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[54] ANTENNA SYSTEM EMPLOYING TOROIDAL REFLECTORS

[75] Inventors: **Serge Drabowitch; Bernard Daveau,** both of Paris, France

[73] Assignee: **Thomson-CSF,** Paris, France

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[52] **U.S. Cl.** **343/837,** 343/840
[51] **Int. Cl.** **H01q 19/10**
[58] **Field of Search** 343/781, 837, 840, 912

[56] **References Cited**

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Primary Examiner—Eli Lieberman
Attorney, Agent, or Firm—Karl F. Ross; Herbert Dubno

[57] ABSTRACT

A microwave antenna consists of two toroidal reflectors turning their concave sides toward a common axis of rotation, i.e., a main reflector farther from that axis and an ancillary reflector closer thereto. The main reflector has a parabolic generatrix with a focal point situated on a point between the axis and the vertex of the ancillary reflector in a common equatorial plane of the two reflectors; the ancillary reflector has a hyperbolic generatrix whose foci substantially coincide with the focal point and with the vertex of the parabolic generatrix.

3 Claims, 7 Drawing Figures

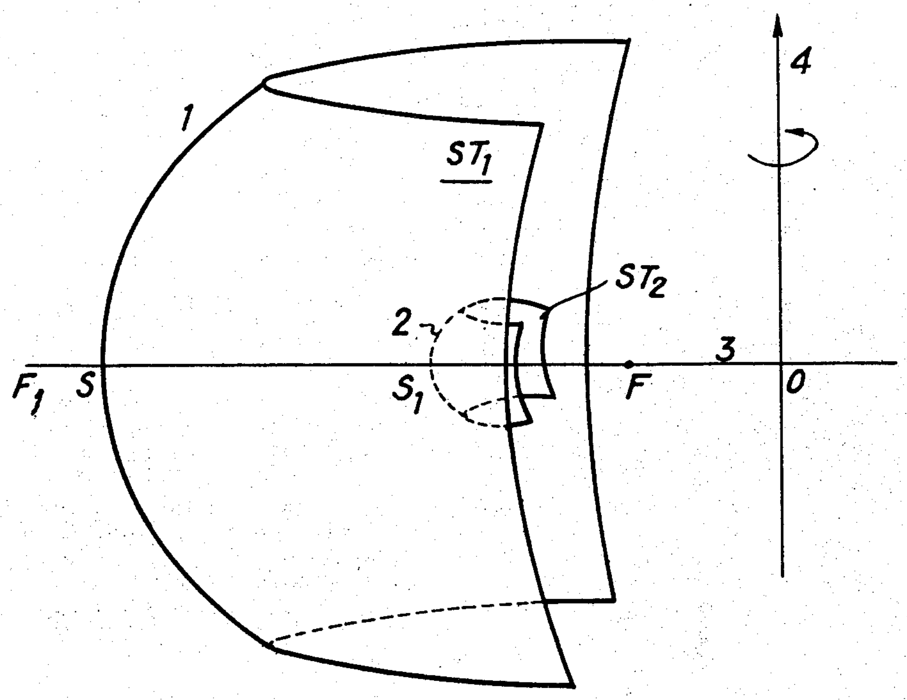


FIG. 1

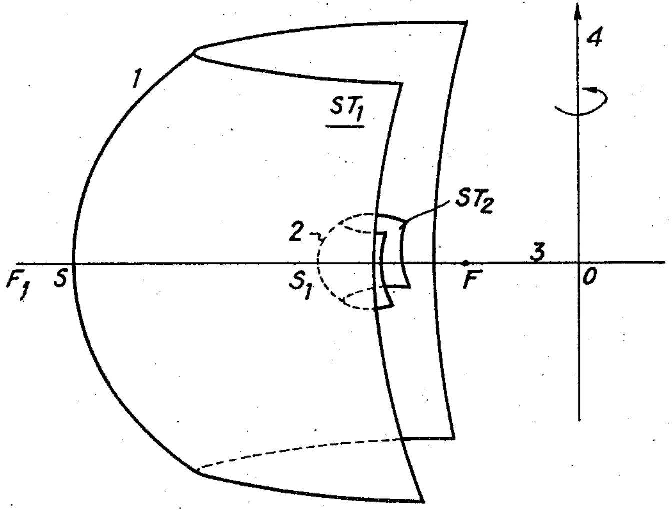


FIG. 2

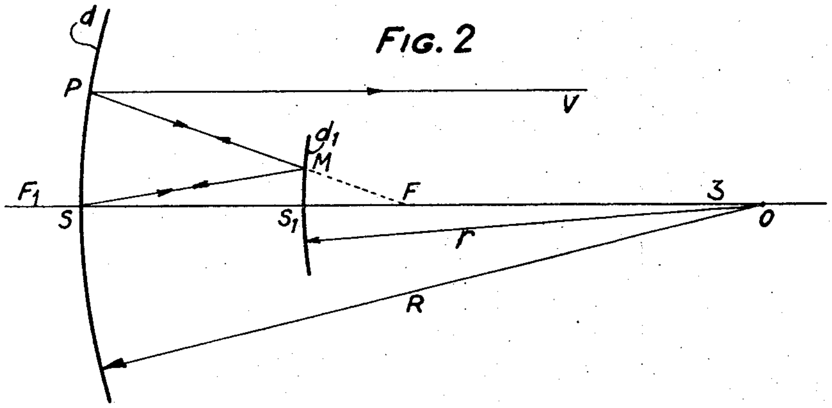


FIG. 3

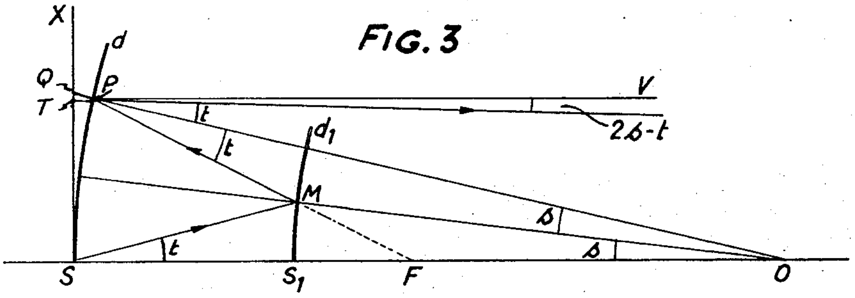


FIG. 4

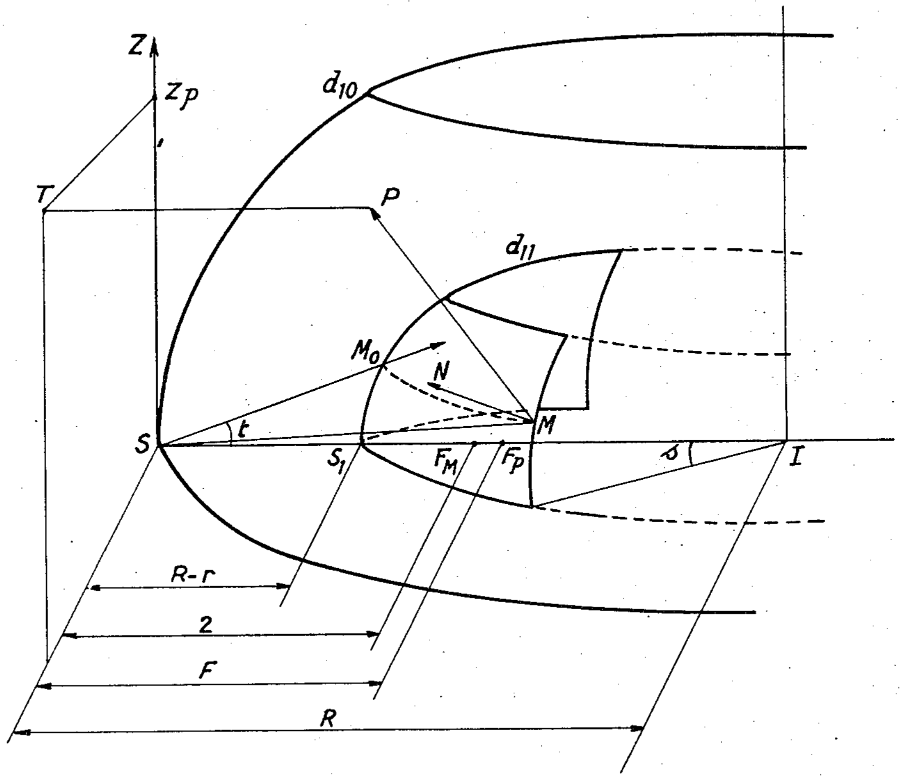


