Dec. 3, 1968 J. S. AJIOKA 3,414,904

MULTIPLE REFLECTOR ANTENNA

Filed May 16, 1966 7 Sheets-Sheet 1

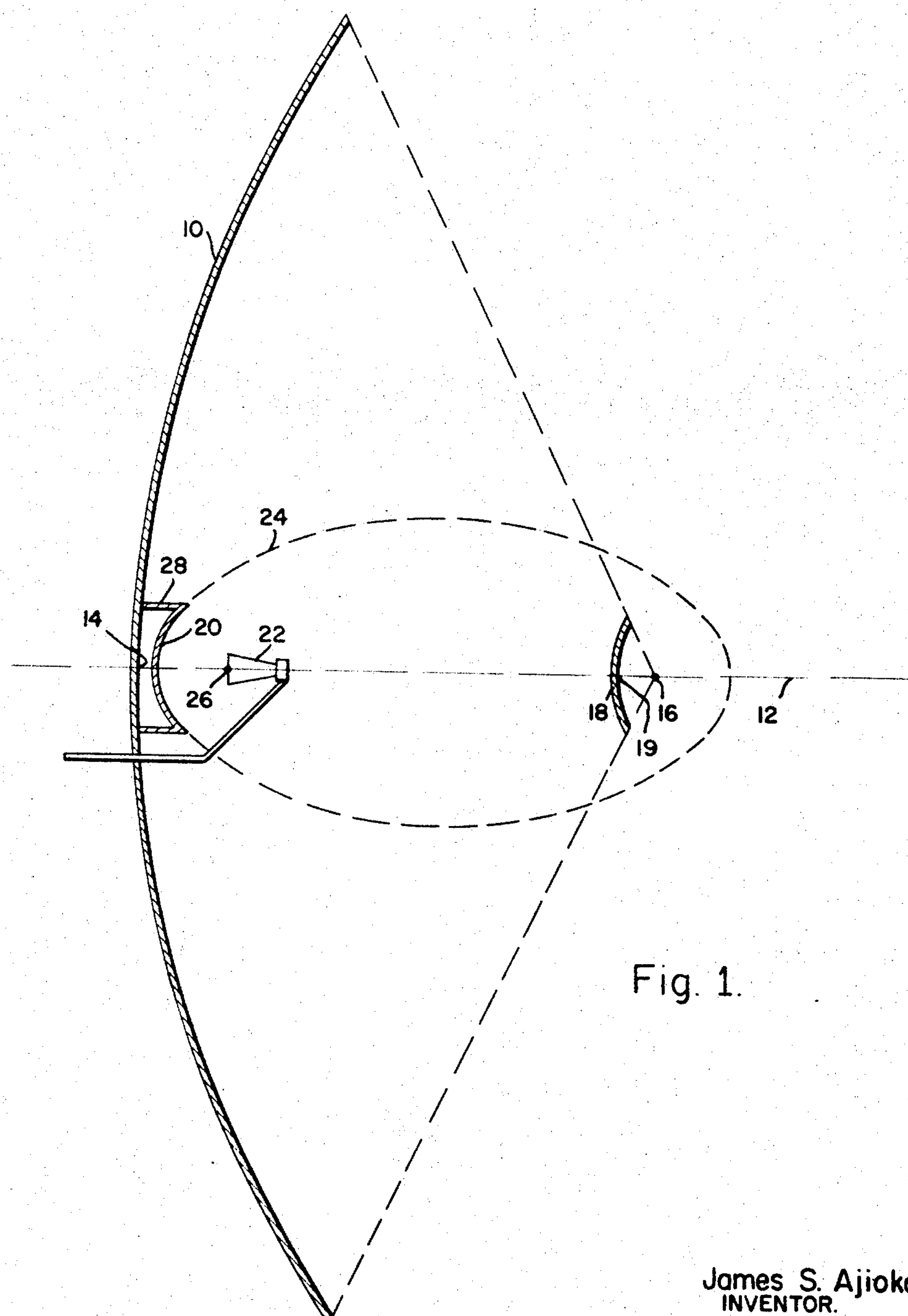

Fig. 1.

