Jan. 23, 1968 K. S. KELLEHER 3,365,720

COMBINED HYPERBOLIC AND PARABOLIC DOUBLE REFLECTOR

Filed Dec. 21, 1961 2 Sheets-Sheet 1

FIG. 1
PRIOR ART

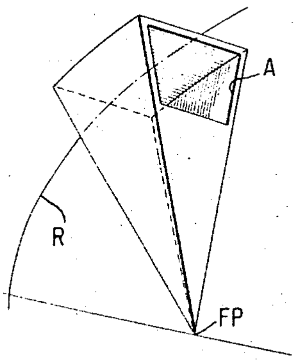


FIG. 2

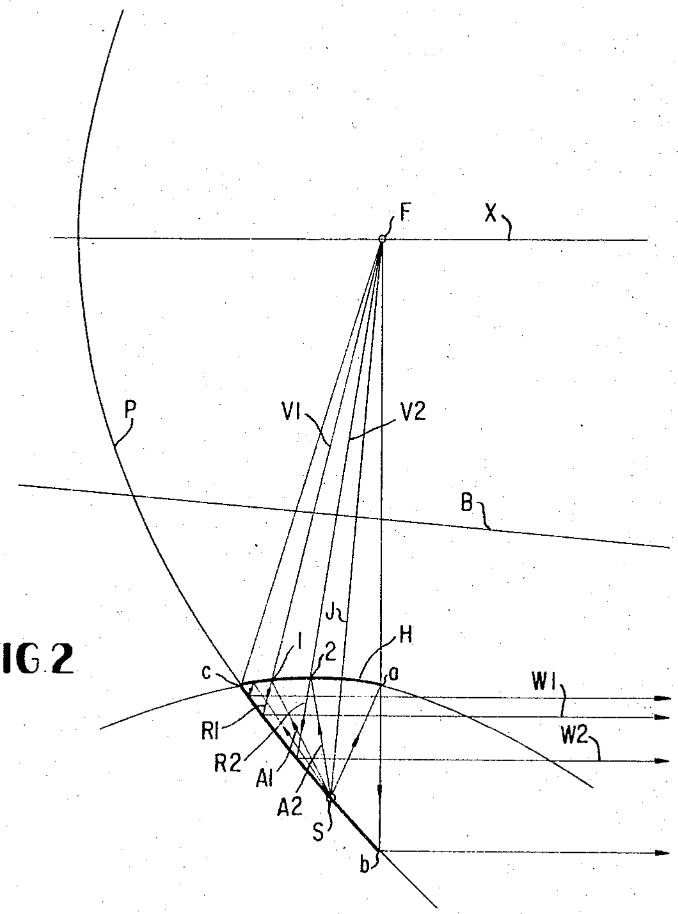


FIG. 3

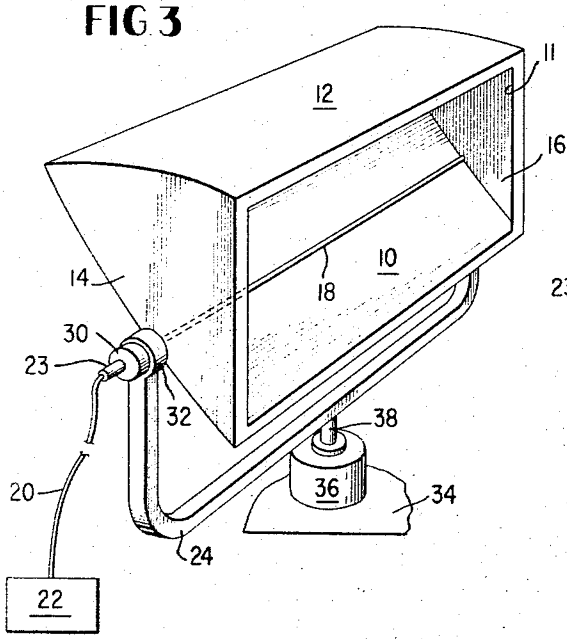
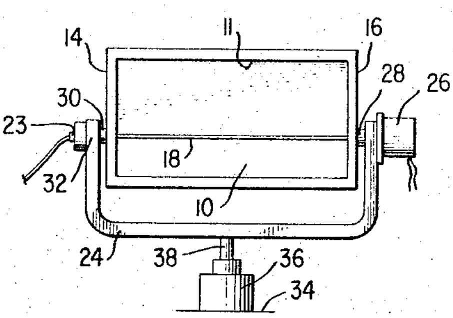


