

Oct. 22, 1968

J. S. COOK ET AL
DIRECTIVE MICROWAVE ANTENNA CAPABLE OF ROTATING
ABOUT TWO INTERSECTING AXES

3,407,404

Filed Oct. 5, 1964

3 Sheets-Sheet 1

FIG. 1

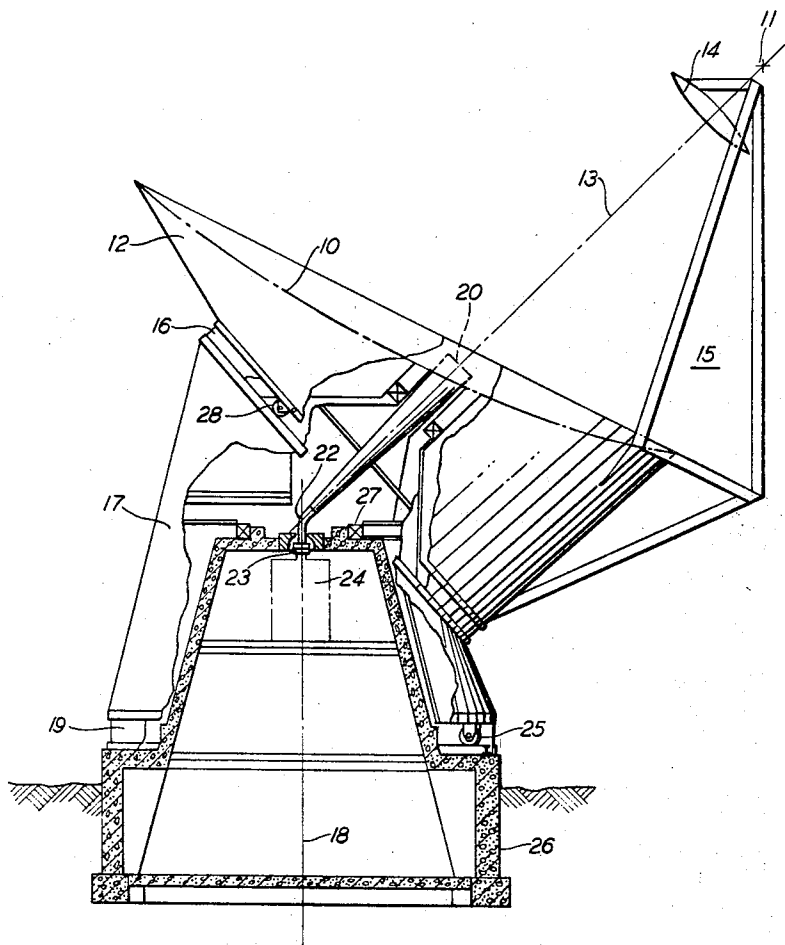
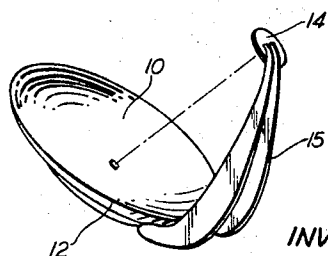


