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May 3, 1960 K. S. KELLEHER ET AL 2,935,745

AIR NAVIGATION ANTENNA DEVICE

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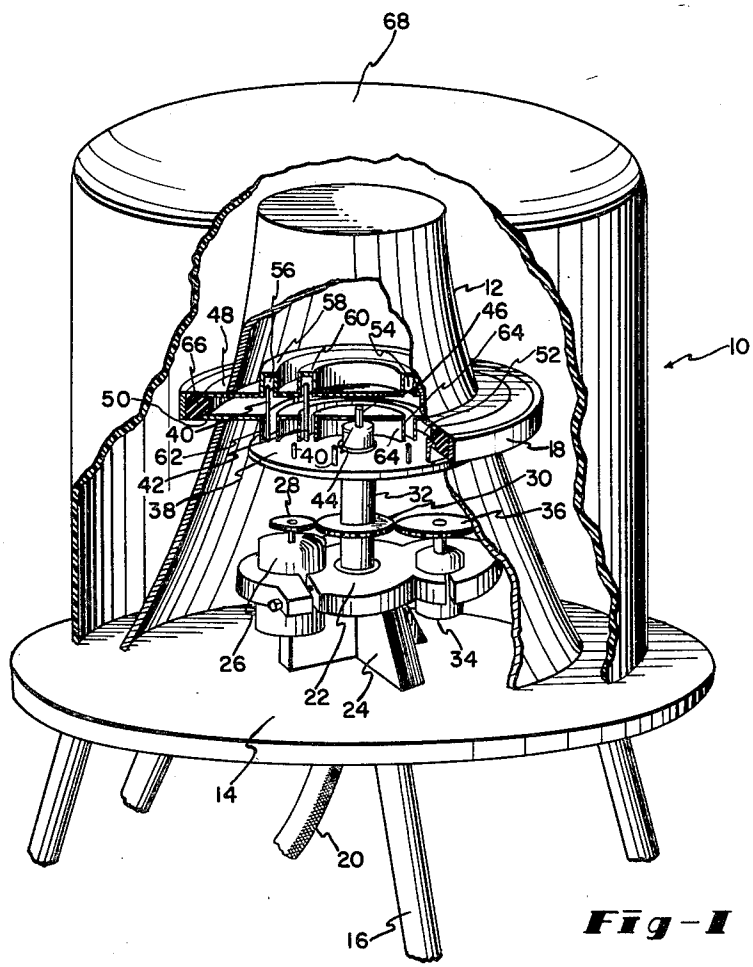


Fig-1

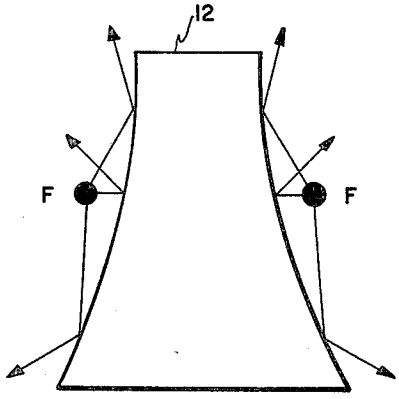


Fig-3

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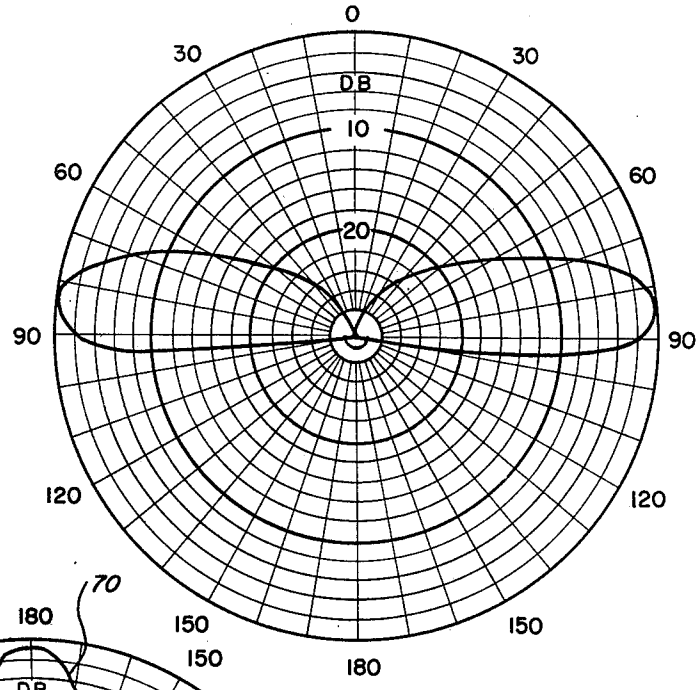
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Fig - 2