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MULTIPLE REFLECTOR ANTENNA

Filed May 16, 1966 7 Sheets-Sheet 2

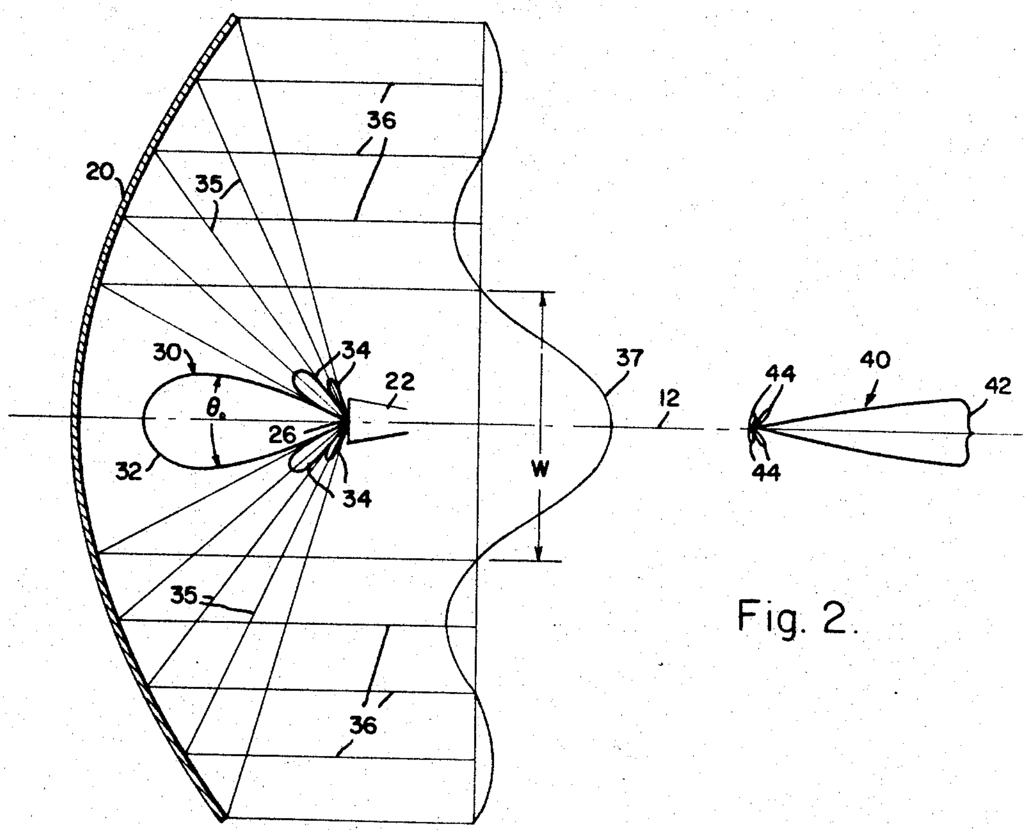

Fig. 2.

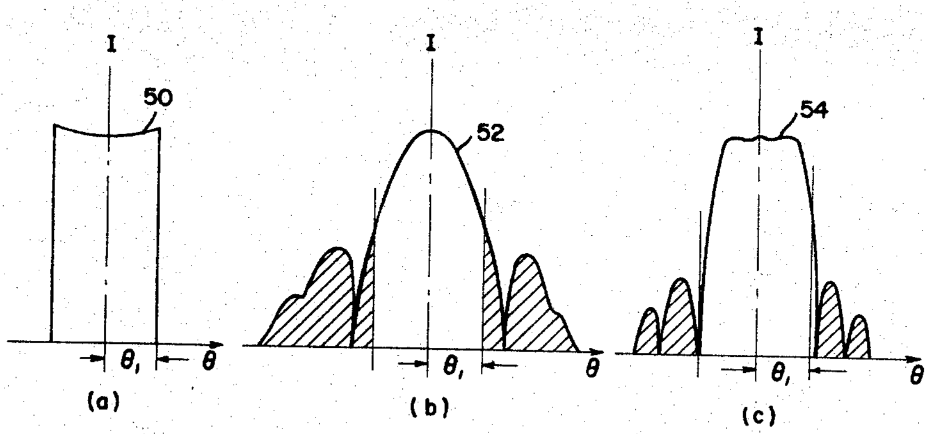

Fig. 3.