FIG. 4



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COMBINED HYPERBOLIC AND PARABOLIC DOUBLE REFLECTOR

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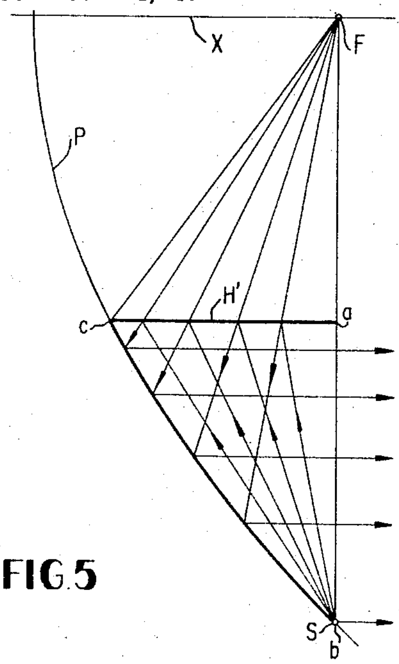


FIG.5

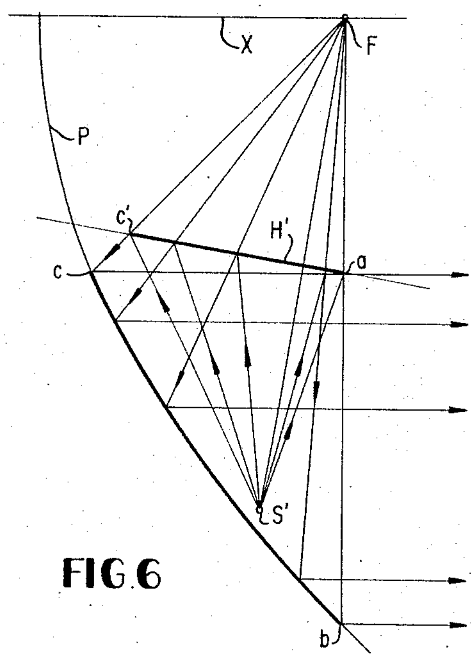


FIG.6

FIG.7

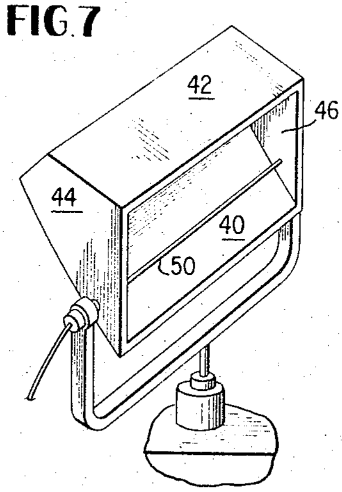
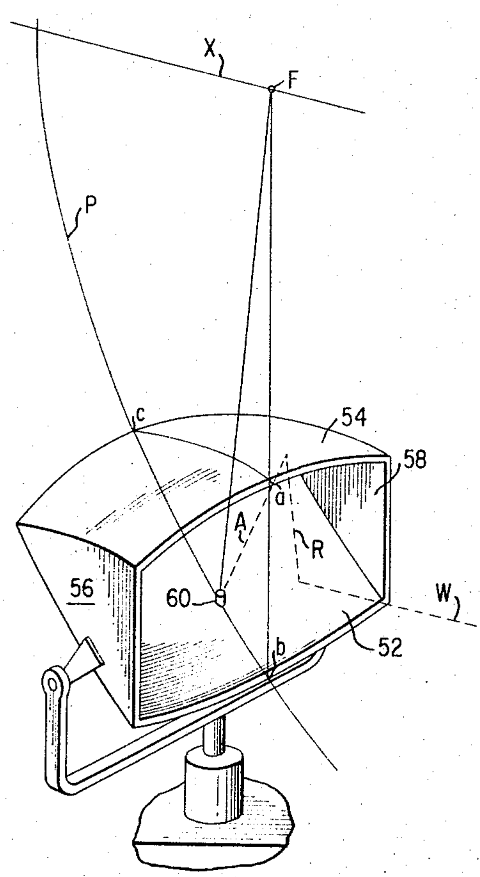


