NASA Case GSC 10,949-1

MILLIMETER WAVE ANTENNA SYSTEM

The present invention relates generally to millimeter wave antenna systems particularly adapted for use in outer space. There is a possibility of use of the antenna system on NIMBUS and/or DRSS.

Reference is made to Figure 2 wherein there is illustrated an antenna system including millimeter wave feeds 22 and 24 respectively employed for narrow and wide beam transmissions. The narrow beam transmission includes a Cassegrain antenna comprising hyperbolic subreflector 23, mounted on supporting structure 26, as well as parabolic reflector 21. The wide beam antenna includes a parabolic reflector 25 mounted on the back surface of supporting structure 26. Feed 24 is mechanically supported only by waveguides 31-34 extending between the periphery of parabolic antenna 21 and feed 24. To prevent skewing of the parabolic antenna to millimeter waves, the antenna is fabricated from laminates of carbon fiber reinforced plastic (CFRP) sheets between which is sandwiched a honeycomb core. An aluminum thin film is deposited on a face of one of the laminates to form the reflector. The waveguides are also fabricated from a sandwich including the laminates and honeycomb structure.

Novelty is believed to reside in the concept of utilizing CFRP sheets to form a parabolic reflector utilized in an outer space millimeter wave system. Another novel feature is believed to be the concept of mechanically supporting a feed at the focus of a parabolic reflecting dish by waveguides extending between the dish and feed.

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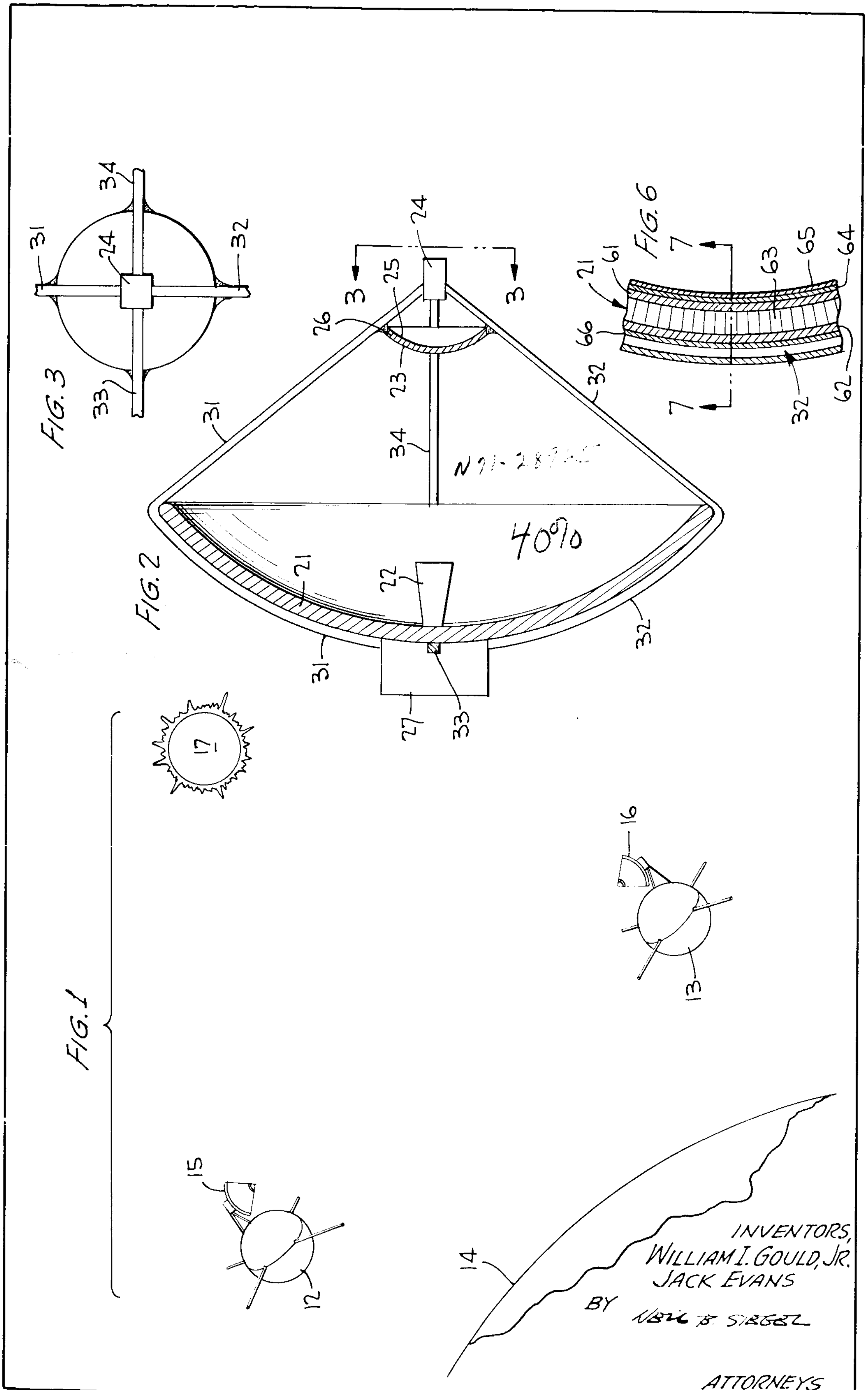