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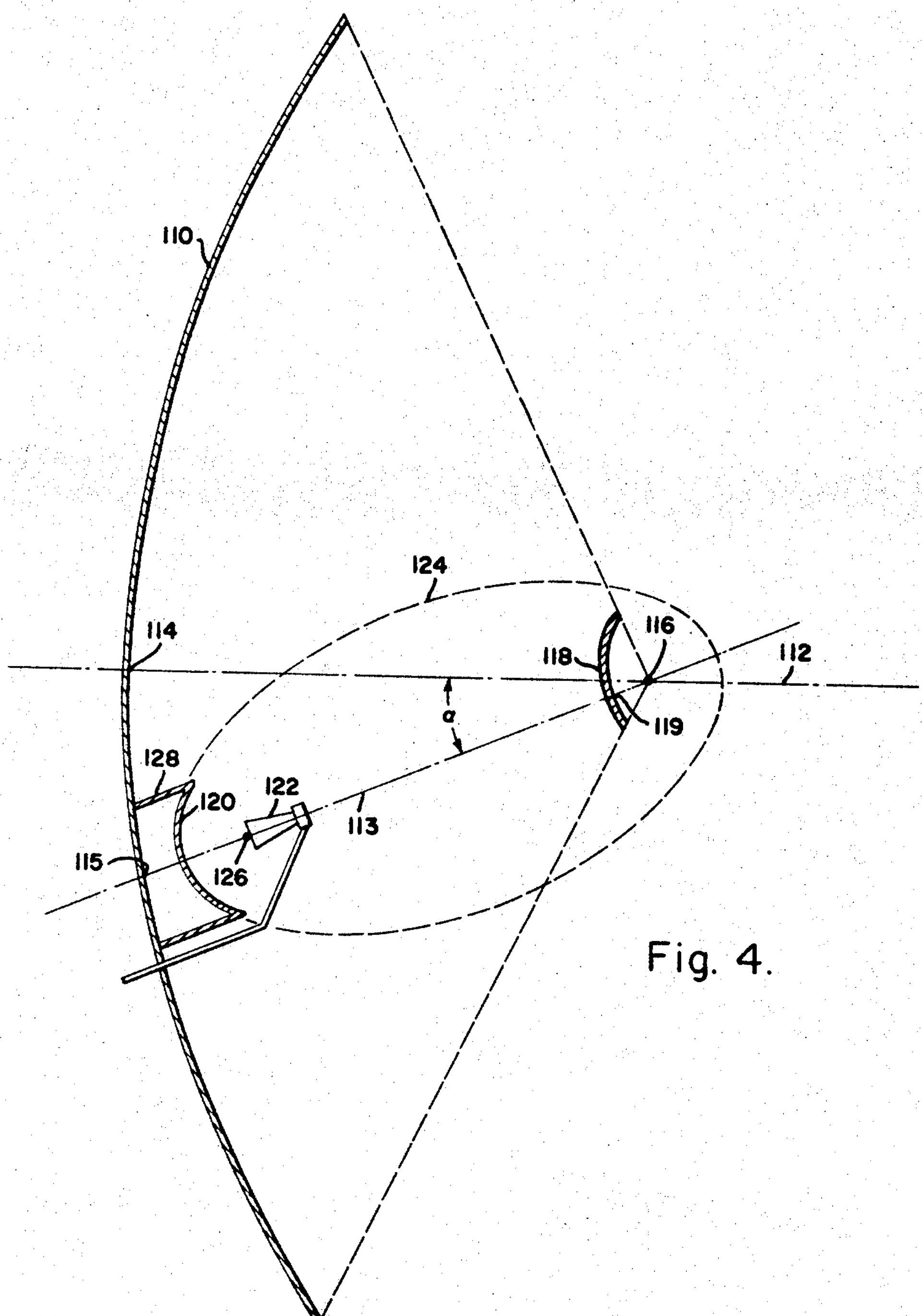

Fig. 4.