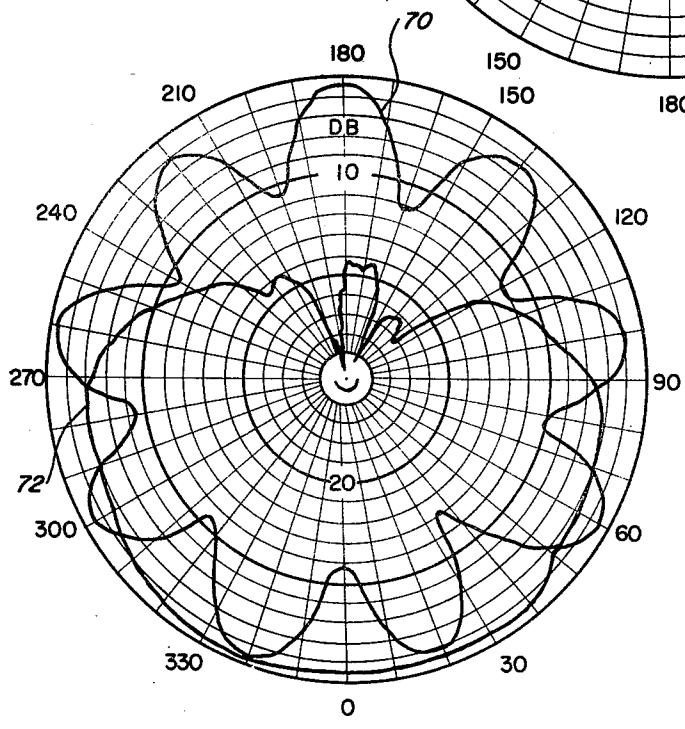


Fig - 4

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AIR NAVIGATION ANTENNA DEVICE

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5 Claims. (Cl. 343—754)

The present invention relates to an antenna device and more particularly to an antenna device and its associated antenna control equipment for use in an air navigational system. The system referred to herein is a polar coordinate type of air navigation system combining an azimuth facility and a distance facility. The aircraft pilot receives from a ground station information which automatically discloses distance in miles and degrees of azimuth to locate the position of his aircraft. Distance accuracy is within plus or minus 600 feet plus 0.15 percent of the distance measured and azimuth accuracy is better than plus or minus one degree.

The prior art antenna utilize reflecting elements of cylindrical configuration to obtain the required azimuth or bearing beam characteristic. At high elevation angles, this characteristic cannot be maintained with a cylindrical-shaped reflector.

This invention is a novel design for a transponder beacon antenna and antenna control equipment which achieves the desired azimuth beam characteristic. The present invention specifically concerns an antenna device in which the reflecting obstacles are all contained within the transmission line region, so that all elevation angles have equal pattern characteristics. Fundamentally, the inventive combination comprises the components of an antenna device, its associated drive and control systems, and the protective radome. The antenna device herein disclosed utilizes a reflector having a parabolic surface of revolution design, providing advantages over the current devices in both electrical and mechanical characteristics.

An object of the present invention is the provision of an antenna device suitable for use in an air navigational system.

Another object is to provide an antenna device based on a reflector having a parabolic surface of revolution design which produces a pattern which is substantially an omnidirectional pattern in azimuth.