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FIG. 7

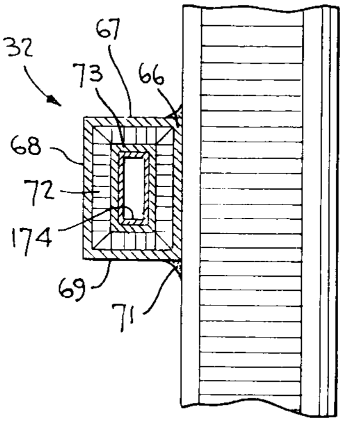


FIG. 4

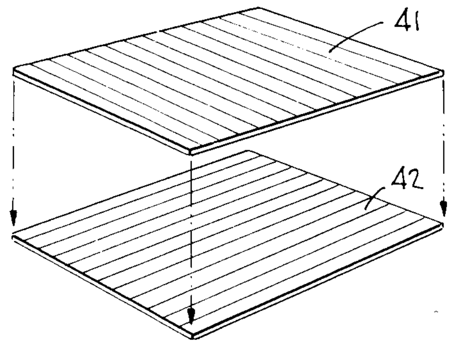


FIG. 5

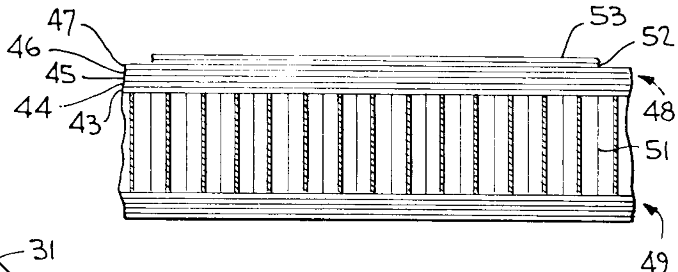


FIG. 8

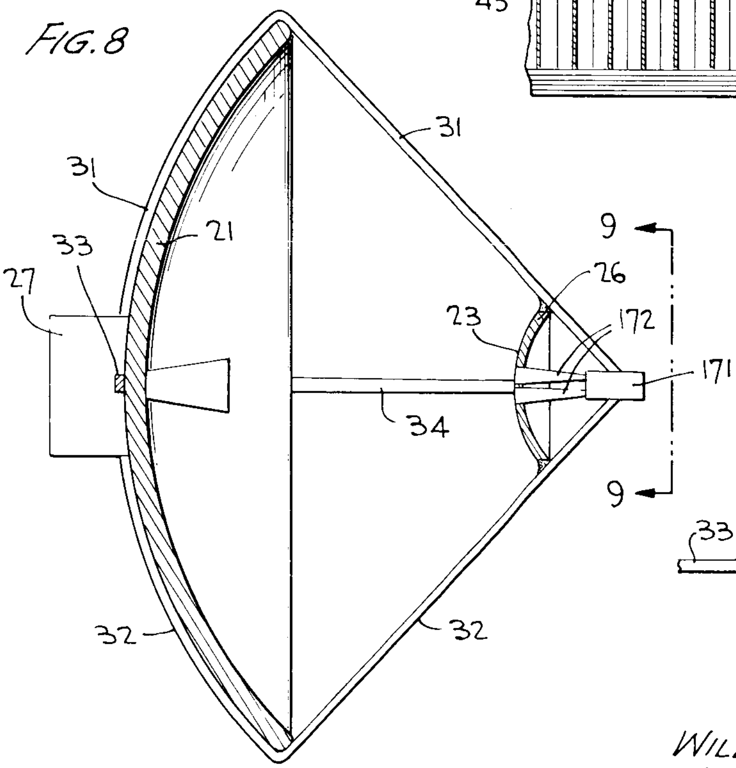
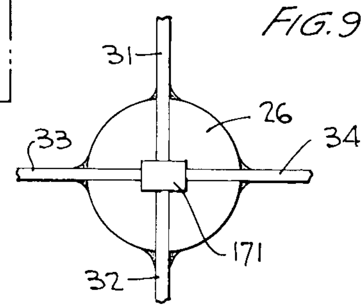


FIG. 9



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NASA Case No. GSC 10,949-1

APPLICATION FOR LETTERS PATENT

TO ALL WHOM IT MAY CONCERN:

BE IT KNOWN THAT WILLIAM I. GOULD, JR. and JACK EVANS, citizens of the United States of America, employees of the United States Government, and residents of Silver Spring, Maryland and Baltimore, Maryland, respectively, have invented certain new and useful improvements in MILLIMETER WAVE ANTENNA SYSTEM, of which the following is a specification:-

ABSTRACT OF THE DISCLOSURE

A millimeter wave antenna mounted on a satellite includes a parabolic reflector fabricated of carbon fiber reinforced plastic (CFRP) composite material to enable the parabolic shape of the reflector to be maintained to within three percent of a millimeter wave length despite possible temperature variations on the order of 300°F. between portions of the reflector illuminated by the sun and in the umbra. Waveguides, fabricated from CFRP, for a feed positioned approximately at the focal point of the reflector are the sole mechanical supporting means for the feed. To take advantage of the physical properties of the carbon fiber reinforced plastic composite materials a honeycomb structure is sandwiched between layers of the CFRP. The surface of the reflector illuminated by the feed is coated with a thin film of aluminum which functions as a millimeter wave reflector. The waveguide CFRP interior is coated with a thin film of aluminum to provide the millimeter wave conducting surface.