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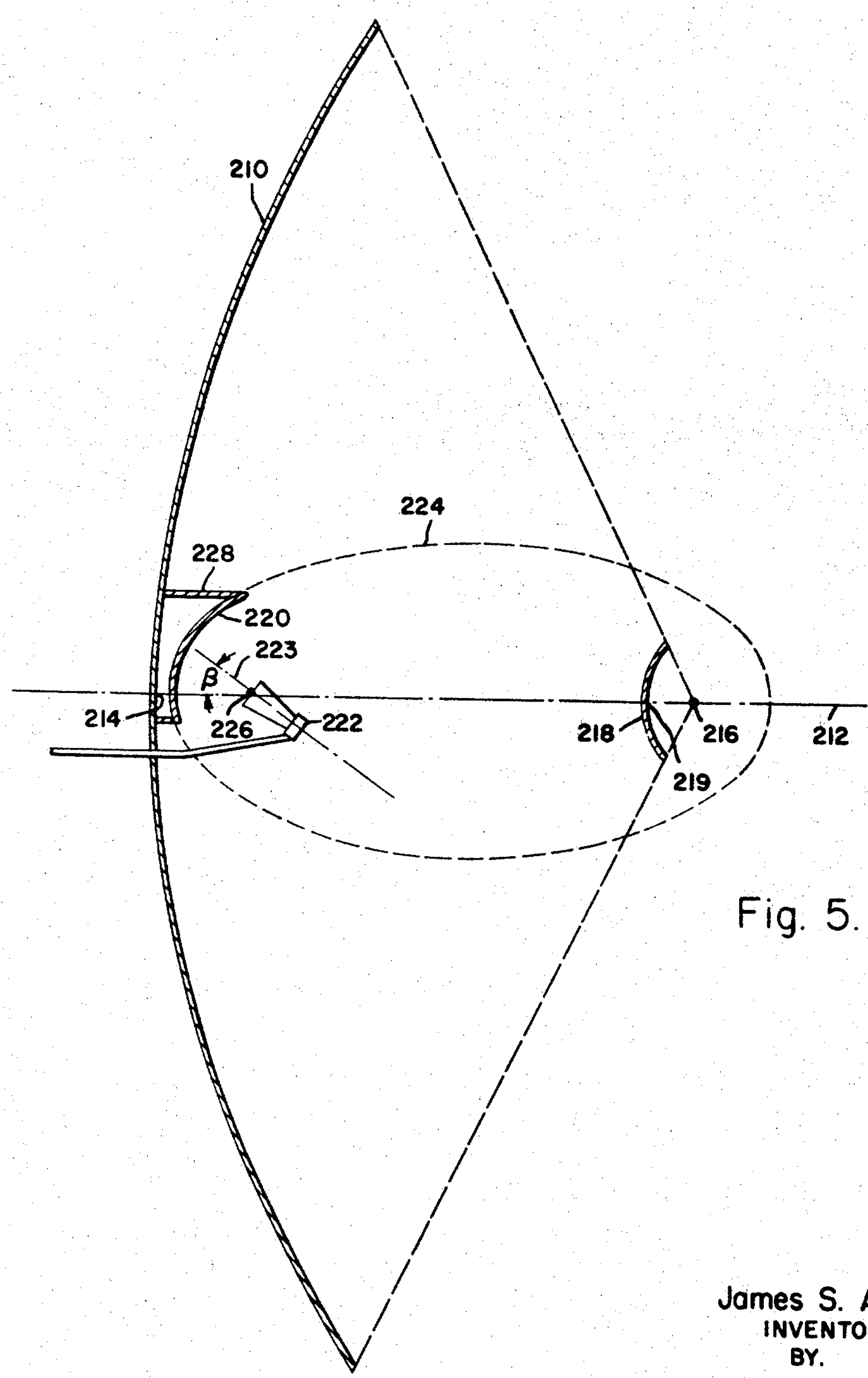

Fig. 5.