FIG. 2



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FIG. 3

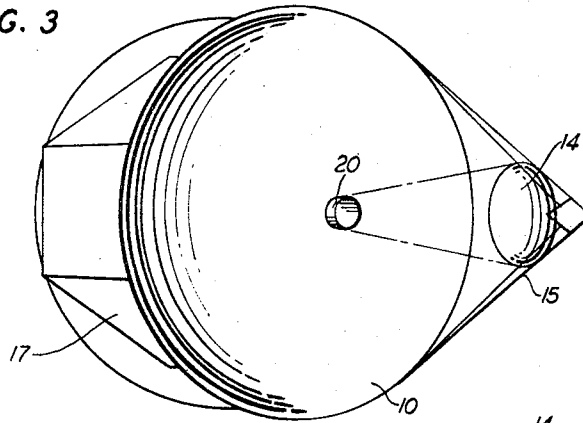


FIG. 6

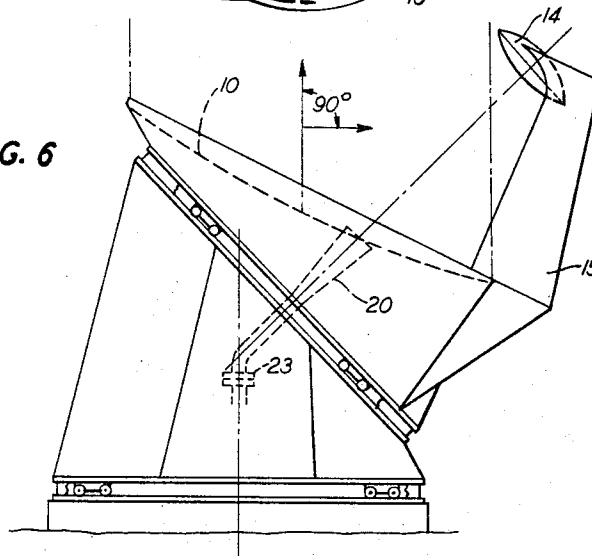
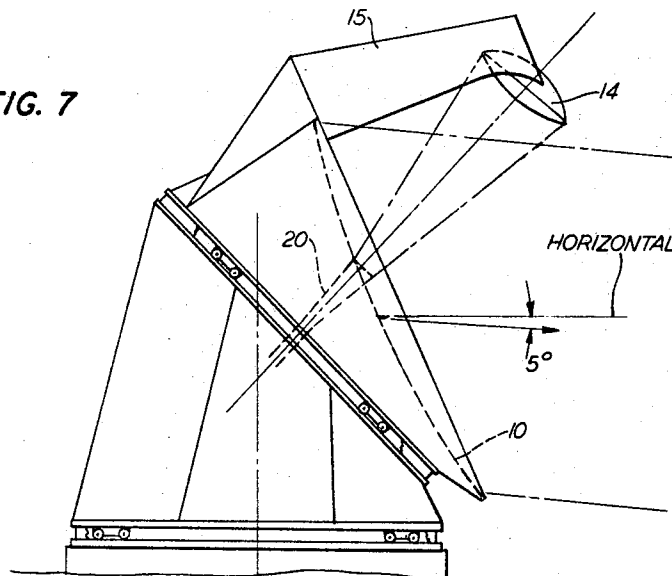