A further object of the invention is the provision of an antenna device that produces a shaped beam in elevation such that a useable signal is available even at high angles.

Another object is to provide an antenna device with rotatably mounted metallic reflecting rods which are positioned about the center thereof for obtaining the desired pattern modulation.

Still another object is the provision of an antenna device which is reliable in operation, economical to manufacture and which possesses all of the qualities of dependability and ruggedness in service.

The ground-based antenna device for an air navigational system is required to produce a pattern which is substantially omnidirectional in azimuth and which has a shaped beam in elevation, with a slope at the horizon of 2 db per degree. It is necessary that this antenna device function up to an elevation angle of 60 degrees. The beam shaping should, therefore, be such that a useable signal is available even at this high angle. Because of

the reduced aircraft range at high angles, a signal level of the order of 25 db below the beam peak can be tolerated at 60 degrees. Between 0 and 60 degrees, there should be no nulls in the pattern and no phase reversals.

An additional requirement on an antenna device of this type is the need for pattern modulation. One technique for obtaining modulation involves rotation of metallic reflecting rods about the center of the antenna device. While an antenna device of a general cylindrical configuration does not satisfactorily offer this modulation at higher angles, it is possible to modify the cylindrical symmetry so that the reflecting rods lay along the longitude lines of the sphere. The invention outlined herein is a completely new antenna design and is based on a reflector having a parabolic surface of revolution design, which is feasible and, moreover, which offers advantage in more compact modulation elements. It can be seen, from symmetry, that the revolved surface will produce an omnidirectional pattern in azimuth. Its elevation pattern is controlled by the vertical cross-section of this surface. If a narrow beam is desired, the vertical cross-section is a parabola. Since a shaped beam is required for an application of this type, the vertical cross-section of the surface is the conventional central section curve of a shaped beam reflector. This curve cannot be described analytically but must be worked out using a geometrical optics technique, based on the particular vertical pattern desired. Essentially, beam shaping is obtained by distorting a part of the parabolic arc. One possibility would involve replacing the arc by a parabolic section in its upper half and a circular section at the lower half. Therefore, the reflector surface formed by rotating the prescribed central section curve about a vertical axis has been used to meet all pattern requirements in this system.

The technique for obtaining modulation in a reflector having a parabolic surface of revolution design is much simpler than that utilized at the present time. Because the reflector is fed from a radial transmission line, it is possible to obtain all modulation within the transmission line. This offers well-known advantages in an antenna design; critical features are locked within the transmission line, and hence, are not subject to the poor control available in a radiated wave. Since this modulation is independent of the elevation angle associated with the vertical pattern, it can be expected that the same degree of modulation is experienced throughout the entire vertical beam. This modulation offers considerable advantage over the conventional structures because of the fact that it is obtained from a pin array of minimum height and diameter. A considerable reduction in the drive motor size can be obtained using this array.

Further, it is to be noted that a reflector having a parabolic surface of revolution design represents a great improvement over the vertical arrays, since the reflector is basically a broadband device.

Other objects and features will become apparent upon a careful consideration of the following detailed description when taken together with the accompanying drawings, the figures of which are designed for the sole purpose of illustration and not as a definition of the limits of the invention, reference for the latter purpose being had to the appended claims.

In the drawings:

Fig. 1 is a perspective view of the antenna device with sections of the device cut away for illustrative purposes;

Fig. 2 is one of the possible elevation pattern configurations obtained in using the present antenna invention;

Fig. 3 is a cross-section view of the parabolic surface of revolution (shown in Fig. 1); and

Fig. 4 is a diagram having two patterns superimposed thereon; the pattern with the many petals being one disclosing a radial transmission line containing modulating

stationary reflectors and the other one disclosing a cardioid pattern of the same antenna without modulators but containing one reflector.

In the embodiment illustrated in Fig. 1, the antenna device **10** is shown as including a reflector **12** having a parabolic surface of revolution design mounted on a stationary base plate **14**. A plurality of leg members **16** support the base plate **14** in the horizontal plane.