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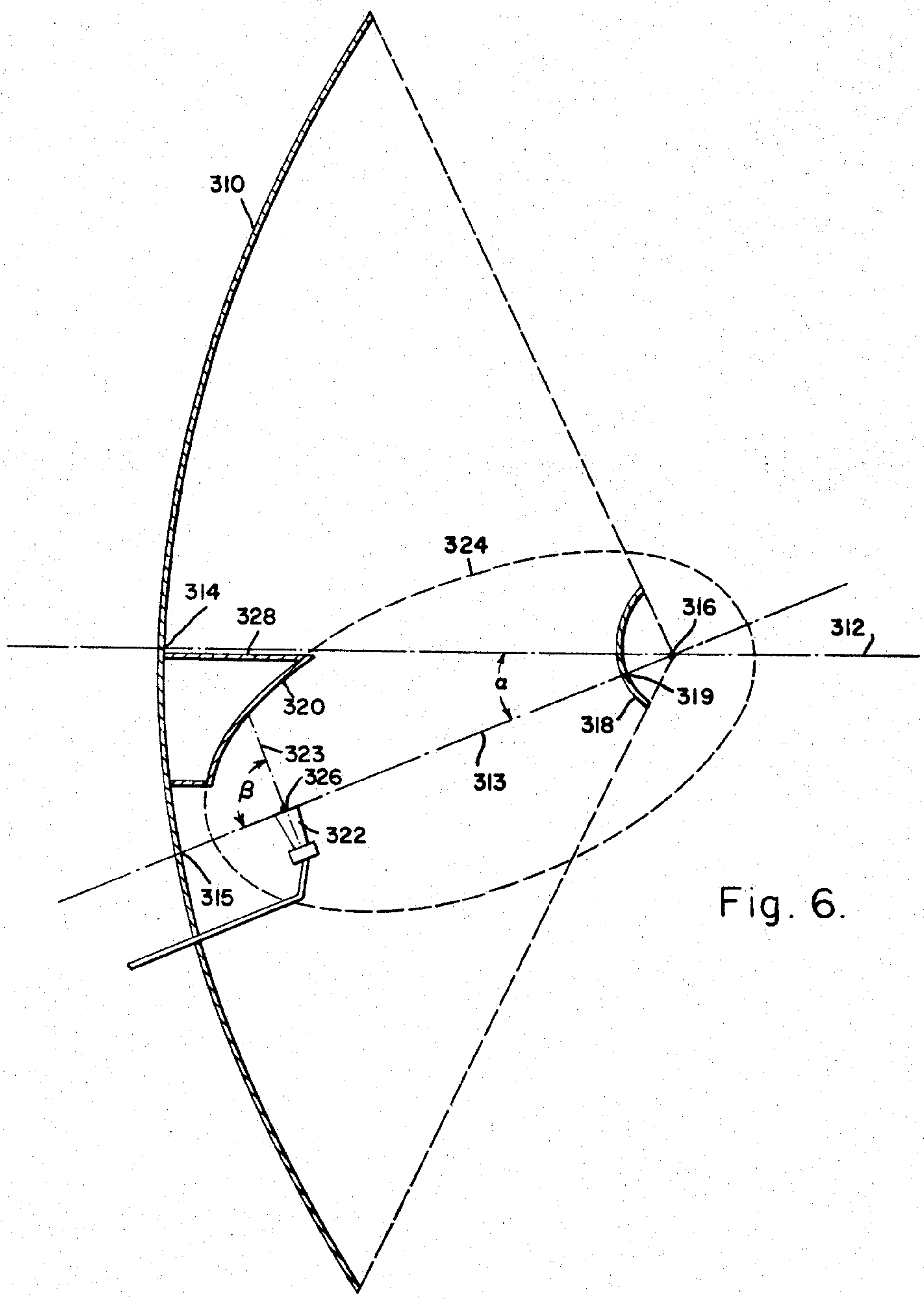

Fig. 6.