FIG. 7



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FIG. 4

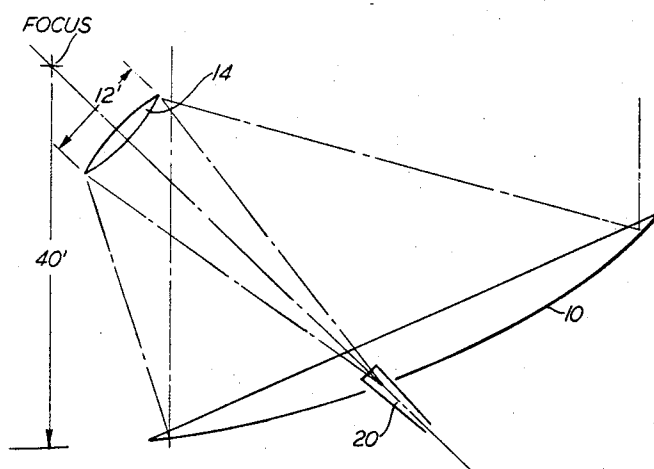


FIG. 5

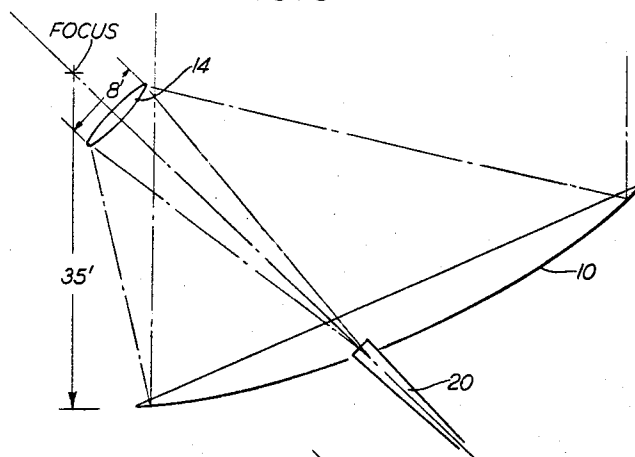


FIG. 8

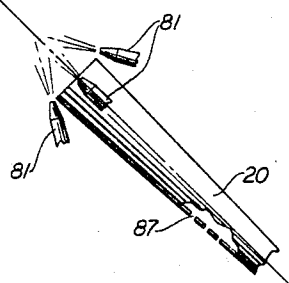
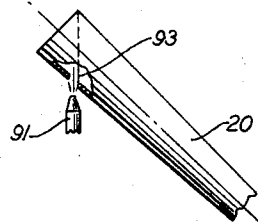


FIG. 9



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DIRECTIVE MICROWAVE ANTENNA CAPABLE OF ROTATING ABOUT TWO INTERSECTING AXES

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14 Claims. (Cl. 343—765)

ABSTRACT OF THE DISCLOSURE

An offset antenna structure, of the Cassegrain configuration, is equipped with a subreflector supported outside of the illuminating area of a main reflector. Both reflectors are supported for rotation together on a slant-mounted housing. The axis of a waveguide feed horn is arranged to coincide with the slant axis of the housing. Consequently, since the horn need not move as the main and subreflectors rotate about the slant axis, it may connect rigidly and directly to a receiver located within the housing. By virtue of the slant mounting, the main reflector always tilts downward, the over-all structure presents a low silhouette, and operation without a protective radome is possible.

This invention relates to directive microwave antennas and more particularly to microwave antennas suitable for use in the tracking of and communication with astronomic objects such as earth satellites. Its principal object is to improve the structural and electrical design of an efficient, low-noise antenna system.

The successful operation of a satellite communication system depends in large measure upon the performance of the ground station antenna. Since an earth satellite generally has a low effective radiated power, the ground station antenna must provide the necessary gain and sensitivity both to transmit an adequate signal to the satellite and to detect and amplify minuscule signals from the satellite as it is tracked. It is implicit that these functions be performed with a high degree of reliability and at a reasonable cost. In reception, the antenna must do its part to maximize the received signal-to-noise ratio for a given set of conditions. The contributors to the antenna system noise temperature include not only the receiver elements but also such factors as antenna spurious radiation and loss characteristics and antenna radome scattering and absorption.

In a Cassegrain antenna, the subreflector and its supporting structure shadow part of the aperture and are responsible for scattering. Scattering and spillover result in propagation of energy in other than the desired direction with consequent spurious lobes in the antenna pattern. These lobes, particularly at low levels of elevation, i.e., when the antenna is pointing within a few degrees of the horizon, pick up man-made and thermal noise reflected or emanating from the ground and the local environment with a resulting decrease in the signal-to-noise ratio.

It is another object of the invention to minimize scattering and spillover by eliminating all shadowing of the main reflector of an antenna by the subreflector and its support.

Increasing antenna gain by increasing the aperture area results in a narrowing of the beam width of the antenna. This introduces stringent requirements on the pointing and tracking accuracy of the antenna mount and drive systems. Further, for reasons of electrical performance, it is desirable that some of the electrical equipment associated with the antenna be in close proximity to the antenna. As antenna size increases, it is of course, impossible to employ short transmission lines.

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It is another object of the invention to increase the effective aperture area of a scanning antenna without a sacrifice of tracking accuracy and in a fashion such that short transmission lines may be used to reach conveniently located associated communications equipment.

It is, therefore, desirable to improve the signal-to-noise ratio by other means, specifically by decreasing the noise temperature of the system. One effective method is to eliminate the radome. The noise contribution of a radome is generally dependent upon the thickness and the dielectric properties of the radome, the type of antenna, and the relative position of the reflector and the radome. Further, the noise temperature varies with the elevation angle of the antenna within the radome. During periods of precipitation, the film of water that forms on the radome increases the received noise appreciably. In the absence of a radome, special consideration must, however, be given to the effect of wind loading and to the pointing accuracy of the antenna. The servo drive system must be able to move the antenna easily and at satisfactorily high velocities, both in azimuth and elevation. Accumulations of ice, snow, and possibly rain, must be promptly removed to maintain the noise temperature at a desired level.