FIG. 5

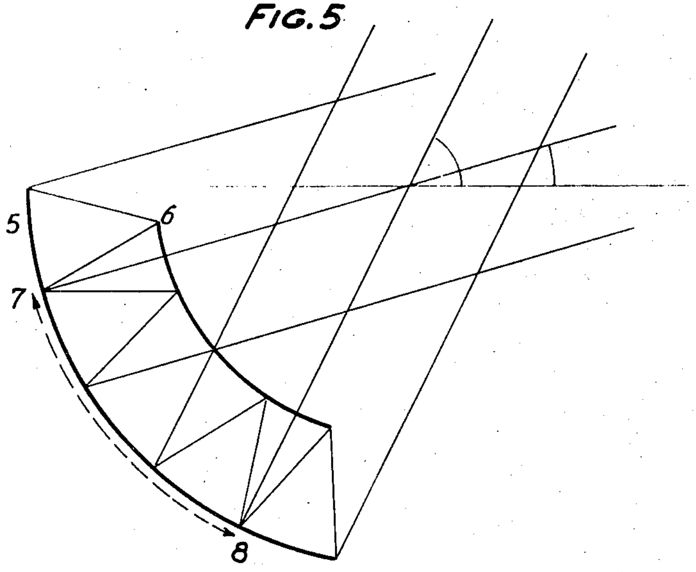


FIG. 6

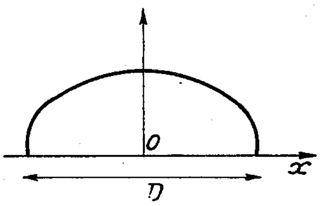
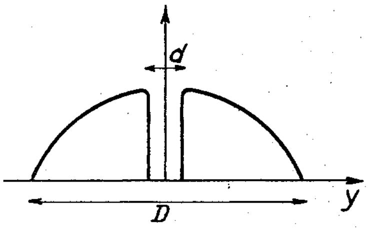


FIG. 7



ANTENNA SYSTEM EMPLOYING TOROIDAL REFLECTORS

BACKGROUND OF THE INVENTION

The present invention relates to improvements in microwave antennas and more particularly to antennas including a toroidal reflector, with a view to reducing some aberration.

Antennas with toroidal reflectors whose surface is generated by a curve known as a generatrix, situated in a plane rotating about a straight line contained within this plane, are known and possess certain important and interesting properties which have been put to good use in certain constructions.

If the generatrix is a circle, the surface is a torus in the strict sense of the term. If the center of the circle is a point on the straight line taken as the axis of revolution, the torus is a sphere.

The properties of a spherical reflector are known and are recalled in what follows. Whatever the angle of incidence of a plane wave may be, it is focused, at least approximately, near a point situated on the straight line parallel to the direction of incidence and passing through the center of the sphere, half way between this center and the point at which that line intersects the sphere. The locus of the focal points is therefore a sphere of radius approximately half the radius of the sphere forming the reflector. Such a reflector allows an aerial to be constructed with multiple beams or with a beam scanning a very large angle in all spatial directions. However, such an antenna has a spherical aberration which becomes apparent from the fact that the equiphased front of the wave radiated by the spherical reflector is not plane, as would be the case with an ideal parabolic reflector, for instance. Obviously means have been sought for correcting, at least partially, this spherical aberration.

One of these means has been to use a reflector of sufficiently large radius for the sphere to be considered, in a first approximation, equivalent to a paraboloid. A second means of compensating for spherical aberration has been to operate directly on the primary sources or to provide correcting lenses. A third means is to alter the surface of a paraboloid by deforming it in steps approaching the shape of a sphere. In this case the spherical aberration is reduced. A transverse cross-section of the reflector thus obtained shows a staircase profile with steps of the order of half the operating wavelength. However, a reflector of this type introduces diffraction on the steps and the bandwidth is relatively small.

If the generatrix is a parabolic arc rotating around an axis parallel to the directrix of the parabola, a parabolic torus is obtained.