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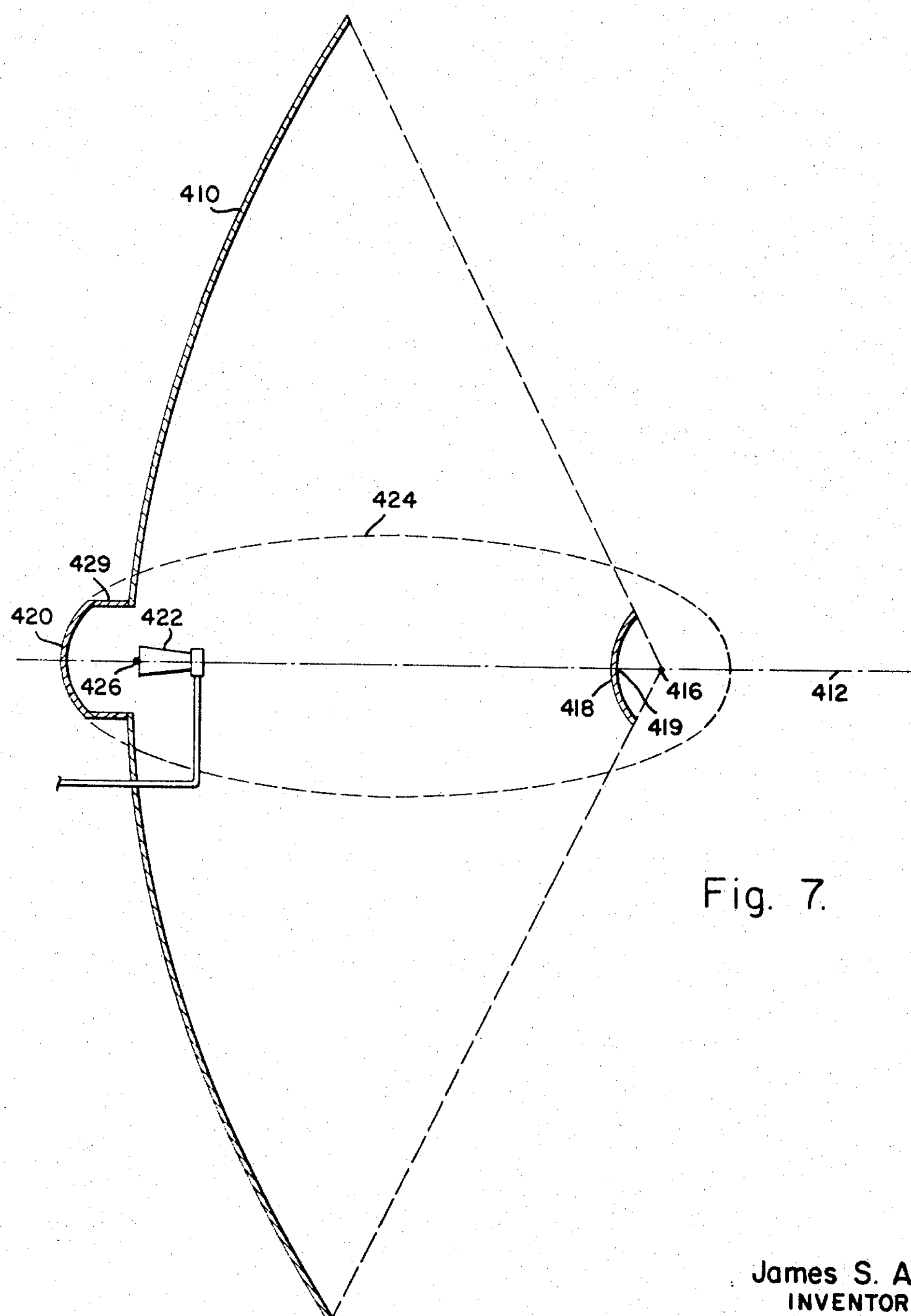

Fig. 7.

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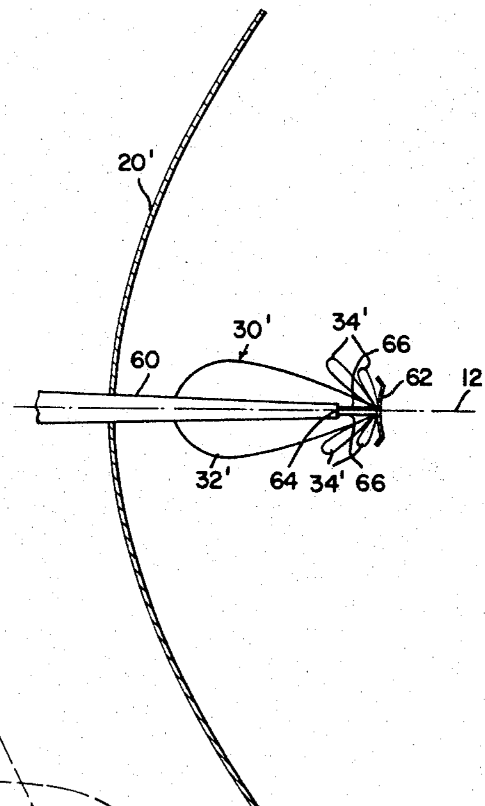

Fig. 9.