It is yet another object of the invention to eliminate the need for a radome for a scanning antenna.

Although broadband microwave antennas of the Cassegrain and horn reflector types meet some and, at times, several of the conditions enumerated above, they nevertheless fail in one or more of them. An improvement in one of them generally necessitates a compromise in others so that mechanical agility and electrical efficiency present a serious conflict in design.

These, seemingly, contradictory requirements are overcome in the present invention by means of an offset antenna structure of the Cassegrain configuration. In accordance with the invention, a subreflector is supported exterior to the illuminating area of a main reflector and the two reflectors together are supported for rotation on a slant mounted support. The slant axis and the primary optical axis, congruent with the waveguide feed horn axis, coincide so that the horn may remain fixed as the main antenna reflector and subreflector rotate about the slant axis. Consequently, the waveguide horn may connect rigidly and directly to a receiver located on the azimuth table. By virtue of the slant mounting, the main reflector tilts downwardly in all of its rotational positions, the over-all structure presents a low silhouette, and operation without a protective radome covering is both feasible and eminently satisfactory.

According to the invention, the main reflector comprises an elliptical sector of a paraboloid of revolution whose axis is vertical when the illuminating field of the sector is directed to zenith and which has its focus outside of the illuminating field. It is supported for azimuth rotation about a first axis, generally perpendicular to the ground. Additionally, it is supported for rotation about a second axis which meets the first axis at an acute angle and passes through the focus of the main reflector. A sub-reflector is affixed to the main reflector near the paraboloid focus. It is symmetrically disposed about the second axis. Waveguide feed means, such as a conical horn which preferably is aligned so that its apex lies near the azimuth axis, terminates in an aperture near the intersection of the second axis with the main reflector and is in substantial alignment with the second axis.

The invention will be fully apprehended from the following detailed description of illustrative embodiments thereof taken in connection with the appended drawings, in which:

FIG. 1 is a partial sectional view of a slant mounted open Cassegrain antenna which illustrates the features of the invention;

FIG. 2 illustrates an alternative, cantilever arm, support for the subreflector in accordance with the present invention;

FIG. 3 is a plan view which shows the effective aperture of the main reflector of the antenna of the invention when viewed from zenith;

FIGS. 4 and 5 illustrate alternative optical profiles of the antenna, its feed horn, and the antenna subreflector;

FIGS. 6 and 7 are elevation views which illustrate the manner in which scanning is carried out with an antenna constructed according to the invention;

FIG. 8 is a simplified view of an antenna feed horn provided with a series of air jets for erecting a protective air curtain at its aperture; and

FIG. 9 is a simplified view of an antenna feed horn equipped with an air dried protective membrane.

FIG. 1 is an elevation view, partially in section, of an open Cassegrain antenna constructed in accordance with the invention. Main reflector 10 comprises a sector of a paraboloid of revolution having its focus at point 11. It is supported by way of a structural enclosure or cowl 12 for rotation about an axis 13 which passes through the paraboloid focus at an acute angle with the horizontal. A subreflector 14 is positioned, by means of support structure 15 connected to one edge of cowl 12, near the focus of the paraboloid. Cowl 12 and support structure 15 are secured to a circular track or turntable 16 on the slant surface of azimuth support structure 17. Evidently, the center of the circular track system must coincide with the point at which slant axis 13 passes through the slant surface of structure 17.

