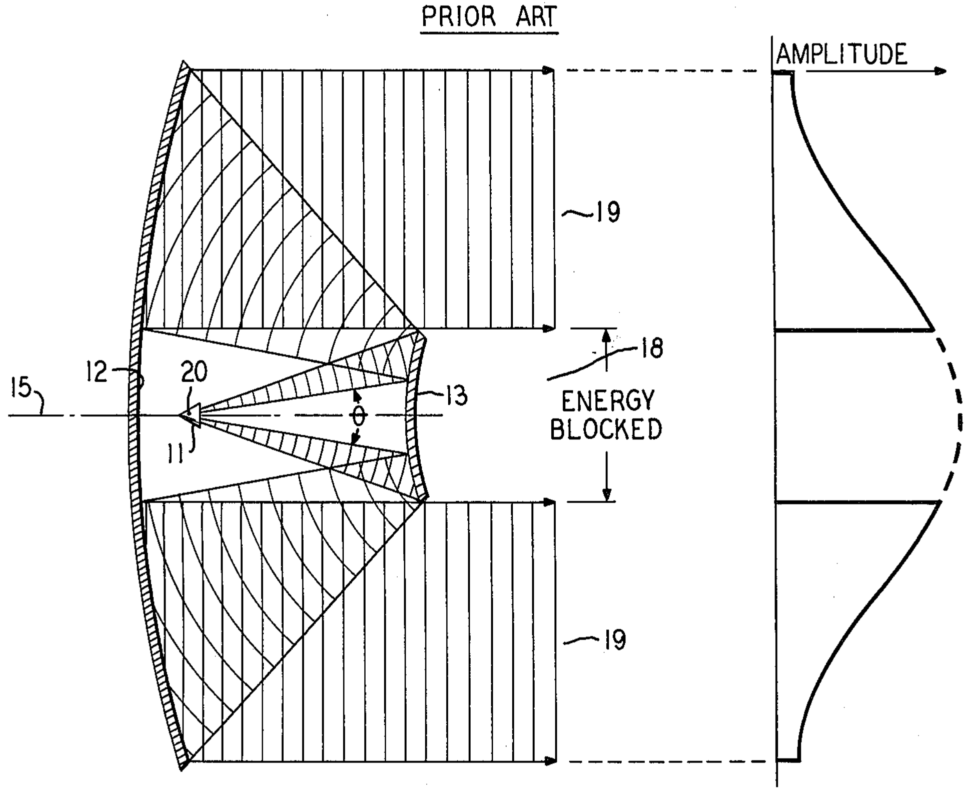
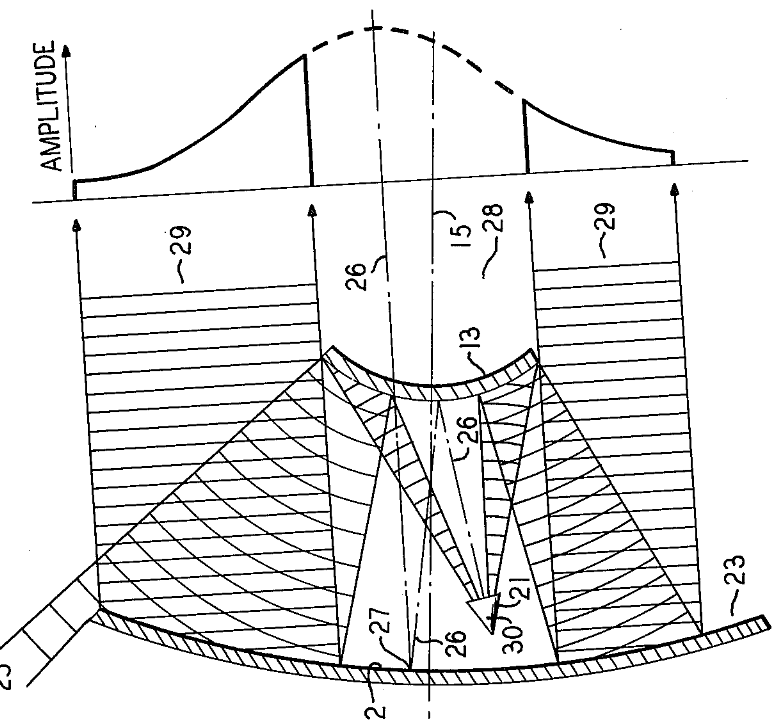


FIG. 4


AMPLITUDE
29
26
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25'
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FIG. 3