ORIGIN OF THE INVENTION

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

FIELD OF INVENTION

The present invention relates generally to antennas and, more particularly, to a millimeter wave antenna system mounted on a spacecraft.

BACKGROUND OF INVENTION

The advantages of utilizing millimeter waves in data relay and tracking systems have been appreciated. A problem in the use of millimeter waves in conjunction with spacecraft systems employing antennas having relatively large parabolic reflectors concerns the difficulty in maintaining a true conic section reflecting dish, e.g., a truly parabolic shape of the reflector dish. The difficulty occurs because of the severe temperature variation, e.g. 300°F., which may exist between the portions of the reflector that are illuminated by the sun and those portions which are shaded. When it is considered that the typical size of a millimeter wave parabolic reflector is on the order of five feet in diameter, it is appreciated that these severe temperature differences tend to establish nonisotropic heating patterns on the reflector dish surface, with a tendency for nonuniform expansion. Nonuniform expansion of the reflector dish surface results in disadvantageous changes in the shape of the antenna beam, and frequently results in a loss of directivity of a parabolic antenna reflecting system. With a loss in directivity, the usefulness of the antenna for tracking, and possibly high gain data transmission, is frequently seriously curtailed. Typically, the permissible tolerance on the surface of a parabolic reflector is ±3 percent of a wavelength of the electromagnetic energy exciting the antenna system. For millimeter waves, this requirement means that the surface of the parabolic reflector must be stabilized to between approximately 0.1 - 0.5 millimeters.