The azimuth support structure 17 is supported for rotation about a vertical or azimuth axis 18 by means of a second track system or turntable 19. Since the slant axis coincides with the primary optical axis, waveguide feed horn 20 extends through an aperture in main reflector 10 at the intersection of the slant axis with the main reflector. It is aligned with the primary optical axis and is coupled by way of a curved member 22 or the like and a rotating waveguide joint 23 to auxiliary transmitter and receiver equipment located preferably on azimuth axis 18, for example, in enclosure 24. The transmission line may, of course, be extended to any desired fixed location within azimuth structure 17, below ground, or elsewhere. Complete hemispheric scanning is thus possible by rotation of cowl 12 about the slant axis and rotation of azimuth support structure 17 about the azimuth axis.

Since the antenna of the present invention is particularly suitable for full time operation without the protection of a radome, and since it is likely that the cowl 12 assembly including the main reflector 10 and subreflector support 15 will be extremely large, considerable attention must be given to the slant elevation and azimuth structures. The azimuth support structure may assume any desired form. For example, it may comprise a cone-like frame preferably formed of structural steel girder and panel members, indicated in the cut-away portion of support 17 of FIG. 1, supported by a system of wheels 25 which rest on circular track 19. The outer surface of the structure may be covered with suitable protective panel members and may be pyramidal or conical in basic form. Track 19 preferably rests on a concrete foundation 26 of any desired shape and construction consonant with good engineering practices. In one form of support structure, a concrete housing of generally conical form extends above and through the track system into the base of the rotating azimuth structure. Because of the considerable lateral load on the movable azimuth structure, an additional set of radial bearings 27 may be employed at the roof of concrete enclosure 26. It has been found that large dimension bearings both at the upper bearing surface and at the lower wheel and track level provide greater stability against overturning moments and permit greater accuracy of alignment and angular control. Further, large drive torques may be achieved

for given maximum motor loads. Somewhat smaller bearing elements, of course, make possible a slightly smaller azimuth structure.

The main reflector assembly is held to the azimuth structure by means of a set of slant elevation support wheels 28 (only one of which is visible in the cut-away view) which ride on the slant surface of azimuth structure 17. To assure a high degree of balance between electrical performance and mechanical simplicity of the reflector system, the permissible displacement of the reflector and of the subreflector must be minimized. Dead weight, snow and ice loading, and wind deflection must be taken into account in the design of the slant elevation support and subreflector support structures. It has been found that a single cantilever structure developed as a space truss is satisfactory. A tripod configuration, shown at 15 in FIG. 1, having the widest base obtainable without shadowing the aperture of the main reflector is preferred. The members of the structure may be either tubular struts or trusses. All members of the superstructure must be tied into "hard" points of the reflector backup structure with particular regard not only to static performance but also to dynamic response to tracking motions, wind loads, Aeolian excitation, ice loads, and thermal effects. Generally, the simpler structures have superior back scatter characteristics.

FIG. 2 shows a single cantilever support for the subreflector. It is developed as a pair of box beams that are tilted toward each other to form an A frame.

Since the turntable of the inclined bearing is close to the main reflector at most points, there are a number of very effective ways for supporting the reflector. In general, a backup structure, within and including cowl 12, must carry the dead weight and all environmental loads from all parts of the reflector to the wheel support points as directly as possible, and it must supply the necessary rigidity for all cantilever portions of the reflector assembly. Further, it must be compatible with and provide secure footings for the subdish support structure. And finally it may provide weather protection for the space behind the main reflector and means for temperature equalization throughout the reflector structure. A radial truss system in which the trusses are slanted to carry the reflector loads to radial lines over the support tracks has been found to be effective. The entire structure preferably is covered with panel members or the like to improve the silhouette. It will be apparent to those skilled in the art that a variety of different structures may be employed to support the main reflector and subreflector structures at the required slant elevation on a rotating azimuth structure.

Considerable latitude exists in the selection of a slant axis angle, aperture size, and focal length. However, once one of the variables is determined, the others are necessarily limited in range. For example, it has been found that the elevation angle of the slant axis should be generally between 40 and 50 degrees, with an optimum at 42.5 degrees from the horizontal. Since the primary optical axis and the slant elevation axis must coincide, the slant axis must pass through the paraboloid focus. A focal length may then be selected in accordance with the desired antenna aperture. For a given aperture, increasing the focal length of the paraboloid increases the possible size of the subreflector. From the electromagnetic viewpoint everything suggests the larger focal length. From the structural and mechanical points of view, increasing the subreflector size is costly. Furthermore, there is a limit to the advantage that can be gained by enlarging that reflector. The selection must be made with regard to the system in which the antenna is to be used. Since the over-all system quality is primarily a function of usable signal-to-noise ratio, a compromise between gain and noise temperature is selected in accordance with the desired application.