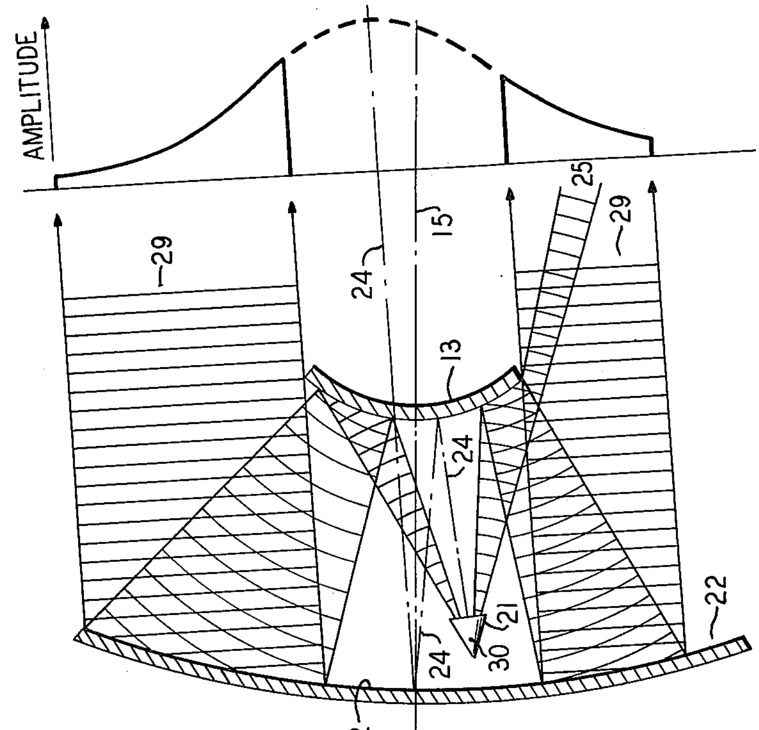
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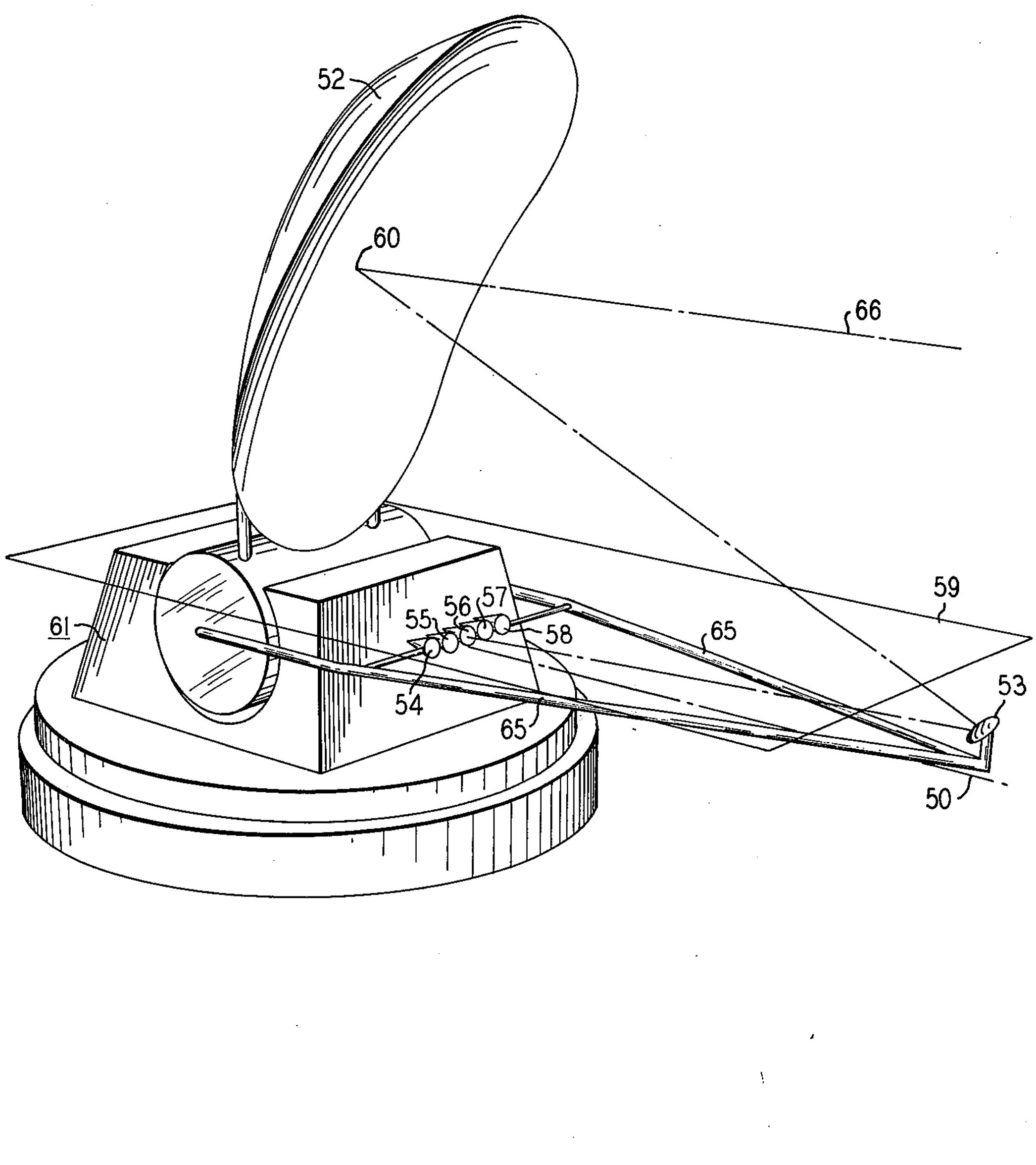
FIG. 5