Parabolic reflectors excited by energy in the millimeter wave region and designed to be placed on spacecraft have in the past generally been fabricated from aluminum sheets. Aluminum has a very high thermal coefficient of expansion so that satellite reflector dishes fabricated from it are usually subject to the problems of surface shape distortion. In the prior art to overcome reflector surface distortion, it has generally been the procedure to equalize, as closely as possible, the temperature gradient across the parabolic reflector surface. One technique has involved utilizing heat pipes, while a second has involved covering the reflecting surface with a shroud opaque to solar energy and substantially transparent to millimeter wave energy. The disadvantage of heat pipes is that they increase the weight of the antenna package substantially. While a shroud does not substantially change the antenna weight, it frequently introduces a substantial attenuation, on the order of 2 db, to the millimeter waves transmitted from or received by the antenna.

In accordance with the present invention, a millimeter wave antenna for spacecraft use includes a conic section reflector having a supporting structure fabricated from a carbon fiber reinforced plastic (CFRP) composite material. This composite material, described in detail in two articles dated November 18, 1968, and November 25, 1968, of Aviation Week, is particularly well suited for spacecraft use as the supporting structure of a conic section reflector excited by millimeter waves because it has virtually a zero temperature coefficient of expansion. In addition, it has a high modulus of elasticity, has relatively great tensile strength, is lightweight and has a relatively high heat degradation factor. CFRP is derived from polyacrylonitrile plastic filaments that are combined with a polyester resin, as described in the Aviation Week articles. The composite material is fabricated in relatively thin sheets, with the fibers aligned in a single direction. Typical laminate layups consist of alternating plies in specific directions. To produce laminates with approximately equal properties in all directions (pseudo-isotropic) the plies typically are directed at ($\pm 45°$), ($0 \pm 45°$, $90°$) in a clockwise reference. To provide strength in two directions at right angles to each other in substantially the same plane, a pair of sheets are joined together by suitable bonding means, such as epoxy resin, with the fibers of the two sheets running orthogonally to each other.

While the CFRP composite sheet materials have considerable strength in the direction of fiber orientation, they are quite susceptible to bending in a plane extending at right angles to the surface of the sheet. To provide strength in the plane at right angles to the sheet, a honeycomb aluminum structure is sandwiched between layers of the CFRP sheets. The aluminum honeycomb is bonded to the CFRP sheets by epoxy resin while the parabolic surface is formed on a mandrel.

It might appear that a problem exists in utilizing an epoxy resin to bond the CFRP sheets to each other and the honeycomb structure because of the relatively high temperature coefficient of expansion of the resin and aluminum material in the honeycomb structure. This problem is not significant, however, because the resin and honeycomb structure have a tendency to expand only in a direction transverse to the plane of the CFRP sheets, rather than in the plane of the sheets. It has been found that distortion at right angles to the plane of the sheets can be tolerated in a parabolic reflector because there is only a relatively small movement of the reflector surface, without effecting the basic reflector shape. Movement at right angles to the CFRP sheets is relatively small in the plane transverse to the sheet because the length of material in that direction is comparatively short and expansion is a direct function of material length. In contrast, in the plane of the sheet, there is a substantial amount of material which can result in considerable expansion of different portions of the reflector relative to each other. Since there is a relatively small amount of aluminum honeycomb structure in a direction parallel to the plane of the CFRP sheets, that material has a relatively insignificant effect on possible elongation of the sheets. Because the mass of the CFRP sheets is considerably greater than that of the epoxy resin bonding the sheets together, the sheets, rather than the resin, control surface dimensions.