If it is desired that the multiple beams or the directions of incidence are all situated approximately in the same plane, the reflector should be so designed that the geometric focus of the parabolic arc coincides with the optimum point of focus, i.e., the center of the straight-line segment joining the center of the torus to the apex of the parabolic arc. The locus of the primary sources to be considered is then a circle of radius equal to half the length of that line segment situated in a plane perpendicular to the axis and passing through the center of the torus. In this case focusing is improved in every plane containing the axis of revolution of the toroidal reflector and the direction of incidence. Nevertheless, this toroidal reflector with parabolic generatrix always shows a certain spherical aberration. Another drawback of toroidal reflectors is the poor accessibility of the primary sources, especially if the assembly is of large size. The installation of the sources also brings with it certain drawbacks. For example, in an installation situated on the surface of a planet, if the directions of incidence are situated above the horizon, the primary sources are necessarily oriented below the horizon and are exposed to the risk of receiving, on account of the "overspill" effect, the planetary thermal noise coming from directions outside the periphery of the reflector.

SUMMARY OF THE INVENTION

The object of our present invention is to remedy the defects which have been cited.

An antenna structure according to our invention comprises a first and a second toroidal reflector centered on a common axis of rotation, each reflector having a surface which is concave toward that common axis and has a vertex located in a common equatorial plane perpendicular thereto. The surface of each reflector has a generatrix which is substantially in the form of a segment of a conic section having a focal point located, within the equatorial plane, between its vertex and the axis.

Advantageously, the two generatrices have a common focal point lying between the axis and the vertex of the smaller, ancillary reflector disposed closer to that axis. The generatrix of the other, main reflector preferably has a parabolic curvature whereas the generatrix of the ancillary reflector is hyberbolically curved, the second focus of the hyperbola substantially coinciding with the vertex of the parabola.

Other features will appear in the course of the description which follows, which is given by way of example with reference to the appended drawing.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 represents an antenna structure according to the invention;

FIG. 2 represents a section through the structure of FIG. 1, in the equatorial plane;

FIG. 3 represents a section through the structure of FIG. 1 in the equatorial plane in the case of a beam divergent from the axis of that structure;

FIG. 4 represents a structure according to the invention in a system with three-dimensional axes;

FIG. 5 represents a structure according to the invention with a mobile exploratory beam; and

FIGS. 6 and 7 represent illumination patterns in elevation and azimuth obtained with an aerial according to the invention.

SPECIFIC DESCRIPTION

As has been indicated above, the object of the invention is to establish a class of antennas operating at microwave frequencies which possess the advantages inherent in toroidal reflectors and avoid their disadvantages, in particular spherical aberration which ought to be reduced as far as possible.

The use of two coaxial reflectors to define this new class of antenna allows certain of the characteristics and advantages inherent in twin-reflector antennas or so-called Cassegrain or Schwarzschild antenna to be introduced. However, it should be noted that the configuration of a twin-reflector aerial which may be described as conventional is different from that conforming to our invention. In fact a conventional twin-reflector antenna is produced by the rotation of two coaxial curves around their common axis and not around an axis perpendicular to this common axis.

FIG. 1 shows the structure of a system of reflectors according to the invention.

It comprises a surface described by a first curve **1** and a second curve **2** both bisected by the same axis **3**. The two curves **1, 2** perform the role of generatrices for the system obtained by rotating the two curves around a straight line **4** which is situated in their common plane and perpendicular to their common axis **3**. It is worth noting that the axis of revolution **4** lies on the concave side of these curves.

By rotating around the axis **4**, curves **1, 2** generate two coaxial toroidal surfaces ST1 and ST2. Surface ST1 forms what may be termed the outside or main reflector and surface ST2 defines the inside or auxiliary reflector.

The generatrices **1** and **2** have curvatures compatible with the desired properties as regards the focusing in any plane passing through the axis of revolution of the system.

In particular these curves are conic sections each having a focal point, namely to point F, located before the axis of revolution **4** and the corresponding vertex S, S_1 in a common equatorial plane of surfaces ST_1 and ST_2. Thus the curve **1** may be a parabolic arc and the curve **2** a hyperbolic arc. The focus F of the parabola **1** coincides approximately with one of the foci of the hyperbola **2**, while the other focus F_1 of the hyperbola is near the apex S of the parabolic arc. The primary source is situated at this focus F_1 which in practice merges with the apex S of the parabola.

A study of the operation of the system shown in FIG. 1 will enable a determination of the optimum structure to be adopted for the antenna according to the invention.

FIG. 2 shows a section through the structure of FIG. 1 in the equatorial plane, i.e., the plane orthogonally intersecting the axis of rotation **4** of the system and containing the common axis **3** of the reflectors.