Geometrically, the reflector **12** is a surface generated by revolving a curve around the horizontal axis. The reflector **12** is symmetrically located with respect to the vertical axis of the antenna device **10**. The cross sectional view Fig. 3 shows the focal points F on the horizontal axis. In the partly broken-away structure of Fig. 1, it is readily seen that the reflector **12** has a cylindrical ring or splash plate **18** being disposed symmetrically with respect to the vertical axis of the antenna device **10**. The ring **18** includes all the focal points F encircling the reflector **12** and is located substantially at the approximate midpoint of the length of the aforesaid vertical axis.

The coaxial cable feed member or transmission line **20** extends from a remotely located transmitter (not shown). The cable **20** is coaxial with the aforesaid vertical axis and extends upwardly through a hole in base plate **14**.

The drive and control assembly for antenna device **10** is mounted on a bracket member **22** which in turn is supported by a crossleg supporting member **24** on base plate **14**. The drive and control assembly comprises a motor **26**, a driving pinion **28** engaging a driven gear **30** that is concentrically mounted on a hollow drive shaft **32**. A conventional follow servo **34** actuates to control the speed of the gear **30**. Servo **34** has a driven gear **36** engaging the said gear **30**. A servo correction mechanism is necessary to maintain a constant speed within plus or minus 0.2 percent with line frequency variations of plus or minus 1 c.p.s., which is a variation plus or minus of 1.7 percent.

The assembly also includes the disk **38** complete with shorting bars. The disk **38** is concentrically rotatably mounted and rigidly secured to the upper end of drive shaft **32** and is positioned parallel to the base plate **14**. A plurality of upstanding metallic reflector rods or parasitic antenna elements **40**, preferably nine in number, are rigidly secured on the rotatable disk **38**. The nine rods are spaced uniformly 40 degrees apart close to the periphery of the disk **38**. A further upstanding metallic reflector rod or parasitic antenna element **42**, preferably a single one, is fixedly secured near the center of the disk **38**. The purpose of the rods or parasitic antenna elements **40**, **42** is explained in detail hereinafter.

The cable feed member **20** extends upwardly through hollow drive shaft **32**. The conductor **44** of feed member **20** terminates as a radiating antenna stub element **46** in a passageway formed by upper annular plate **48** and by lower annular plate **50**. Said plates **48**, **50** are parallel to base plate **14** and are concentrically positioned with respect to feed member **20**. The reflector **12** has an opening **52** of an axial dimension substantially equal to the axial dimension of ring **18**. The opposed circular edges of opening **52** are symmetrically disposed with respect to the plane of the circular cross section of reflector **12** and are located substantially at the approximate midpoint of the length of the reflector **12**.

The rods **40**, **42** extend through a pair of aligned concentric apertures **54**, **56** of upper and lower annular plates **48**, **50**. The lower plate **50** has concentric downwardly extending chambers **62**, **64** for housing the upwardly extending rods **40**, **42**, respectively. The upper plate **48** has concentric upstanding chambers **58**, **60** for housing the terminal ends of rods **40**, **42**, respectively. Said chambers **62**, **64** terminate slightly above rotatable disk **38**.

The annular plates **48**, **50** conductively connect the respective edges of opening **52** and extend outwardly and slightly past the circular wall of reflector **12**, but terminating short of ring **18**. A dielectric torus or doughnut shaped member **66** is positioned between the outer edges of annular plates **48**, **50** and ring **18** and contiguous thereto.

It is necessary to protect all airborne and some surface-based antennas from wind and weather. The housing or radome **68** described herein is designed to withstand winds of 100 knots and an ice load of 10 pounds per square foot. The radome **68** is preferably of a honeycomb construction to provide a maximum strength versus weight ratio. The radome **68** surrounds reflector **12** and is sealed to the supporting base plate **14** with a flat resilient material. The radome **68** is composed of a material such as fiberglass or polyester which is transparent to and readily passes electromagnetic wave energy of the frequency employed in radar beams. The radome **68** is cylindrical shaped and is of appropriate dimensions to protect and strengthen the structure. For such a cylindrical configuration the radiation falls on radome **68** essentially at normal incidence, the angle of incidence being defined as the angle between the incident radiation and the normal to the surface at the point of incidence.