To provide a reflecting surface for the millimeter electromagnetic waves, the CFRP sheet illuminated by the electromagnetic energy is coated with a thin film of aluminum. Aluminum is deposited on the CFRP sheet to a thickness on the order of 4,000 angstroms utilizing conventional vacuum vapor deposition techniques. The mass of the aluminum thin film is so small as to have virtually no effect on the expansion properties of the CFRP sheet to which it is deposited. To provide further stabilization for the surface of the parabolic reflector as a function of temperature, a silicon oxide film is deposited on the thin film of aluminum. The silicon oxide, which is preferably silicon monoxide, is also deposited utilzing vapor vacuum deposition techniques and functions to reduce the possible temperature gradient over the reflector surface.

A further feature of the invention is that a feed positioned approximately at the focal point of the parabolic reflector is supported solely by waveguides coupling millimeter wave electromagnetic energy to the feed. The waveguides are fabricated from an aluminum honeycomb or laminate structure formed as a shaft having a hollow center in cross section. When using honeycomb, the inner and outer peripheries of the structure are layers of CFRP sheets. The inner sheet has a conducting aluminum layer which may be a deposited film or a thin shell upon which the laminate is laid. Preferably, the waveguide surface and shaft have a rectangular cross section so that they provide a minimum blocking area for the reflector aperture. In one configuration, the feed located approximately at the focus of a main parabolic reflector illuminates a small subreflector located intermediate of the main reflector and the feed. In this configuration, the area of the struts is sufficiently small in the direction of wave propagation to considerably reduce scattering of the wide beam pattern associated with the small dish or reflector.

It is, accordingly, an object of the present invention to provide a new and improved antenna system particularly adapted for millimeter waves on spacecraft.

Another object of the present invention is to provide a new and improved millimeter wave reflector dish utilized on spacecrafts, wherein the shape of the reflector is maintained to within ±3 percent of the millimeter wave excitation despite differential sun heating and shading of the reflector surface.

A further object of the invention is to provide a new and improved millimeter wave reflector for use on spacecraft, which reflector has a stable surface without the use of heat pipes or sun shrouds.

Another object of the invention is to provide a new and improved millimeter wave reflecting dish to be utilized on spacecraft, which reflector has a stable surface independent of temperature without adding weight to the satellite or reducing the transmission properties of the antenna system with which the reflecting dish is associated.

Another object of the present invention is to provide a new and improved millimeter wave reflecting dish for use on spacecraft, which reflecting dish is fabricated from a material that exhibits substantially zero thermal coefficient of expansion.

Still a further object of the invention is to provide a new and improved millimeter wave antenna system including a reflecting dish with a feed located approximately at its focus and wherein structural and electrical connections between the reflecting dish and feed have substantially no effect on the pattern of the antenna system.

Another object of the invention is to provide a new and improved millimeter wave antenna system wherein waveguide elements extending between a reflecting dish and a feed are the sole supporting elements connecting the feed to the reflector.

The above and still further objects, features and advantages of the present invention will become apparent upon consideration of the following detailed description of several specific embodiments thereof, especially when taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a pictoral view of the environment with which the present invention is to be employed;

Figure 2 is a side view of an antenna system in accordance with the present invention;

Figure 3 is an end view of a portion of the antenna system of Figure 2;

Figure 4 is an exploded view illustrating the relative orientation of a pair of CFRP sheets employed in the reflector dish of the present invention;

Figure 5 is a side view, with great magnification of certain elements, of the reflector dish illustrated in Figure 2;

Figure 6 is an enlarged view of a portion of the reflector of Figure 2;

Figure 7 is a sectional view taken through the line 7-7, Figure 4;

Figure 8 is a side view of a further antenna system in accordance with the present invention; and

Figure 9 is an end view of the antenna system illustrated in Figure 8.