In the case of FIG. 2 it is assumed that the focus F_1 associated with the curve d_1 (i.e., with a great circle of toroidal surface ST_2 of FIG. **1**) merges with the apex S of the parabola **1** so as to come to lie on a great circle of toroidal surface ST_1 represented in FIG. 3 by the curve *d*. A primary source is located at this point S. A beam S–M issuing from the point S is reflected from the convex ancillary mirror ST_2 toward the concave main mirror ST_1 on which it impinges at P and from where it is again reflected in a direction S–O parallel to the axis **3**. Conversely, an incident wave whose direction of incidence is situated in a plane perpendicular to the axis of revolution, corresponding to a line V–P, is first reflected by the main reflector ST_1 which redirects it along line P–M onto the auxiliary reflector ST_2. The latter in its turn redirects it to focal point F_1 coinciding with the apex S of the main reflector.

In the case of FIG. 2 it has been assumed that the Gauss approximation applies, i.e., that the beams are but slightly inclined with respect to the optical axis of the system. It is then possible to establish a relationship between the radii R = OS of the main reflector and *r* = OS_1 of the auxiliary reflector. Applying the classic laws of optics one obtains:

$$1/\overline{S_1S} + 1/\overline{S_1F} = 2/\overline{S_1O}$$

or

$$\frac{1}{r-R} + \frac{1}{r-\frac{R}{2}} = \frac{2}{r}$$

whence $r = 2R/3$.

Under these conditions the aerial structure is stigmatic for paraxial rays.

However, when the beams emitted from the point S or impinging thereon diverge sufficiently from the axis for the Gauss approximation to be no longer valid, it may be advantageous to slightly modify the ratio of the two reflectors r/R if it is desired that the aberrations be kept at an acceptable minimum level for a given aperture (scanning angle) of the system.

FIG. 3 shows a plot of the aberrations in the equatorial plane. In this Figure an axis S–X passes perpendicularly to the axis S–P through the apex S, and the projection of the point P of the main reflector on this axis S–X is designated T. At t we have shown the angle between the line S–M and the horizontal axis and at *s* the angle at which the point of incidence M of the incident beam on the auxiliary mirror ST_2 (represented by curve d_1) is viewed from the center O. In this case the line P–V is no longer parallel to the horizontal axis but diverges from it by an angle equal to $2s–t$ and the extension of line O–P intersects the axis S–X at point Q.

An aberration parameter D is then given by:

$$D = \overline{SM} + \overline{MP} - \overline{QP} - 2\overline{S_1S}$$

where $\overline{SM} = \overline{MP} = (R^2 + r^2 - 2\ Rr \cos s)$
and $QP = R\ 1 - \cos 2\ s/\cos\ (2s - t)$

If this parameter is developed with respect to *s* to the fourth order it is found that:

$$SM = R - r + [rR/2\ (R - r)]\ s^2 - [rR/24\ (R - r)]\ (1 + [3rR/(R - r)^2])\ s^4$$

To find the distance QP, recourse is had to the fact that the relation $OM/\sin t = OS/\sin\ (t + s)$ allows the angle *t* to be calculated from its tangent which is $\tan t = r \sin s/R - r \cos s$

It can be shown that, with the exception of the sixth-order term of *s*, $\overline{QP} = \overline{ST} = R\ (1 - \cos 2s)$ where T is the intersection of the axis S–X with the extension of the path P–V of an emitted or incident beam not parallel to the horizontal axis S–O, whence

$$\overline{QP} = R\ (2\ s^2 - [2/3]\ s^4)$$

and the aberration $D = [R/R - r]\ (3r - 2R)\ s^2 + [R/12]\ [8 - [r/R - r]\ (1 + [3rR/(R - r)]\ 2)]s^4$. D is a fourth order function of *s* if $r = 2/3\ R$, in which case $D = - 2/5\ R\ s$. With the exception of the third-order term of *s*, $\overline{SQ} = \overline{ST} = 2\ Rs = X$ from which $D = (5/32)\ (X^4/R^3)$.

This relationship shows that the phase error, at a point of the reflector for which the coordinate X is given, varies in inverse ratio to the cube of the radius R. Put another way, any reduction in R intended to reduce the size of the system results in a rapid increase in aberrations.

However, it should be noted that the twin-reflector system according to the invention enables, in comparison with a single reflector of the same size, the phase error to be reduced by a considerable proportion. In an actual example this proportion has been found to be of the order of 1.6.