The selected aperture diameter and focal length deter-

mine the main reflector size and shape. For a given focal length, the main reflector is selected to be a sector of a paraboloid of revolution that is not intersected by the axis of revolution. It is further selected such that the aperture diameter, measured in a plane perpendicular to the paraboloid axis, is a circle outside of the area of the subreflector. This makes it possible for a subreflector placed near the focus to be entirely outside of the sector beam, which is parallel to the paraboloid axis at all points on the paraboloid.

FIG. 3 illustrates the effective aperture of the main reflector viewed along the main beam axis. As a result of the location of the secondary reflector, neither the reflector nor its support shadows the main beam in any orientation of the antenna. Consequently, neither is responsible for beam scattering. Not only is extraneous scattering minimized, but primary spillover, i.e., radiation past the edge of the subreflector, is confined to an elevation of about 30 to 55 degrees above the horizon regardless of the antenna position. Secondary spillover, i.e., radiation past the edge of the main reflector, likewise is essentially independent of elevation angle.

The subreflector is accordingly selected to have the largest possible diameter permitted by the antenna geometry. It is oriented to direct incoming energy reaching the focus from the main reflector away from the paraboloid axis, preferably at an acute angle with it. In a preferred form of the invention, it directs the beam at an acute angle away from the paraboloid axis to intersect the main reflector. In most configurations, the subreflector is located between the paraboloid focus and the main reflector surface at a point relatively near the focus, i.e., not midway between the focus and reflector surface. Accordingly, its surface shape is selected to be a sector of an hyperboloid complementary to that of the main reflector so that an effective focus is established in the waveguide horn.

FIGS. 4 and 5 illustrate two possible optical profiles of main and subreflectors which meet the several requirements enumerated above. With the preferred configuration of FIG. 4, a focal length of 40 feet permits the use of a subreflector with a diameter of approximately 12 feet. With the slightly smaller configuration of FIG. 5, a decrease in focal length of only 5 feet, permits the subreflector diameter to be reduced to an 8 foot diameter. With both configurations, horn assembly 20 extends through main reflector 10 in alignment with the primary optical axis and the indicated structure is supported for rotation about the slant axis.

Thus, for whatever configuration, the feed horn is aligned with the angled beam direction between the subreflector and its intersection with the main reflector surface. It terminates in an aperture in the surface large enough to accommodate the beam diameter at the main reflector aperture, i.e., its size is a function of the distance from the paraboloid focus and the shape and location of the subreflector. The horn is tapered according to traditional waveguide principles to bring it to normal waveguide dimensions with controlled mode conversion. Blocking of the main beam occurs only to a slight degree where the feed horn protrudes through the main dish.

FIG. 6 is an elevation view showing an antenna constructed in accordance with the invention at its zenith position. It should be noted that the tracking "dead zone" at zenith, common to the more usual elevation-over-azimuth orthogonal axis arrangements, is minimized. The extent of the overhead zone through which a satellite cannot be followed is related to the rotational speed and acceleration capability of the antenna drive system. With the configuration of the present invention, the zone is unusually small by virtue of the structural arrangement which exhibits a low moment of inertia and a large drive moment. The construction further permits the use of relatively large bearing and drive diameters. Even in a relatively high wind, the drive moment afforded by the

large diameter bearings permits precision autotracking and tape tracking.