Whereas the principles of operation of the antenna device **10** have not been fully ascertained, and consequently the discussion below is not to be considered limiting, it is deemed that the function of the antenna device is as follows.

Radio frequency energy is fed from a remotely located transmitter through the coaxial cable feed member **20** and then such energy radiates outwardly from antenna stub element **46** into the concentrical formed passageway between upper and lower annular plates **48**, **50**.

As heretofore described the disk **38** carries a single parasitic antenna rod **42**. As the disk **38** rotates with rod **42** thereon, a cardioid pattern is generated. The rotation is normally 15 r.p.s. An aircraft would receive under this condition, a 15 c.p.s. audio sine wave. A coded reference signal transmitted by a disk of this type serves as a timing reference.

An aircraft receiving such a pulse would use it to measure the phase of the pulse envelope wave that would result from this cardioid type system. Therefore, the azimuth of the aircraft relative to the ground station can be determined and appropriately disclosed to the cognizant party.

The accuracy of simply the cardioid system is definitely limited in its scope. Therefore, the antenna device **10** has in addition to the single rod **42**, nine parasitic antenna rods **40** rigidly mounted near the periphery of rotatable disk **38**. The nine parasitic antenna rods are spaced preferably forty degrees apart. As these rods **40**, **42** rotate at 15 r.p.s., a resulting composite pattern is generated. Thus, the overall cardioid pattern is still displaced, but superimposed upon it are nine secondary ripples with a maximum spaced forty degrees apart.

The composite envelope wave received on an aircraft has a ninth harmonic frequency of 135 c.p.s.

By filtering and utilizing both signals, small changes in azimuth within any forty degree sector can be determined, producing a fine or vernier indication. The ambiguity of the 135 c.p.s. phase measurement is resolved by the 15 c.p.s. phase measurement.

Site errors are, as a general rule, propagational rather than instrumentational. To avoid such errors it is necessary that the ground beacon of an omnirange station be situated over flat terrain with no high hills or structures within a considerable distance. This type of error is minimized by use of the disclosed nine-lobed vernier omnirange antenna device.

Referring to the cross-sectional view, Fig. 3, reflector **12** is shown as being fed with R-F wave energy from

points F and as yielding the heretofore described omnidirectional pattern shown in Fig. 2.

An antenna device **10** that comprises a stationary modulating reflector rods **40** would yield a petal pattern **70** shown in Fig. 4. An antenna device **10** devoid of modulating reflector rods **40** but containing the single reflector rod **42** would yield the cardioid pattern **72** disclosed in Fig. 4. Consequently, by combining the two rod features **40**, **42** and adding a splash plate **18** to direct the energy back toward reflector **12**, it is possible to obtain an overall radiation pattern that is substantially omnidirectional in azimuth and has a shaped beam in elevation with a slope at the horizon of 2 db per degree.

For a better understanding of the inventive concept described herein, the following theoretical analysis is recited. As mentioned heretofore, applicants' method for obtaining modulation in the hourglass reflector is much simpler than that used by present technicians familiar with the art. It is possible to obtain all modulation within the transmission line because the hourglass reflector is fed from a radial transmission line. Figure 1 illustrates a conception of the modulating reflectors used within the radial transmission lines. The same degree of modulation is encountered throughout the entire vertical beam since the modulation is independent of vertical angle.

Numerous pattern configurations are available which meet these conditions. One possibility is shown in Figure 2.