DETAILED DESCRIPTION OF THE INVENTION

Reference is now made to Figure 1 of the drawings wherein there is pictorally illustrated a pair of earth orbiting spacecrafts or satellites 12 and 13, positioned either in synchronous or low orbit above the surface of the earth 14. Satellites 12 and 13 include substantially identical millimeter wave antenna systems 15 and 16, respectively. Each of antenna systems 15 and 16 includes a relatively large parabolic reflecting dish for data transmission and precision tracking purposes, as well as a wide beam dish for tracking acquisition purposes. The reflecting dishes of antenna systems 15 and 16 are susceptible to severe temperature gradients because a portion of the dishes may be exposed to direct illumination from the sun 17, while a different portion of the dishes may be in the umbra. The temperature difference between the portions of the dishes exposed and not exposed to solar radiation may be on the order of 300°F. The severe temperature gradient across different portions of the reflector has a tendency to distort the reflector surface and thereby adversely change the beam width of the antenna system.

Side and end views of one embodiment of an antenna system of the type that can be employed on satellites 12 and 13 are respectively illustrated in Figures 2 and 3. The antenna system includes a parabolic reflector 21 having a diameter on the order of sixty inches in a typical narrow beam millimeter wave data transmission and target tracking system. Parabolic reflector 21 is illuminated in response to millimeter waves propagating between the reflector and millimeter wave feed 22 via a hyperbolic subreflector 23, typically having a six inch lenght. The feed 22 is centrally located on reflector 21 to form, in conjunction with reflectors 21 and 23, a Cassegrain system. Feed 22 is effectively, although not physically, located at the focal point of reflector 21 to enable a narrow beam, high gain pattern to be achieved.

A wide beam target acquisition system having a boresight axis coincident with the boresight axis of the Cassegrain antenna system is formed by millimeter feed 24 and parabolic reflector 25, positioned in back-to-back relationship with reflector 23. Reflectors 23 and 25 have a common supporting structure 26, with the two reflectors being formed on opposite faces of the supporting structure. Feed 24 is positioned substantially at a common focal point for reflectors 21 and 25.

Each of millimeter wave feeds 22 and 24 is a four-horn monopulse feed capable of excitation in both circular polarization modes. Feeds 22 and 24 are excited with millimeter wave energy by equipment included in an electronic package 27 mounted on the back face of reflector 21, i.e., the face opposite from that through which feed 22 extends. Waveguides, not shown, extend through reflector 21 to feed 22 for excitation of each of the four elements included in feed 24 in response to energization of active elements included within package 27.

Excition of feed 24 is via four waveguides 31-34, which are positioned mutually orthogonally to each other and extend between package 27 and the wide beam feed. One portion of each of waveguides 31-34 extends from package 27 along the surface of reflector 21 to the periphery of the reflecting dish 21 about which it is turned. Waveguides 31-34 extend to four-horn monopulse feed 24, with which they are electrically and mechanically connected. The four waveguides 31-34 thereby form struts and provide the sole menas of support for the millimeter wave feed package 24.

Supporting surface 26 for reflectors 23 and 25 is bonded by a suitable means, e.g. epoxy cement, to the exterior surfaces of waveguides 31-34 at an intermediate point between reflector 21 and feed 24 where the vertical separation between struts 31 and 32 is approximately six inches. By employing the same structure to feed millimeter waves to feed package 24 as the mechanical supporting means for the feed, the millimeter wave beams derived from reflectors 21 and 25 are presented with a minimum obstruction area.

To provide the dimensional stability required to maintain the shape of parabolic reflector 21 to within ±3 percent of a millimeter wavelength, reflectors 21, 23 and 25 are formed on a supporting structure including sheets of CFRP, the properties of which are described supra in the introduction. CFRP sheets are fabricated with isotropically directed longitudinal fibers, i.e., the sheets have a grain running in a single direction, as illustrated on sheets 41 and 42, Figure 4, and typically have a thickness of approximately twenty mils. To provide dimensional stability in two directions as a function of temperature, a pair of CFRP sheets is bonded to each other by epoxy so that the grains of the two sheets run orthogonally to each other.