FIG.8



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COMBINED HYPERBOLIC AND PARABOLIC DOUBLE REFLECTOR

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Filed Dec. 21, 1961, Ser. No. 161,018
12 Claims. (Cl. 343—837)

The invention described herein was made in the performance of work under a NASA contract and is subject to the provisions of Section 305 of the National Aeronautics and Space Act of 1958, Public Law 85-568 (72 Stat. 435; U.S.C. 2457).

The present invention relates generally to microwave technology, and, more particularly, to a compact, low-noise, microwave antenna assembly.

In the microwave antenna art, some of the problems which constantly arise are: (1) noise caused by heat energy from the earth; (2) undesired side lobes which appear in the radiation pattern; and (3) feed blocking of the reflected waves. Feed blocking may be explained as follows: If a symmetrical paraboloid of revolution is used as the reflector, and a feed horn or the like is provided at the focus of the parabola, then there will be blocking of some of the waves which are reflected from the paraboloid of revolution and this disadvantageously affects the radiation pattern, especially since this blocking occurs in the center of the wave path. There have been attempts in the past to correct this condition.

One type of low-noise antenna for microwave transmission is the shielded horn of the type illustrated in FIGURE 1 and which is disclosed by Kenneth S. Kelleher on pages 12-14 of the Antenna Engineering Handbook published by the McGraw-Hill Book Company, Inc. This is a horn paraboloid reflector system, also called a shielded horn, and is a very successful system which provides a partial solution to problems (1) and (2), and which is useful in reducing wide-angle radiation. Another beneficial feature of this system is that the feed point FP at the focus of the parabola R in no way interferes with the reflected waves which are directed through radiation aperture A from the parabolic surface, so that there is no feed blocking.

However, this shielded horn is subject to the disadvantage of being fairly large in size. Such a horn must be at least as great in length as the aperture dimensions. Although a wide flare angle may be used in an attempt to reduce the length of the horn, when this is done, poor pattern characteristics follow. Therefore, while the low-noise characteristic of such an antenna assembly is desirable, its large size presents a disadvantage.

With these defects of the prior art in mind, it is a main object of the present invention to reduce drastically the size of present low-noise antenna systems.

A further object of this invention is to provide an antenna assembly of the type described which provides a relatively low level of noise, yet is compact.

Another object is to provide an antenna assembly which substantially reduces noise caused by heat energy from the earth.

Still another object is to provide an antenna assembly which effectively lessens spill over and undesired side lobes which detract from the radiation pattern.

Yet a further object of the invention is to substantially eliminate feed blocking.

These objects and others ancillary thereto are accomplished according to preferred embodiments of the invention, wherein two reflectors are used which are situated so that there will be substantially no blocking of the waves between the feed source and the finally directed wave path. This is particularly important in the center of the path and in some instances blocking may be tolerated

about the edges if this is needed to obtain certain desired characteristics.

The feed source is disposed on one reflector and directed by a horn or the like toward the other reflector. The second reflector reflects the waves back in such a manner that they are reflected from the first reflector in a parallel arrangement so that the antenna may be directed or aimed as desired.

For example, instead of using a reflector which forms a symmetrical parabola with respect to the feed point and the axis of this curve, only a portion of one side of the parabola is used so as to eliminate feed blocking. Another reflector, which is a segment of a hyperbola, faces this arcuate portion of the parabolic reflector and in an extreme case may be planar.