The basic technique in beam shaping is based on the principle of energy conservation, that is, all the energy emanating from the antenna feeding the reflector is assumed to go into the reflector beam. A close approximation to the pattern which is obtained from a feed for a reflector having a parabolic surface of revolution design is given by

Equation 1

$$I(\varphi)=10^{-.3(\varphi/\varphi_3)^2}$$

where φ is the feed pattern angle and φ_3 is one-half of the total half-power beamwidth. The desired beam pattern might be given by

Equation 2

$$P(\theta)=1 \qquad 0\leq\theta\leq 60$$
$$P(\theta)=0 \qquad \text{all other } \theta$$

This function is chosen here both for simplicity and because the actual pattern would appear as larger loops than are shown in Fig. 3. By the principle of conservation of energy

Equation 3

$$\frac{\int_{\varphi_1}^{\varphi} I(\varphi)\,d\varphi}{\int_{\varphi_1}^{\varphi_2} I(\varphi)\,d\varphi}=\frac{\int_{\theta_1}^{\theta} P(\theta)\,d\theta}{\int_{\theta_1}^{\theta_2} P(\theta)\,d\theta}$$

Equations 1, 2, and 3 now serve to yield a relation between the feed angle, φ, and the beam angle θ. It can be shown that if ρ is the distance from the feed point to reflector

Equation 4

$$\tan i=\frac{1}{\rho}\frac{d\rho}{d\varphi}$$

where i is the incident angle of a ray striking the reflector, and

Equation 5

$$i=\frac{\theta+\varphi}{2}$$

It is not usually possible to perform the integration indicated in Equation 3 directly. Accordingly, (1), (2), (3) and (5) are used to construct a graph of tan i versus φ. By numerical integration then, Equation 4 can be used to find a function of φ.

Using this method, the reflector whose cross-section is shown in Figure 3 has been designed. As pointed out above, such a reflector, if fed from points F should yield an omnidirectional pattern in azimuth and the elevation pattern similar to Figure 2, but with larger loops. The same method could be used to yield the pattern given in Figure 2. In the latter case a much shorter reflector could be used since coverage is not required at such high angles.

The air navigation system described herein operates in the realm of 1,000 mc. A single multichannel receiver-transmitter that is put into action with pulses, furnishes omnirange and distance information. Pulse coding is not utilized for channeling purposes, which makes it feasible to add other functions as a marker beacon and a localizer.

The distance indication is an outgrowth of radar ranging methods whereby distance is computed by measuring the round trip time of travel radio pulses. The interrogation pulses of each plane are wobbled to prevent ambiguities that might occur if regular pulses from two or more planes coincided. Actually two similar pulses are used with prearranged spacing of 12 microseconds. Both air and ground receivers comprise similar paired pulse decoders that reject single pulses or groups with other than prearranged spacing.

Whereas the antenna of the invention is especially useful for transmitting purposes, it is equally advantageous for reception and for duplex operation.

Where there has been described what is at present considered a preferred embodiment of the invention, it will be obvious to those skilled in the art that various changes and modifications may be made therein without departing from the invention, and it is aimed in the appended claims to cover all such changes and modifications as fall within the true spirit and scope of the invention.

What is claimed is:

1. An antenna device comprising in combination, a parabolic surface of revolution symmetrically located with respect to the vertical axis of said antenna device, said revolved surface having an opening of predetermined axial dimension, the opposed circular edges of said opening being symmetrically disposed with respect to the plane of the circular cross-section of said revolved surface and located substantially at the approximate midpoint of the length thereof of said vertical axis, a coaxial cable feed member coaxial with said vertical axis, the conductor of said feed member having an outer diameter substantially less than the diameter of said revolved surface in the aforesaid plane of said midpoint circular section, said conductor having a cylindrical cross-section of axial dimension substantially equal to the aforesaid predetermined axial dimension of said opening in said revolved surface, a first annular plate conductively connecting the lower circular edge of said opening in said revolved surface, a second annular plate conductively connecting the upper edge of said cylindrical opening and being positioned parallel and spaced thereabove from said first annular plate, said annular plates thereby providing a passageway for the transfer of energy from said feed member to said revolved surface, a disk symmetrically located with respect to said vertical axis and positioned below said first and second annular plates, means for rotating said disk, a plurality of metallic reflector rods mounted on said rotatable disk, said annular plates having concentric chamber means therein for accommodating said rods which extend through aforesaid passageway between said annular plates, said reflecting rods performing the function of shaping a desired antenna pattern, the inner conductor of said feed member terminating in said passageway, a cylindrical conductive ring coaxial with said antenna of axial dimension substantially equal to said opening in said revolved surface and spaced outwardly therefrom, said ring being disposed symmetrically with respect to said vertical axis and including the focal line of said revolved surface, said ring being adapted to reflect energy flowing between said revolved surface and said