In one specific embodiment, illustrated in Figure 5, laminate 48 is formed by bonding five sheets 43-47 to each other in layers so that adjacent sheets have fibers extending at right angles to each other. A second laminate 49, substantially identical to laminate 48, is also formed. Sandwiched between laminates 48 and 49 is an aluminum honeycomb structure 51 having walls with a thickness on the order of .8 mil to form longitudinally extending compartments between laminates 48 and 49. The length of the honeycomb compartments is at least one-half inch to provide sufficient lateral stiffness and strength to the resulting sandwich structure whereby the honeycomb forms the core for reflector 21 and supporting structure 26. Laminates 48 and 49 are bonded to the top and bottom planar faces of honeycomb structure 51, e.g., by epoxy cement. The physical properties of the structure illustrated in Figure 5 are ideally suited as a supporting element for a millimeter wave reflector of an outer space antenna system.

To form the sandwich structure comprising laminates 48 and 49 and honeycomb structure 51 into a supporting structure for a parabolic reflector the sandwich is molded on a mandrel having the desired shape. One face of laminate 48 is placed against the mandrel and the exposed face of laminate 49 is depressed by pressure applied thereto by a bag. Sufficient pressure is applied to the bag to deform the sandwich to the shape of the mandrel to produce the desired shape.

After the sandwich comprising laminates 48 and 49, as well as honeycomb structure 51, has been appropriately shaped to conform with the parabolic contour of reflector 21, or the combined hyperbolic and parabolic contours of reflectors 23 and 25, a reflecting surface is deposited on surfaces illuminated by millimeter waves. The reflecting surface is formed by vacuum vapor depositing an aluminum thin film layer, having a thickness on the order of 40,000 angstroms, on an appropriate exposed face of laminates 48 and/or 49. On aluminum layer 52 there is deposited a silicon oxide thin film layer 53, having a thickness on the same order of magnitude as aluminum layer 52. Silicon oxide layer 53, which is preferably silicon monoxide, reduces the temperature gradient on the reflecting surface. The structure is very strong physically in a direction perpendicular to the plane of sheets 43-47, even though the sheets have a thickness on the order of only 20 mils and the honeycomb structure by itself does not possess appreciable shear strength, i.e., strength in a direction between the faces thereof loaded by laminates 48 and 49. More importantly, the thermal stability of the structure in the plane in which laminates 48 and 49 lie is extremely great. The CFRP sheets comprising laminates 48 and 49 have virtually zero temperature coefficient of expansion in the direction of grain orientation. The honeycomb structure, even though fabricated from aluminum, does not expand appreciably in the planes parallel to the surfaces of the CFRP sheets because of the small cross-sectional mass thereof.

Reference is now made to Figures 6 and 7 of the drawings wherein there are illustrated enlarged views of reflector 21 in combination with waveguide 32. Reflector 21 includes CFRP laminates 61 and 62, as described in conjunction with Figure 5. CFRP laminates 61 and 62 are bonded, preferably by epoxy, to opposite, substantially parallel faces of honeycomb aluminum structure 63, having longitudinal sections extending between the laminates. On the exterior face of laminate 61, the face of reflector 21 that is illuminated by the millimeter waves derived from feed 22, are deposited successive thin film layers 64 and 65 of aluminum and silicon monoxide.

Wall 66 of rectangular waveguide 32 is bonded to the outer face of CFRP laminate 62 by epoxy cement. Wall 66, as well as the remaining exterior walls 67-69 of waveguide 32, are fabricated from a five-sheet laminate of CFRP, as described in conjunction with Figure 5. To provide a more rigid support between wall 66 and CFRP laminate 62 of reflector 21, a curved section 71 of CFRP laminate is bonded to wall 69 and laminate 62 so that it is slightly spaced from the inner section between the wall and laminate.