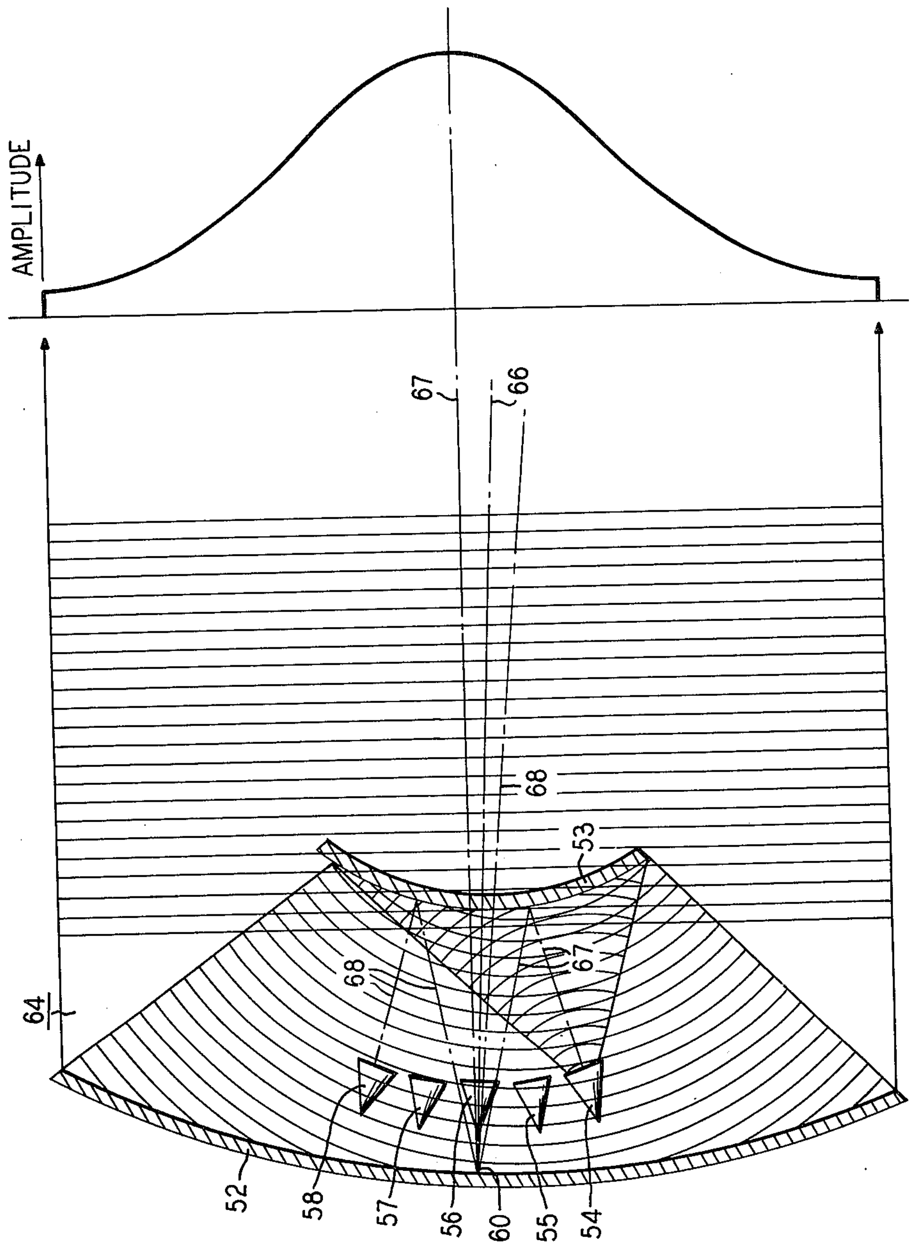


FIG. 6A

FIG. 6C

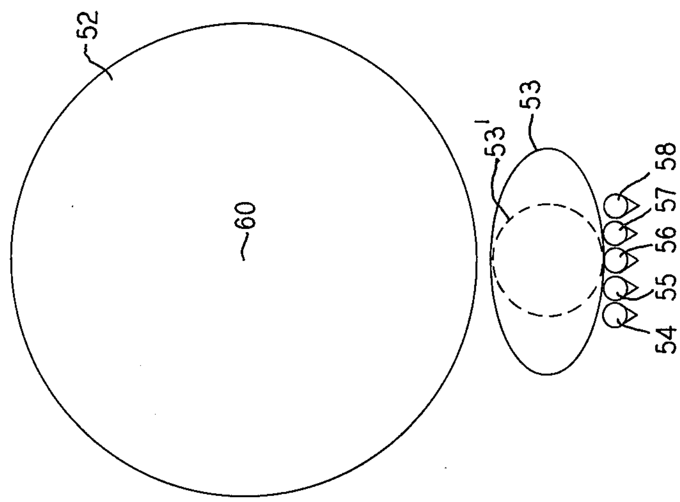
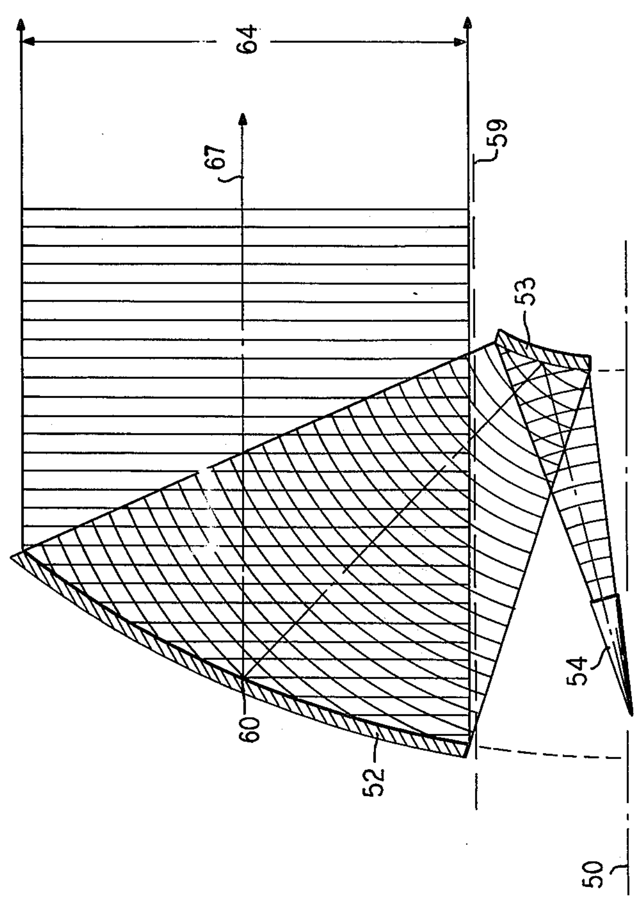


FIG. 6B



MULTIPLE-BEAM CASSEGRAINIAN ANTENNA

BACKGROUND OF THE INVENTION

This invention relates to antennas, and more particularly to multibeam antennas for operation in satellite communication systems at GHz frequencies.

A Cassegrainian configuration is a conventionally used antenna which is compact and yet exhibits an intrinsically large focal length to diameter ratio. It includes a main reflector, a subreflector much smaller than the main reflector, and a feed. The feed is aimed toward the subreflector which in turn causes reflection toward the main reflector. This reflector radiates energy through the antenna aperture. Both the subreflector and main reflector are normally symmetrically oriented about the antenna axis and the feed is normally located on the axis near the axial intersection of vertex of the main reflector at a point referred to herein as the on-axis focal point. The literature, such as "Microwave Antennas Derived from the Cassegrain Telescope" by Peter W. Hannan, *IRE Transactions on Antennas and Propagation*, March 1961, page 140, describes the geometry of the Cassegrainian system. This on-axis focal point, which is the point where a point source must be placed to produce a plane wave output, is termed the real focal point of the system. The beam from the feed is symmetrical with respect to the feed axis, and the feed and antenna axes coincide. Additionally, the phase center of the feed coincides with the on-axis focal point.