passageway, the overall radiation pattern of said antenna device being substantially omnidirectional in azimuth and having a shaped beam in elevation with a slope at the horizon of 2 db per degree.

2. An antenna device comprising in combination, a parabolic surface of revolution symmetrically located with respect to the vertical axis of said antenna device, said revolved surface having an opening of predetermined axial dimension, the opposed circular edges of said opening being symmetrically disposed with respect to the plane of the circular cross-section of said revolved surface and located substantially at the approximate midpoint of the length thereof of said vertical axis, a coaxial cable feed member coaxial with said vertical axis, the outer conductor of said feed member having an outer diameter substantially less than the diameter of said revolved surface in the aforesaid plane of said midpoint circular section, said outer conductor having a cylindrical cross-section of axial dimension substantially equal to the aforesaid predetermined axial dimension of said opening in said revolved surface, a first annular plate conductively connecting the lower circular edge of said opening in said revolved surface, a second annular plate conductively connecting the upper edge of said cylindrical opening and being positioned parallel and spaced thereabove from said first annular plate, said annular plates thereby providing a passageway for the transfer of energy from said feed member to said revolved surface, a disk symmetrically located with respect to said vertical axis and positioned below said first and second annular plates, means for rotating said disk, a metallic reflector rod means mounted near the periphery of said rotatable disk, a second metallic reflector rod means mounted near the center of said rotatable disk, said annular plates having concentric chamber means therein for accommodating said rod means which extend through aforesaid passageway between said annular plates, said reflecting rod means performing the function of shaping a desired antenna pattern, the inner conductor of said feed member terminating in said passageway, a cylindrical conductive ring coaxial with said antenna of axial dimension substantially equal to said opening in said revolved surface and spaced outwardly therefrom, said ring being disposed symmetrically with respect to said vertical axis and including the focal line of said revolved surface, said ring being adapted to reflect energy flowing between said revolved surface and said passageway, the overall radiation pattern of said antenna device being substantially omnidirectional in azimuth and having a shaped beam in elevation with a slope at the horizon of 2 db per degree.

3. An antenna device comprising in combination, a reflector having a parabolic surface of revolution design symmetrically located with respect to the vertical axis of said antenna, said reflector having an opening of predetermined axial dimension, the opposed circular edges of said opening being symmetrically disposed with respect to the plane of the circular cross-section of said reflector and located substantially at the approximate midpoint of the length thereof of said vertical axis, a coaxial cable feed member coaxial with said vertical axis, the conductor of said feed member having an outer diameter substantially less than the diameter of said reflector in the aforesaid plane of said midpoint circular section, said conductor having a cylindrical cross-section of axial dimension substantially equal to the aforesaid predetermined axial dimension of said opening in said reflector, a first annular plate conductively connecting the lower circular edge of said opening in said reflector, a second annular plate conductively connecting the upper edge of said cylindrical opening and being positioned parallel and spaced thereabove from said first annular plate, said annular plates thereby providing a passageway for the transfer of energy from said feed member to said reflector, a disk symmetrically located with respect to said vertical axis and positioned below said first and second annular plates, means for rotating said disk, a plurality of metallic reflector rods mounted on said rotatable disk, said annular plates having concentric chamber means therein for accommodating said rods which extend through aforesaid passageway between said annular plates, said reflecting rods performing the function of shaping a desired antenna pattern, the conductor of said feed member terminating in said passageway, a cylindrical conductive ring coaxial with said vertical axis of axial dimension substantially equal to said opening in said reflector and spaced outwardly therefrom, said ring being disposed symmetrically with respect to said vertical axis and including the focal line of said revolved surface, said ring being adapted to reflect energy flowing between said revolved surface and said passageway, the overall radiation pattern of said antenna device being substantially omnidirectional in azimuth and having a shaped beam in elevation with a slope at the horizon of 2 db per degree.