Waveguide 32 includes a honeycomb core 72, having longitudinally extending sections running generally at right angles between the inner and outer faces of the waveguide. At the corners of the waveguide, the honeycomb structure 72 is bent so that a hollow shaft is formed and the walls of adjacent longitudinally extending sections are not necessarily parallel.

A further five-sheet laminate 73 of CFRP is bonded on the inner periphery of honeycomb structure 72 by epoxy cement. On the interior, rectangular peripheral wall of laminate 73, there is vacuum vapor deposited a thin film or shell 174 of aluminum to form the conducting surface for waveguide 32. Film 174 is dimensionally very stable, being located interiorly of the sandwich construction comprising a honeycomb structure and a pair of CFRP laminates. The waveguide structure also possesses considerable three-dimensional strength because of the combination of the honeycomb with the pair of laminates on the opposite faces of the honeycomb structure. The cross section of waveguide 32 for the portion of the waveguide extending between the periphery of reflector 21 and feed 24 is identical to that illustrated in Figure 5 and possesses sufficient strength to carry support structure 26 for reflectors 23 and 25, as well as feed package 24.

In response to a temperature gradient being established across parabolic reflecting dish 21 there is a tendency for differential expansion of honeycomb structure 63 and laminates 61 and 62 in a direction at right angles to the planes of the laminates. The differential expansion in this direction, however, has an insignificant effect on the millimeter wave beam pattern derived from dish 21 because the total possible expansion in this direction relative to the focal distance is less than one percent. Because of the very low coefficient of heat expansion of the CFRP laminates 61 and 62 along the surfaces of the sheets comprising the laminates, the temperature gradient established across differing portions of reflector 21 do not cause differential expansion of the reflector along the surfaces of the laminates. Thereby, the reflector retains its parabolic shape and does not have tendency to skew about the reflector focal point. Skew is virtually completely eliminated so that surface of reflector 21 can be considered as parabolic to within ±3 percent of a wavelength of a millimeter wave. Because skew of parabolic reflector 21 is virtually eliminated, a plane wave is derived from the reflector, enabling a very narrow beam width and high gain to be achieved.

Reference is now made to Figures 8 and 9 of the drawings wherein there is illustrated a further millimeter wave antenna system in accordance with the present invention. In the system of Figures 8 and 9, the tracking and data transmission antenna system is essentially the same as described with regard to the embodiment of Figures 2 and 3 and thereby includes a Cassegrain assembly comprising parabolic reflecting dish 21, hyperbolic subreflector 23 mounted on support structure 26, and four-horn monopulse millimeter wave feed 22. As in the embodiment of Figure 2, millimeter waveguides 31-34 extend from four corners of reflector 21 to a four-horn millimeter wave monopulse feed acquisition package 171. Waveguides 31-34 are also connected to supporting structure 26 for reflector 23. In the system of Figures 8 and 9, however, horns 172 of feed 171 extend through apertures provided in supporting structure 26 and subreflector 23 to illuminate parabolic reflector 21. The ends of horns 172 are thereby positioned inside the focal point for reflector 21, which focal point is defined by the intersection of waveguides 31-34. By moving the ends of horns 172 from the focal point for reflector 21, the beam resulting from millimeter wave excitation of horns 172 is spoiled and thereby has a greater width, enabling it to be employed for acquisition purposes.

In all embodiments shown, reflector 21, supporting structure 26, and waveguides 3134 are fabricated from a sandwich comprising laminates of CFRP and a honeycomb interior structure.

Also, horns 22 and 172 are made from CFRP. Thereby, dimensional stability to within three percent of a millimeter wavelength is achieved by the entire antenna assembly. Because the waveguides are small, typically 1/8"X1/4" in cross section for millimeter wave frequencies, the use of honeycomb for members 31-34 may be eliminated. The waveguides may then be fabricated from CFRP sheets only.

While there have been described and illustrated several specific embodiments of the invention, it will be clear that variations in the details of the embodiments specifically illustrated and described may be made without departing from the true spirit and scope of the invention as defined in the appended claims.