Earth stations for proposed satellite communication systems, especially those using closely spaced satellites, will utilize multiple-beam antennas to simultaneously communicate with the plurality of satellites. Similarly, the satellite's antenna may be of the multibeam variety with each beam directed to one of many separated earth stations.

The characteristics of a Cassegrainian antenna make it a preferred form of antenna for satellite systems, and multiple feeds utilized in combination with a reflective surface can produce multiple-beam antennas. However, if multiple point-source feeds are employed with a conventional Cassegrainian antenna, some feeds are displaced from the on-axis focal point and less than optimum operation results due to aperture blockage by the subreflector and displacement of the feeds from the on-axis focal point. Inefficiencies due to blockage are caused by the subreflector's location within the aperture of the antenna while inefficiencies due to displacement of the feeds are caused by two spillover effects. First, the energy from a feed laterally displaced from a focal point will spill over a subreflector which has been optimized for a full Cassegrainian antenna. Secondly, if this spillover is minimized by reaiming the feed so that the center of its beam impinges upon the center of the subreflector, some of the energy reflected from the subreflector will spill over the main reflector.

It is the object of the present invention to utilize the inherent characteristics of the Cassegrainian antenna, but to avoid aperture blockage and to enable a single Cassegrainian antenna to operate with a number of well isolated individually aimed beams.

SUMMARY OF THE INVENTION

In accordance with the present invention, a Cassegrainian antenna is designed to yield efficient multiple-beam operation. The aperture blockage common in Cassegrainian antennas is avoided by utilizing an "offset" Cassegrainian design which includes portions of the conventional reflective surfaces positioned asymmetrically with respect to the antenna axis. The main reflector in the offset design constitutes only a portion of the normal paraboloidal surface and it is located exclusively on one side of a plane parallel to and displaced from the axis. The feeds and hyperboloidal subreflector are located exclusively on the other side of the displaced plane. In this manner the plane provides a conceptual line of demarcation — the antenna aperture on one side and the subreflector on the other. Thus, beams radiating toward or from the main reflector pass through the aperture without being blocked by either the feeds or the subreflector which are both on the other side of the conceptual barrier.

To permit operation with an isolated multiplicity of beams, a cluster of feeds is placed about the on-axis focal point. The subreflector surface area is enlarged in the dimension in which the feeds are displaced in order to accommodate the beams emanating from the off-axis feeds. This expansion creates an oblong subreflector elongated laterally to form a billboard shape if the feeds are laterally displaced. This increased subreflector size avoids the spillover which would otherwise be caused by a beam being directed beyond the edge of the subreflector (subreflector spillover) or alternatively by a reflected beam being directed beyond the edge of the main reflector (main-reflector spillover). In a conventional Cassegrainian antenna, an enlarged subreflector would increase the beam blockage which in turn would increase the sidelobe levels and reduce the isolation between beams, but since the subreflector causes no blockage in the offset Cassegrainian, there is no disadvantage created by the enlarged subreflector.

The illumination efficiency is enhanced by careful aiming of the multiple feeds. A feed located at the on-axis focal point is properly aimed if it causes the center of its beam to impinge upon the effective center of the main reflector. This results in a beam with good circular symmetry and the lowest sidelobes for a given illumination efficiency. However, if other feeds clustered about the on-axis focal point are not reaimed toward the subreflector, their beam centers intercept points on the main reflector displaced from this effective center point with resultant beam degradations. Accordingly, each feed is individually aimed in a precise manner so that the center of its beam impinges the same effective center of the main reflector. In this manner all feeds generate beams which, while angularly displaced from one another by virtue of their feed displacement from the on-axis focal point, are centered at the same point of the main reflector.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a perspective view of a conventional Cassegrainian antenna;

FIG. 2 is a cross-sectional view of the antenna of FIG. 1 illustrating its radiation pattern;

FIGS. 3 and 4 are cross-sectional views of conventional Cassegrainian antennas having offset feeds and illustrating two forms of spillover;

FIG. 5 is a perspective view of a multibeam Cassegrainian antenna designed in accordance with the present invention;

FIGS. 6A and 6B are respectively top and side cross-sectional views of the antenna of FIG. 5 illustrating the radiation pattern of one of its beams; and

FIG. 6C is an end view of the antenna of FIG. 5.