If the focus of the parabolic reflector is assumed to be one of the focal points of a hyperbola, and the feed for the antenna is assumed to be the other of the focal points of a hyperbola, then the combination of the parabola and a hyperbola, constructed from these two focal points, will form the reflecting surfaces. These surfaces will then be such that the feed or lower focal point of the hyperbola, which is preferably disposed on the parabola, will have its waves reflected from the hyperbolic reflector to the parabolic reflector where they will appear to have emanated from the focus of the parabola which is now the virtual feed. The reflected waves are reflected from the parabolic reflector and in a direction parallel to the axis of the parabola and through the radiation aperture formed between the edges of the parabolic and the hyperbolic reflectors.

The reflectors may be hyperbolic and parabolic cylinders or paraboloids and hyperboloids of revolution. The reflectors may also be planar surfaces in combination with parabolic cylinders or paraboloids of revolution. In the case of cylindrical reflectors it is preferable to have a line feed source, while in the case of surfaces of revolution, a point feed source is preferable.

Additional objects and advantages of the present invention will become apparent upon consideration of the following description when taken in conjunction with the accompanying drawings in which:

FIGURE 1 is a perspective view of the shielded horn antenna system which is known in the prior art.

FIGURE 2 is a digrammatic view illustrating the theory of the parabolic and hyperbolic reflectors, with the feed disposed along the length of the parabolic reflector.

FIGURE 3 is a perspective view of an antenna constructed in accordance with FIGURE 2 and of the type wherein the reflectors are hyperbolic and parabolic cylinders.

FIGURE 4 is a front elevational view illustrating the mounting arrangement for the antenna system.

FIGURE 5 is a diagrammatic view of the geometrical arrangement of the reflectors wherein the hyperbolic surface has been replaced by a planar surface and the feed is at the edge of the parabolic surface.

FIGURE 6 is a diagrammatic view similar to FIGURE 5, but wherein the feed is disposed between the two reflectors.

FIGURE 7 is a perspective view of the embodiment of FIGURE 6.

FIGURE 8 is a perspective view of a dome-like assembly, wherein paraboloids and hyperboloids of revolution are used as reflectors, and taken looking into the radiation aperture.

In the study, analysis, and design of antennas, transmitting and receiving antennas are treated alike. That is, both types are considered as transmitting antennas. It should therefore be noted that although the analysis which follows may seem to indicate that the antenna of the present invention is a transmitting antenna, it is primarily a receiving antenna, albeit usable for transmitting purposes with excellent results. In accordance with the above, the "feed source," or "feed," which is associated with the antenna, means a feed for the antenna in the case of transmitting, and a feed for the receiver in the case of receiving. This convention is also followed in the claims. However, in several instances, which should be immediately apparent, this convention has not been followed, and the waves are considered as travelling toward, rather than away from, the antenna.

The reflectors should be such that, considering them as a receiving antenna for the moment, the parallel waves entering the aperture will be reflected from the first surface on which the feed source is located and directed toward the second reflector. The wavefront of the waves reflected from the second reflector should be spherical and focus to the feed source on the first reflector. Also, to prevent feed blocking, the first reflector should be asymmetrical.

Thus, the problem may be set up as follows using the relationships taught by Kenneth S. Kelleher in "Relations Concerning Wave Fronts and Reflectors" in the June 1950, issue of "Journal of Applied Physics," volume 21, No. 6, pages 573–576.

Given the primary asymmetric reflector R and the incident plane wave X, fined the reflected wavefront Y.

$$Y = X + 2\eta[\eta \cdot (R - X)]$$

$$\eta = \frac{R_u \times R_v}{|R_u \times R_v|} = \frac{k y_v - j + i y_u}{\sqrt{1 + y_u^2 + y_v^2}}$$

$$X = iu + ja + kv$$

$$R = iu + jy + kv$$

$$y = y(u, v)$$

$$Y = (u, a, v) - \frac{2(y - a)(y_u, {}^{-1}, y_v)}{1 + y_u^2 + y_v^2}$$

$$(x, y, z) = ix + jy + kz$$

Now, from the reflected wavefront Y, find the second reflector surface $\overline{R}$ which produces a reflected wave focusing to a point on the primary asymmetrical reflector.

$$\overline{R} = Y + \frac{C^2 - (Y - X)^2}{2[C + (Y - X) \cdot \xi]} \xi$$

for $X = 0$, origin at focal point

$$\overline{R} = Y + \frac{C^2 - Y^2}{2[C + Y \cdot \xi]} \xi$$

Since ξ is perpendicular to Y

$$\overline{R} = Y + \frac{C - Y^2}{2C} \xi$$

where

$$\xi = \frac{Y_u \times Y_v}{|Y_u \times Y_v|}$$

and C is a constant.