When the angle s increases, it is possible to compensate for the rapid increase in the aberration D by means of the second-order term of s by taking a value for the radius r of the auxiliary reflector greater than 2R/3. If the relationship D/R is calculated as a function of X/R for $r/R = 2/3$ and $r/R = 0.675$, it is found that, for this latter value, the maximum phase error on a reflector of diameter 2R/3 is minimal.

A study of the aberrations may be performed for the general case and FIG. 4 shows the system which makes this study possible. However, the detailed calculations will not be made here. The calculation of the path-length difference $D = (SM + MP - PT) - 2\ (SS1)$ requires that the hyperbolic meridian d_{11} and the parabolic meridian d_{10} be determined to calculate the coordinates of the various points M, M_0, P.

The phase-error as a function of t and s may be stated as $E\ (t,s) = [360\ D\ (t,s)/\lambda]$ in degrees where λ is the operating wavelength and $D(t,s)$ is the difference in path length as a function of the angles s and t.

It may thus be seen that the class of antennas according to the invention offers a certain number of advantages derived both from the properties of antennas with toroidal reflectors and from antennas with twin reflectors.

In particular, the primary sources become accessible, being situated behind the main reflector, and they are directed towards the sky, which shields them from the disturbances of terrestral radiation.

These antennas with double toroidal reflectors operate with a large aperture (scanning angle), the radiation characteristics becoming independent of the direction of incidence. As for spherical aberration, which is highly inconvenient in antennas with a single toroidal reflector, this is reduced for a toroidal aerial with twin reflectors of the same size.

According to the principles set out above, an antenna has been produced capable of exploring in a given azimuth an area of space included within a considerable angle of elevation, of the order of 40°. The sweep is carried out by means of a mobile beam whose angular width corresponds to a radiation aperture of the order of 30 *m* and whose wavelength is 30 cm (1,000 Mhz).

The antenna is formed by two coaxial toroidal reflectors, i.e., a main reflector **5** and an auxiliary reflector **6** (FIG. **5**).

The primary source is situated in the vertical plane of symmetry of the system, near the main reflector **5**.

To carry out the elevational sweep of the space to be explored, this primary source oscillates about the axis of revolution of the system.

FIG. **5** shows in schematic fashion such an antenna system with two extreme positions **7** and **8** of the primary source and the directions of the beams in these cases.

The relationship of the radii of the main and auxiliary reflectors is so chosen, in accordance with what has been indicated above, that the spherical aberration is reduced in considerable proportion with respect to what it would be for an antenna with a single toroidal reflector of the same size.

For an antenna so defined the polar diagrams (illumination laws) may be plotted according to the main elevation and azimuth diagrams.

FIG. **6** gives the illumination pattern in elevation, whereas FIG. **7** gives the illumination pattern in azimuth from which it will be noticed that there is a masking effect due to the auxiliary reflector; this effect does not exist in elevation, where it would be a good deal more inconvenient.

What we claim is:

1. An antenna structure for the focusing of microwaves, comprising a first toroidal reflector and a second toroidal reflector centered on a common axis of rotation, each of said reflectors having a surface which is concave toward said axis of rotation and has a generatrix substantially in the form of a segment of a conic section having a focal point located between said axis of rotation and a vertex of the respective surface in a common equatorial plane of said reflectors perpendicular to said axis of rotation; said second reflector lying between said axis of rotation and said first reflector, the generatrix of said first reflector being a segment of a parabola, the generatrix of said second reflector being a segment of a hyperbola having a focus substantially coinciding with the vertex of said parabola, said parabola and hyperbola having a common focal point between said second reflector and said axis of rotation.

2. An antenna structure for the focusing of microwaves, comprising a first toroidal reflector and a second toroidal reflector centered on a common axis of rotation, each of said reflectors having a surface which is concave toward said axis of rotation and has a generatrix substantially in the form of a segment of a conic section having a focal point located between said axis of rotation and a vertex of the respective surface in a common equatorial plane of said reflectors perpendicular to said axis of rotation; the surface of said first reflector following a great circle of radius R in said equatorial plane and the surface of said second reflector following a great circle of radius r in said equatorial plane, said radii substantially satisfying the relationship $r = 2R/3$.

3. An antenna structure as defined in claim **2** wherein the ratio of said radii is substantially given by $r/R = 0.675$.

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