DETAILED DESCRIPTION

Conventional Cassegrainian antennas, such as the one shown in FIG. 1, generate an antenna aperture generally in the shape of a doughnut since subreflector 13 blocks reflection from main reflector 12 within cylindrial region 18 centered about the antenna's geometric axis 15. A feed 11, which can be a corrugated feed horn, is located on the axis 15 at the on-axis focal point and radiates energy toward subreflector 13 which, in turn, redirects it toward main reflector 12. The antenna is, of course, capable of radiating and/or receiving, but for convenience all antenna structures will be described herein as radiating while it should be clearly understood that the invention is in no way limited to radiating antennas inasmuch as the identical structure is simultaneously capable of receiving.

FIG. 2 is a diagrammatic sectional veiw taken through axis 15 of the antenna of FIG. 1. Since the antenna is symmetrical about axis 15, FIG. 2 is illustrative of all such axial sections. As can be clearly seen from that diagram, energy radiating from feed 11 impinges the hyperboloidal surface of subreflector 13 and is reflected to the paraboloidal surface of main reflector 12 from which it is rereflected through the antenna aperture. As a consequence of the focusing properties of the reflecting surfaces the wave radiating from surface 12 exhibits parallel phase fronts perpendicular to the direction of radiation. This radiation leaving surface 12 would fill the entire antenna aperture, but subreflector 13 blocks the center cylinder 18 so that useful energy leaving the antenna lies only in the doughnut shaped pattern represented by region 19 resulting in the amplitude distribution shown to the right of FIG. 2. A cone emanating from the on-axis focal point 20 at the phase center of feed 11 and diverging with an angle θ defines that portion of the energy emanating from feed 11 which after reflection by main reflector 12 will be blocked by subreflector 13.

If the feed in a Cassegrainian antenna of FIG. 1 is displaced from the antenna axis 15, radiation from the displaced feed will produce spillover as well as aperture blockage. This is shown in FIGS. 3 and 4, top sectional diagrammatic views, taken through the antenna axis 15 of a Cassegrainian antenna having its feed 21 offset from axis 15. Radiation from this feed emanates from an effective point source at 30 toward subreflector 13 which, in turn, redirects it toward the main reflector 12. Subreflector 13 and main reflector 12 in FIG. 3 are identical to those shown in FIG. 2, but the displacement of the feed to location 30 causes radiation toward subreflector 13 to spill over the subreflector, resulting in a loss of energy and potential interference. If feed 21 is aimed toward the vertex of the main reflector, that is, so that the center of its beam 24 intercepts main reflector 12 at axis 15, some of the radiation from feed 21 illuminates an area beyond the outer perimeter of subreflector 13 so that the antenna emits a narrow errant beam 25. This beam is angularly displaced from the main doughnut shaped beam in zone 29 and is generally undesirable. The displacement of the feed to location 30 also eliminates illumination of a portion 22 of main reflector 12. In addition, the lateral offset of the feed causes an angular displacement of beam 24 from axis 15 and an associated change in the orientation of the wave fronts in zone 29. At the right of FIG. 3 a graph illustrates the amplitude distribution of the in-phase antenna pattern produced in the plane of the cross-section of FIG. 3. As can be seen, the peak amplitude along beam center 24 is lost due to blockage while the average energy is displaced in the direction (upward in the drawing) of the offset of beam center 24, and this asymmetrical pattern will inherently create sidelobes worse than those of a symmetrical pattern.

If, to avoid the subreflector spillover of FIG. 3 feed 21 is reaimed as in FIG. 4, that is, its beam center 26 intercepts main reflector 12 at 27 offset from axis 15, the spillover shown as 25 in FIG. 3 will be eliminated, but the radiating beam will in part miss surface 12 and cause main reflector spillover as errant beam 25'. This is similarly misdirected from the main aperture radiation and is, of course, undesirable. A portion 23 of main reflector 12 will also be unused. It is noted that beam center 26 is parallel to beam center 24 since feed 21 remains at 30, but it is displaced from antenna axis 15 more than was beam center 24 and as a result the amplitude distribution of the in-phase antenna radiation shown at the right of FIG. 4 is skewed (upward in the drawing) to a greater degree than in the FIG. 3 case of subreflector spillover. However, the peak amplitude is blocked in both cases. The amplitude distribution in planes orthogonal to those of FIGS. 3 and 4, is essentially the same as that shown for FIG. 2, and it will also have the peak amplitude blocked.

Accordingly, aperture blockage and feed displacement produce energy loss. However, it is well known that an antenna with a large focal length to diameter ratio (F/D) can support a number of multiple beams and that an inherent characteristic of a Cassegrainian antenna is the requisite large F/D ratio. Therefore, to take advantage of this characteristic of a Cassegrainian antenna is the requisite large F/D ratio. Therefore, to take advantage of this characteristic and produce a useful useful multibeam system, the problems of spillover and aperture blockage must be overcome.