An elevation view of the antenna of the invention directed at its minimum elevation, preferably at -5° , is shown in FIG. 7. The lowest elevation excursion is determined by the angle of the slant axis. Since antenna elevation is a function of the reflector's orientation about both azimuth and slant axes, a singularity occurs at the lowest slant rotation position of the main reflector. At this point, the same motion may be produced by rotation either about the azimuth axis or about the slant axis. Such an ambiguity cannot, of course, be tolerated, particularly if it occurs near the horizon. It is essential in acquiring a satellite near the horizon that unambiguous control be assured and that relatively high scanning speeds be achieved. Accordingly, the singularity is placed below the horizon so that, at the horizon, distinctly different motions about the azimuth and slant axes produce distinctly different motions of the main reflector. Concomitantly, placing the point of singularity below the horizon aids in calibrating the antenna. Bore-sighting on a signal source located at, for example, minus 2 degrees, may be readily used to assure accuracy.

Further, unlike elevation over azimuth arrangements in which the two axes of rotation are orthogonal, tracking with the slant mounted antenna is generally carried out by means of simultaneous rotation about the slant elevation and azimuth axes. The appreciable burden placed on elevation bearing and drive systems in tracking fast moving objects, e.g., near the horizon, is thus alleviated since the burden may be placed jointly on two sets of bearing and drive systems. Response of the associated servo apparatus is similarly improved with combined azimuth and slant movements.

Of particular concern with an antenna used without the protection of a radome covering is its reaction to precipitation. With the slant mounted configuration of the present invention, the main reflector is, regardless of its beam position, always tilted downward. It cannot collect and hold water. Warm air may be supplied from below or from internal heating elements to melt sleet or snow which then runs off. On the other hand, the feed horn tilts upward in all orientations so that it is susceptible to precipitation. Accordingly, the mouth of the horn is protected preferably by a series of air jets around the horn periphery. FIG. 8 illustrates a suitable arrangement. Jets 81 erect a relatively high intensity field for some distance in front of horn 20 and thus exclude rain and snow. Any heavy rain that might spray through the protective air curtain is drained out of the horn through openings 87 near the aperture. Alternatively, a thin protective plastic membrane 93 within the horn opening, as shown in FIG. 9, tilted at an acute angle away from the entrance port and continuously dried by air jets 91 may be used.

The above-described arrangements are, of course, merely illustrative of the application of the principles of the invention. Numerous other arrangements may be devised by those skilled in the art without departing from the spirit and scope of the invention. For example, the diameter of the slant elevation support wheel may be considerably enlarged, either to the effective diameter of the cowl structure supporting the main reflector, or larger in accordance with the permissible azimuth rotation structure. Enlarging the slant elevation surface generally improves the resistance of the reflector structure to deflection at the expense of azimuth structure mass and mechanical rotation requirements.

What is claimed is:

1. A directive antenna which comprises a first reflector which is an off-axis sector of a paraboloid of revolution, a second reflector which is a sector of a hyperboloid of revolution located near the focus of said paraboloid of revolution with an orientation such that the axis of a transmission path between said first and said second reflectors meets the axis of revolution of said paraboloid at

an acute angle, and means for supporting said first and said second reflectors for rotation about said transmission path axis.

2. A directive microwave antenna which comprises a first reflector which is an off-axis sector of a paraboloid of revolution that is not intersected by the axis of revolution, a second reflector which is a sector of a hyperboloid of revolution located near the focus of said paraboloid of revolution with an orientation such that the axis of a transmission path between said first and said second reflectors meets the axis of revolution of said paraboloid at an acute angle and does not lie in any plane perpendicular thereto, means for establishing a transmission path between said first and said second reflectors, and means for rotating said first and said second reflectors together about said transmission path axis.

3. A directive microwave antenna as defined in claim 2 wherein said means for establishing a transmission path between said first and said second reflectors comprises an open ended waveguide horn aligned with the axis of said transmission path, the open end of said horn protruding through an aperture in said first reflector at the intersection of said transmission path axis with said first reflector.

4. A directive microwave antenna as defined in claim 3 wherein said means for establishing a transmission path between said first and said second reflectors includes a plurality of relatively high velocity air jets supported around the periphery of said open ended waveguide horn, said jets being aligned to establish a high intensity air field exterior to the opening of said horn for preventing precipitation from entering said horn.