Using such formulas, it can be calculated that the following curves may be used to complement each other:

parabola=hyperbola
catenary=catenary complement
circle=cardioid

the latter of which is known as the Ziess Cardioid and has been described by Zernike.

With more particular reference to the drawings, FIGURE 2 is a diagram indicating the geometrical arrangement of one form of the assembly, which may be considered to be a cross section of an antenna system. In a typical reflector arrangement, a parabolic reflector is provided, which may be considered as curve P. In this arrangement a point feed source would be located at the

focal point F of the parabola. This parabola has an axis X which is parallel to the radiating direction, and a directrix (not shown) which is required in order to construct the parabola so that all points therealong are equidistant from focus F and lines which are at right angles to the directrix.

In order to reduce the size of this parabolic reflector P, a hyperbola H is constructed from upper and lower focal points F and S, which are the focus of the parabola P and the feed point, respectively. A construction line J is drawn between these focal points F and S, and a perpendicular bisector B is constructed. From this given information, the hyperbola H may be constructed. The hyperbola H intersects parabola P at point *c*.

Now for the preferred embodiment which yields optimum results insofar as gain is concerned, the line *ab* which defines the plane of the radiating aperture, should be at right angles to the parabola axis X and pass through its focus F. At the same time, an imaginary line adjoining *a* and *c* of hyperbola H should be disposed parallel to axis X. With such a construction, the waves emanating therefrom will be directional and parallel to axis X.

However, it should be noted that in order to obtain particular characteristics it may become necessary to deviate somewhat from this optimal arrangement. For example, imaginary line *ac* may be disposed at an angle with respect to axis X in such manner that there is some blocking of waves. This may be readily tolerated up to about 10% blocking. Also, since this blocking occurs at the side or edge of the wave path, it is not as objectionable as the type of feed blocking mentioned hereinbefore which is at the center of the wave path.

Points **1** and **2** along hyperbolic reflector H have been chosen at random. Lines **V1** and **V2** are now drawn from focus F to points **1** and **2**. If we now assume that point S is a feed source and feed microwaves thereto, a wave **A1** will be radiated as indicated and will arrive at hyperbolic reflector H at point **1** and be reflected therefrom along the line **R1**. This will then be reflected in a direction parallel to axis X along line **W1**. A similar result will be provided by a radiated wave **A2** which is reflected as indicated by line **R2** and is then emitted from the radiating aperture as indicated by line **W2**.

From the foregoing it may be seen that although the actual point of radiation is disposed along the parabolic reflector P between points *c* and *b*, the waves which are reflected from the hyperbolic reflector H, **R1** and **R2**, will actually be extensions of and coincident with lines **V1** and **V2**. It will thus appear that these waves have originally emanated from focus F of parabola P which may be considered the virtual feed source. Thus, the system has all of the attributes of the typical parabolic reflector P, but is obviously drastically reduced in size.

This system will also have the low-noise characteristic provided by the shielded horn illustrated in FIGURE 1, but will be of much smaller size.

With more particular reference to FIGURES 3 and 4, a practical device is illustrated which is constructed in accordance with FIGURE 2. A curved plate of conducting sheet metal **10** is provided which conforms to a parabola so as to define a parabolic cylinder, and which may be considered as the arcuate section of curve P between points *b* and *c*. Panel **12** is constructed of similar material and is a hyperbolic cylinder which may be considered as the curve H, that is a hyperbola, between the points *a* and *c*. End panels **14** and **16**, which are parallel to each other, are provided to join and support the edges of panels **10** and **12**, and the edges of panels **10**, **12**, **14** and **16**, are disposed in a plane and define a radiating aperture **11**. The abutting edges of panels **10** and **12** are contiguous so that a closed four-sided reflector is provided. A line source of radiation is provided in the form of feed **18** which is fed by a transmission line **20** from a suitable microwave generating or receiving apparatus **22**, which is well known in this art.