The antenna design shown in FIG. 5 provides multiple-beam operation in accordance with the invention. In order to avoid aperture blockage an asymmetrical partial version of a Cassegrainian antenna is used. This essentially employs only portions of those reflective surfaces utilized in the full Cassegrainian design of FIG. 1. Main reflector 52 is that portion of the full paraboloidal surface which is located on one side of a conceptual plane 59 parallel to and displaced from the major geometric axis 50 of the parabola of reflector 52. For clarity connections to feeds 54–58 are omitted, and support 61, which includes conventional azimuth and elevation control mechanism, is shown only in block form. FIG. 6A shows the offset arrangement of the Cassegrainian antenna in cross-sectional view taken through the beam axis of the on-axis beam from subreflector 53 to center point 60, and FIGS. 6B and 6C show side and end views, respectively, of the antenna. The main reflector 52 is restricted to the space above plane 59 and the subreflector 53 is restricted to the space above axis 50 but below plane 59. It is noted that axis 50 is a geometric axis defined with regard to the axes of revolution of the paraboloidal and hyperboloidal surfaces. It is a line emanating from the center of the paraboloid of which surface **52** is a part but it does not intercept surface **52.**

Feed horns **54–58** radiate toward subreflector **53.** The resultant beams are reflected to main reflector **52** and radiate outwardly through the antenna aperture **64** which is located exclusively on one side of boundary plane **59.** The simple expedient of an asymmetrical organization of the partial Cassegrainian surfaces eliminates the aperture blockage so long as subreflector **53** is positioned outside aperture **64**; that is, as long as the space or aperture **64** through which reflected radiation from main reflector **52** passes is exclusively on the same side of plane **59** as is main reflector **52,** the elements which are located on the other side of the plane such as subreflector **53** and feeds **54–58** cannot block the radiation, and thus the resultant radiating pattern is not of the doughnut variety and the dimensions of the specific antenna can be designed without regard to an unusable hole in the radiating pattern. In addition, the support members such as spars **65** need not be designed with regard to their effects on radiation as essentially no radiation impinges upon them.

If, however, this offset configuration is to be utilized efficiently for multiple beams, the problem of spillover must be overcome. The plurality of feeds **54, 55, 57** and **58** clustered about the on-axis focal position of feed **56,** would each tend, due to its displacement from the axis, to create spillover from either the subreflector or the main reflector. To avoid subreflector spillover the surface area of subreflector **53** is extended laterally from boundary **53'** in order to accommodate a number of horizontally displaced feeds. The clustered feeds **54,** 55, 57 and **58** lie on an essentially straight line through the on-axis focal point, and if the feeds are laterally displaced so that this line is horizontal, the horizontal dimension of the subreflector is made substantially larger than the vertical dimension. This horizontally elongated pattern of subreflector **53** is referred to as a billboard, and it and the location of the off-axis feeds **54,** 55, 57 and **58** are shown in FIGS. **6A** and **6C.** It is noted that simple enlarging the subreflector surface may not provide optimum operation and accordingly the subreflector surface may be reshaped to deviate from a true hyperboloidal surface, especially in the areas of the elongations. The main reflector may also require reshaping to improve performance.

While preventing subreflector spillover, the increased size of the subreflector does not totally eliminate the problem of main-reflector spillover, nor does it cure the defects caused by misaimed beams. Each of the multiple beams is expected to point toward a unique point, such as a specific earth station, if the antenna is used on a satellite; or to a specific satellite if the antenna is used at an earth station. Displacement of the feeds from one another will, of course, cause the required divergence of the resultant beams, but the symmetry of the amplitude distribution across the aperture of the paraboloidal main reflector diminishes if the center of the incident beam to be reflected deviates from the effective center point **60** of surface **52.** This effective center point is chosen so that when a beam radiated from an on-axis feed, such as **56,** is centered on this effective center **60** of the main reflector **52,** the resulting beam radiating from the antenna is optimally focused to pass through aperture **64** with the phase fronts perpendicular to the main beam axis **66.** Any deviation from this center point **60** will cause the resulting beam to have an asymmetrical amplitude distribution as it emanates from the antenna. Accordingly, each of the multiple feeds is pointed individually so that it causes its beam to impinge upon surface **52** at the common effective center point **60.** This produces an amplitude distribution for each beam essentially as shown in FIG. 6A. Thus, the feed displacement determines the beam's angle but for every beam the radiation is distributed symmetrically about its beam center without blockage or spillover.