5. A directive microwave antenna as defined in claim 3 wherein said means for establishing a transmission path between said first and said second reflectors includes a thin plastic membrane stretched over the opening of said waveguide horn and oriented in a downward direction at an acute angle with said transmission path axis, and means including an air jet for continuously drying said membrane thereby to prevent precipitation from entering said horn.

6. A directive microwave antenna as defined in claim 2 wherein said acute angle is in the range between 40 degrees and 50 degrees.

7. A directive microwave antenna as defined in claim 2 wherein said acute angle is 47.5 degrees.

8. A scanning antenna which comprises, a first reflector comprising an elliptical sector of a paraboloid of revolution whose axis is vertical when the illuminating field of said sector is directed to zenith and which has its focus outside said illuminating field, means for supporting said first reflector for azimuth rotation about a first axis, means for supporting said first reflector for rotation about a second axis which meets said first axis at an acute angle and passes through the focus of said first reflector, a second reflector affixed to said first reflector substantially on said second axis near said paraboloid focus, and waveguide transmission means which terminates in an aperture near the intersection of said second axis with said first reflector and is in substantial alignment with said second axis.

9. A scanning antenna which comprises, a main reflector comprising an elliptical sector of a paraboloid of revolution whose axis is vertical when the illuminating field of said sector is directed to zenith and which has its focus outside said illuminating field, means for supporting said main reflector for azimuth rotation about a first axis, means for supporting said main reflector for rotation about a second axis which meets said first axis at an acute angle and passes through the focus of said main reflector, a subreflector comprising a sector of a hyperboloid of revolution, means for affixing said subreflector to said main reflector near said paraboloid focus

and symmetrically disposed about said second axis, feed horn means which terminates in an aperture near the intersection of said second axis with said main reflector and is in substantial alignment with said second axis, and rotating means for coupling said feed horn to a waveguide aligned with said first axis.

10. A scanning antenna as defined in claim 9 wherein said means for affixing said subreflector to said main reflector comprises a cantilever structure attached to said means for supporting said main reflector for rotation about said second axis.

11. A scanning antenna as defined in claim 9 wherein said acute angle is 47.5 degrees.

12. An antenna system which comprises in combination a base support member, means associated with said base support member for providing rotation of said member about a first axis, a second support member affixed to said first member at an angle of approximately 45 degrees, means associated with said second member for providing rotation of said second member about a second axis which intersects said first axis at an angle of approximately 45 degrees, a first reflector which is an off-axis sector of a paraboloid of revolution supported by said second support member, a second reflector which is a sector of a hyperboloid of revolution located near the focus of said first reflector and substantially on said second axis of rotation with an orientation such that the axis of a transmission path between said first and said second reflectors meets the axis of revolution of said paraboloid at an acute angle and such that said transmission path axis is in alignment with said second axis of rotation, and means for establishing said transmission path.

13. An antenna system as defined in claim 12 wherein said first reflector comprises an elliptical sector of a paraboloid of revolution whose axis is vertical when the illuminating field of said sector is directed to zenith and which has its focus outside of said illuminating field.

14. An antenna system which comprises in combination a base support member, means associated with said base support member for providing rotation of said member about a first axis, a second support member affixed to said first member at an angle of approximately 45 degrees, means associated with said second member for providing rotation of said second member about a second axis which intersects said first axis at an angle of approximately 45 degrees, a first reflector which is an off-axis sector of a paraboloid of revolution supported by said second support member, a second reflector which is a sector of a hyperboloid of revolution located near the focus of said first reflector and near said second axis of rotation such that the axis of a transmission path between said first and said second reflectors meets the axis of revolution of said first reflector at an acute angle and means for establishing a transmission path between said reflectors comprising a waveguide feed horn which terminates at its horn end in an aperture in said first reflector at the point of intersection of said second axis with said first reflector and which terminates at its other end at a point of said first axis of rotation.

References Cited

UNITED STATES PATENTS

2,540,518	2/1951	Gluyas	343—837 X
3,105,969	10/1963	Blanche et al.	343—765 X

OTHER REFERENCES

Electronics, July 15, 1960, vol. 33. No. 29, page 19.

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