4. An antenna device comprising in combination, a parabolic surface of revolution symmetrically located with respect to the vertical axis of said antenna device, said revolved surface having an opening of predetermined axial dimension, the opposed circular edges of said opening being symmetrically disposed with respect to the plane of the circular cross-section of said revolved surface and located substantially at the approximate midpoint of the length thereof of said vertical axis, a coaxial cable feed member having an outer diameter substantially less than the diameter of said revolved surface in the aforesaid plane of said midpoint circular section, said feed member having a cylindrical cross-section of axial dimension substantially equal to the aforesaid predetermined axial dimension of said opening in said revolved surface, a first annular plate mounted concentric of said feed member, a second annular plate mounted concentric of said feed member and being positioned parallel and spaced thereabove from said first annular plate, said annular plates thereby providing a passageway for the transfer of energy from said feed member to said revolved surface, the inner conductor of said feed member terminating in said passageway, a disk symmetrically located with respect to said vertical axis and positioned below said first and second annular plates, means for rotating said disk, a plurality of metallic reflector rods mounted on said rotatable disk, said annular plates having concentric chamber means therein for accommodating said rods which extend through aforesaid passageway between said annular plates, said reflecting rods performing the function of shaping a desired antenna pattern, a cylindrical conductive ring coaxial with said vertical axis of axial dimension substantially equal to said opening in said revolved surface and spaced outwardly therefrom, said ring being disposed symmetrically with respect to said reflector and including the focal line of said revolved surface, said ring being adapted to reflect energy flowing between said revolved surface and said passageway, a protective radome which surrounds said reflector and which freely passes electromagnetic wave energy so as not to interfere materially with the transmission or reception of said antenna device, the overall radiation pattern of said antenna device being substantially omnidirectional in azimuth and having a shaped beam in elevation with a slope at the horizon of 2 db per degree.

5. An antenna device comprising in combination, a parabolic surface of revolution symmetrically located with respect to the vertical axis of said antenna device, said revolved surface having an opening of predetermined axial dimension, the opposed circular edges of said opening being symmetrically disposed with respect to the plane of the circular cross-section of said revolved surface and located substantially at the approximate midpoint of the length thereof of said vertical axis, a transmission line coaxial with said vertical axis, the conductor of said transmission line having a diameter substantially less than the diameter of said revolved surface in the

aforesaid plane of said midpoint circular section, said conductor having a cylindrical cross-section of axial dimension substantially equal to the aforesaid predetermined axial dimension of said opening in said revolved surface, a disk symmetrically located with respect to said vertical axis, an annular plate means extending beyond said cylindrical opening and being positioned parallel and spaced thereabove from said disk, said conductor of said transmission line terminating as an antenna stub element, means for rotating said disk, a plurality of metallic reflector rods mounted on said rotatable disk, said annular plate means having concentric chamber means therein for accommodating said rods, said reflecting rods performing the function of shaping a desired antenna pattern, a cylindrical conductive ring coaxial with said vertical axis of axial dimension substantially equal to said opening in said revolved surface and spaced outwardly therefrom, said ring being disposed symmetrically with

respect to said vertical axis and including the focal line of said revolved surface, said ring being adapted to reflect energy radiated by said antenna stub element, a protective radome surrounding said revolved surface and which freely passes electromagnetic wave energy so as not to interfere materially with the transmission or reception of said antenna device, the overall radiation pattern of said antenna device being substantially omnidirectional in azimuth.

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