This microwave assembly is supported by means of a yoke **24**, having a motor **26** joined to one leg thereof and a drive shaft **28** attached to panel **16**, so that upon rotation of motor **26**, shaft **28** will turn and force the entire assembly to rotate in a direction about a transverse axis which is shown as being coincident with feed source **18**. The other leg of the yoke has a bearing **32** connected thereto and in which a shaft **30** is journalled. The other end of this shaft is rigidly fastened to panel **14**, so that the entire assembly may rotate within the yoke **24**.

A conduit **23** is provided through an opening passing through shaft **30**, to house transmission line **20**.

The yoke itself is mounted upon a support **34** having a motor **36** mounted thereon and which is connected with and rotates yoke **24** by means of a motor drive shaft **38** which is connected to yoke **24**. Thus, by controlling motors **26** and **36** the directional antenna assembly may be controlled so as to emit the waves in any desired direction.

With more particular reference to FIGURE 5, another embodiment is illustrated which, in construction and operation is very similar to that of FIGURES 2–4, but with certain specific differences. For example, in this embodiment the feed source S is disposed at the edge of parabola P at point *b*. The hyperbola H of FIG. 2 has become, in this case, planar or a straight line H′. With such a construction point *a* is equidistant from points F and *b*.

FIGURE 6 shows an embodiment which is similar to FIGURE 5, but wherein the feed source S′ is disposed between the curves P and H′. Furthermore, the two adjacent surfaces of curves P and H′ are not contiguous, but are spaced from each other as may be seen by the space between points *c* on the parabola P and *c*′ on curve H′. The construction of the curves in this example is the same as those set forth in the other examples. However, it should be noted that an imaginary line joining points *a* and *c* is parallel to axis X so that the radiating aperture between points *a* and *b* defines the extreme limits of the radiation surfaces which will radiate in the intended radiating direction. All of the constructional elements in these figures which are similar to those of FIGURE 2 are indicated by identical reference characters.

In the perspective view of this embodiment illustrated in FIGURE 7, the parabolic reflector **40** and the extreme hyperbolic or planar reflector **42** do not touch each other but are spaced and are supported by end panels **44** and **46** and any other suitable reenforcing structure which may be required. The end panels **44** and **46** rigidify the ends of the reflectors **40** and **42**. In this instance also the feed is a line source **50** which is mounted so as to be disposed inwardly of the surface of parabolic reflector **40**.

In the embodiment illustrated in FIGURE 8 the parabolic and hyperbolic reflectors are a paraboloid of revolution **52** and a hyperboloid **54** which are joined together at their adjacent ends to form a contiguous surface and are provided with supporting end panels **56** and **58**. In this instance a point source of radiation **60** is provided, and a reflected wave is indicated with the same indicia, as was used in FIGURES 1, 5 and 6, to indicate the reflection of a wave within the assembly and then externally of the horn in the desired direction.

Thus, by means of this embodiment of the present invention the real source, which is mounted in close proximity to the radiation aperture of a shielded horn, can produce a virtual source for waves reflected from the hyperbola. This virtual source is a great distance from the radiation aperture and matches in every respect the characteristics of a real source placed at this distance from the aperture. In general, the feed point for introducing wave guide energy into the antenna assembly will be positioned at some point along the parabolic surface which is equidistant from the two side panels.

As was mentioned above, although it is not a necessity that line *ab* be at right angles to axis X and pass through focus F, such a construction will provide optimum condition will provide optimum conditions for high gain purposes. The feed may be provided by a directional horn to direct the waves toward the intended reflector, and this will reduce spill over to a large extent.

The hereinabove described antenna system is useful in the microwave region which is in the range of about 10^9 or 10^{10} cycles per second. A typical size for a practical embodiment for FIGURE 8 would be ten feet by ten feet, with a depth of eight feet. From these dimensions it should be readily realized that the size of such an antenna is quite drastically reduced from that which would be required for the typical type of parabolic reflector or shielded horn which has been used in the past.

Any type of suitable control may be provided to accurately control movement of the motor shafts so that the antenna assembly may be critically aimed, if desired. Such motors and controls therefor are already known per se and therefore will not be described in detail.