For purposes of clarity, only the radiation pattern of one representative beam, that emanating from offset feed **54,** is shown, but all feeds **54–58** are aimed so that their beam centers pass through the common effective center **60.** Representative feed **54** generates a beam centered on line **67.** This beam axis is reflected by surface **52** at point **60** but arrives at a different angle (as seen in FIG. **6A**) from main beam axis **66** radiating from on-axis feed **56.** It therefore emerges as a beam centered on axis **67** angularly displaced from beam axis **66.** The plane fronts of this displaced beam will, of course, be perpendicular to its axis **67** as is desired. Beams emanating from other feeds, such as **58,** will in turn emanate from point **60** but will be centered on other axes, such as **68** which is angularly displaced from all other axes.

The lateral displacement of the feeds will cause angular displacement in one plane, as shown as the horizontal plane in FIG. 6A, but all beam centers will lie in a common orthogonal plane as can be seen in FIG. **6B.** If a displacement of the beams in the orthogonal plane is desired, feeds would have to be offset in the direction perpendicular to that shown in FIG. **5,** and this would require a corresponding elongation of subreflector **53** in the vertical direction to avoid subreflector spillover. It is, of course, possible to displace feeds both laterally and vertically, or each of the clustered feeds could be displaced from the on-axis focal point in a different direction; such arrangements would, of course, be required for those specific applications where the multiple beams are to be pointed in divergent directions.

In all cases it is to be understood that the above-described arrangements are merely illustrative of a small number of the many possible applications of the principles of the invention. Numerous and varied other arrangements in accordance with these principles may readily be devised by those skilled in the art without departing from the spirit and scope of the invention.

What is claimed is:

1. A multiple beam antenna comprising a main reflector having an aperture, a smaller subreflector, said antenna having an on-axis focal point lying outside the aperture, a plurality of means for feeding energy toward the subreflector, at least one of the feeding means being displaced from the on-axis focal point, the subreflector having a surface area elongated to avoid spillover in each direction corresponding to the displacement of a feeding means from the on-axis focal point, the feeding means and the subreflector being positioned so that they lie outside the aperture of the main reflector and center the energy from each feeding means on the main reflector, the subreflector reflecting energy from the feeding means directly to the main reflector.

2. An antenna as claimed in claim **1** wherein the reflectors are arranged to form a Cassegrainian antenna and the plurality of feeding means are clustered about the on-axis focal point of the Cassegrainian antenna.

3. An antenna as claimed in claim 2 further including a focal feeding means located at the on-axis focal point for feeding energy toward the subreflector.

4. An antenna as claimed in claim 2 wherein the surface of the main reflector is essentially paraboloidal and the surface of the subreflector is essentially hyperboloidal, and the feeding means are feed horns.

5. An antenna as claimed in claim 2 wherein the plurality of feeding means are displaced from the on-axis focal point along an essentially straight line through the on-axis focal point and the subreflector has an essentially oblate boundary having its longer axis in the direction of the straight line.

6. An antenna comprising a main reflector, a smaller subreflector, the subreflector being positioned to redirect radiation incident upon it toward the main reflector, said reflectors being positioned to form a Cassegrainian antenna, primary feed means located at the on-axis focal point of the Cassegrainian antenna for feeding energy toward the subreflector and the main reflector causing radiation emanating from it to form a main beam which passes through an antenna aperture, characterized in that the subreflector and said primary means for feeding energy are located outside said aperture, said antenna further comprising at least one secondary means for feeding energy toward the subreflector, said secondary means for feeding energy being located remote from the on-axis focal point and being aimed toward the subreflector so that the center of its beam impinges upon the main reflector at a center point common to the center of the beam generated by the primary feed means, the subreflector being enlarged in area so that spillover from the secondary means is avoided.

7. An antenna as claimed in claim 6 wherein the surface of the main reflector is essentially paraboloidal and the surface of the subreflector is essentially hyperboloidal and the primary and secondary means for feeding energy are feed horns.

8. An antenna as claimed in claim 6 wherein the surface of the subreflector is essentially hyperboloidal and the boundary of the subreflector is essentially oblate, having its larger axis in the direction in which the secondary means for feeding energy is displaced from the on-axis focal point.

9. An antenna as claimed in claim 6 wherein the antenna comprises a plurality of secondary feeding means clustered about said on-axis focal point, each of the plurality being individually aimed toward the subreflector so that the centers of their beams impinge upon a common effective point on the main reflector but due to their displacement from the on-axis focal point radiate beams through the aperture having paths divergent from the axis of the main beam and from each other.

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