Each of the arrangements set forth in FIGURES 2, 5, and 6, may be constructed with the reflectors as parabolic and hyperbolic cylinders as shown in FIGURE 3, or as paraboloids and hyperboloids of revolution as shown in FIGURE 8. However, by using the hereinabove described invention, the reflectors may be provided with other configurations which will provide similar results. Such configurations may be calculated by using the above formulas. The antenna of the present invention drastically reduces heat energy noise from the earth and spill over, as well as feed blocking. Accordingly, the low-noise characteristic of this antenna is extremely favorable.

It will be understood that the above description of the present invention is susceptible to various modifications, changes, and adaptations, and the same are intended to be comprehended within the meaning and range of equivalents of the appended claims.

What is claimed is:

1. A microwave antenna assembly for radiating microwaves in an intended direction comprising, in combination:

(a) a first reflector defining a hyperbolic arc in cross section;

(b) a second reflector adjacent said first reflector and defining a parabolic arc in cross section whose focus is disposed exteriorly of said assembly; and

(c) a radiation feed source disposed for radiating waves toward said first reflector; said reflectors together defining a radiation aperture which is in a plane disposed at right angles to the intended radiation direction, said hyperbolic arc having the focus of said parabolic arc as one focal point and said feed source as another focal point, said reflectors being arranged so that waves from said source directed toward said first reflector are reflected toward said second reflector along lines coincident with imaginary lines between the focus and said second reflector, whereby all waves reflected from said second reflector will be directed in a direction at right angles to the plane of said radiation aperture.

2. An assembly as defined in claim **1**, wherein the focus of the parabolic arc of said second reflector is in the same plane as said radiation aperture.

3. An assembly as defined in claim **2**, wherein said first reflector is a hyperbolic cylinder and said second reflector is a parabolic cylinder.

4. An assembly as defined in claim **3**, wherein said source extends for the length of said reflectors.

5. An assembly as defined in claim **1**, wherein said source is a point source.

6. An assembly as defined in claim **2**, wherein said reflectors form a contiguous surface.

7. An assembly as defined in claim **1**, wherein said first reflector is a hyperboloid of revolution and said second reflector is a paraboloid of revolution.

8. An assembly as defined in claim 7, wherein said source is a point source of radiation.

9. An assembly as defined in claim 2, wherein said source is mounted on said second reflector.

10. A directional, low-noise microwave antenna assembly, comprising, in combination:

(a) a first reflector defining a hyperbolic arc in cross section;
(b) a second reflector adjacent said first reflector and defining a parabolic arc in cross section whose focus is disposed exteriorly of said assembly;
(c) a radiation feed source disposed within said assembly; and
(d) a pair of end frame panels disposed in planes parallel to the intended radiation direction of said assembly, said panels and said reflectors together defining a radiation aperture which is disposed in a plane at right angles to the intended radiation direction and in the same plane as the focus of the parabolic arc defining said second reflector, said hyperbolic arc having the focus of said parabolic arc as one focal point and said feed source as another focal point, said reflectors being arranged so that waves from said source directed toward said first reflector are reflected toward said second reflector along lines coincident with imaginary lines between the focus and said second reflector, whereby all waves reflected from said first reflector will eventually be directed in a direction at right angles to the plane of said radiation aperture.

11. An assembly as defined in claim 10, wherein said reflectors are arranged so that an imaginary line, between

the edge of said first reflector defining in part said radiation aperture, and the edge of said second reflector adjacent said first reflector, is disposed in the intended radiation direction.

12. In a low-noise microwave antenna, the combination which comprises:

(a) a parabolic reflector having an axis along which there is a focus;
(b) a radiation source spaced from said focus; and
(c) a hyperbolic reflector which is hyperbolic with respect to said source and said focus for directing toward said parabolic reflector radiation directed by said source against said hyperbolic reflector such that said source appears to said parabolic reflector, to emanate from said focus so that said parabolic reflector directs the radiation in a direction parallel to said axis, said hyperbolic reflector being located substantially outside of the radiation reflected by said parabolic reflector.

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