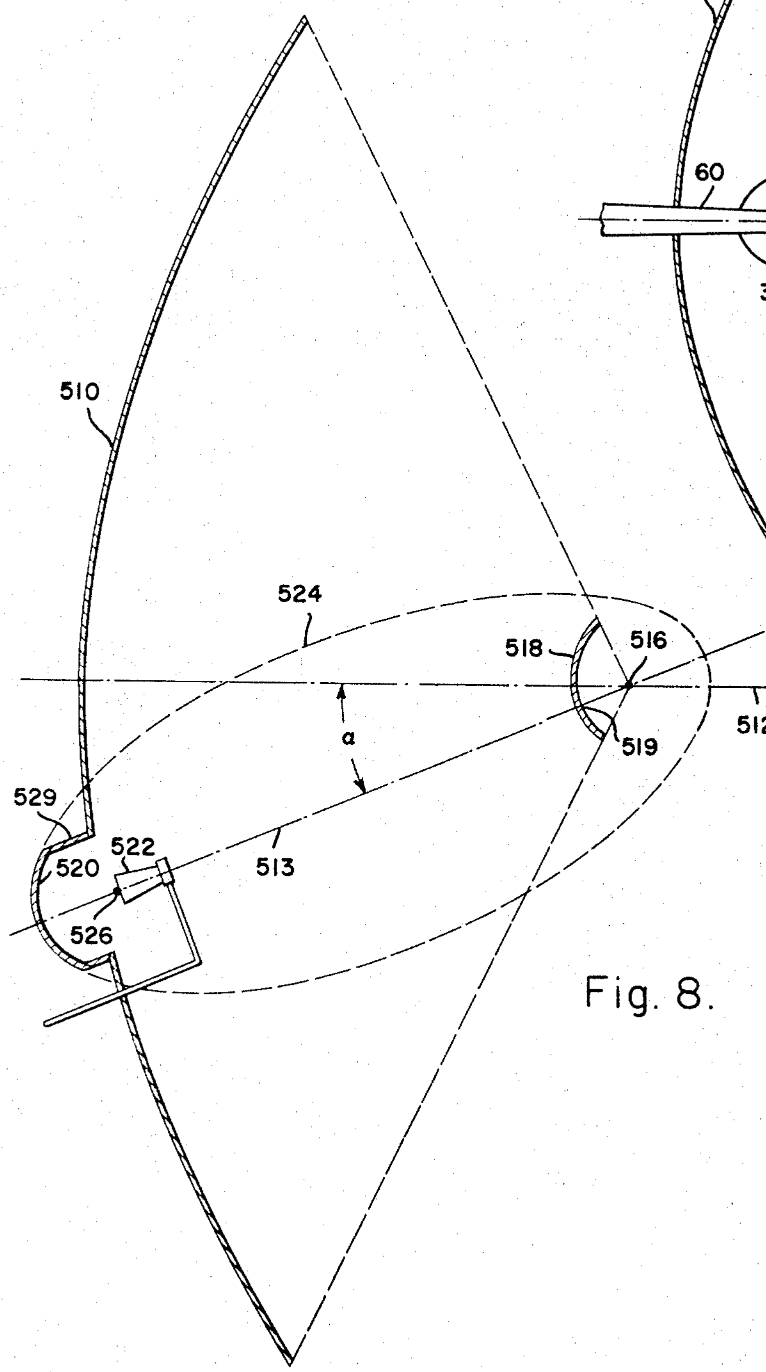

Fig. 8.

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MULTIPLE REFLECTOR ANTENNA

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18 Claims. (Cl. 343—781)

This invention relates to antennas, and more particularly relates to a multiple reflector antenna of the Cassegrain type which achieves highly efficient, low noise operation over a wide frequency range.

In order to radiate highly directional beams of electromagnetic wave energy into space, as well as to receive such beams, directional antennas have been developed in which a feed element is located at the focal point of a paraboloidal reflector. A problem encountered with such antennas is that an appreciable amount of energy, termed "spillover," is radiated or intercepted by the feed element directly without interception by the paraboloidal reflector. This spillover energy not only results in power loss and inefficient operation, but interception of a portion of the spillover energy by the earth greatly increases antenna noise.

An attempt to reduce the spillover energy by illuminating the paraboloidal reflective surface more efficiently has resulted in the application of the Cassegrain telescope principle to paraboloidal reflector antennas. In the Cassegrain antenna, a feed element located in the general region of the vertex of a paraboloidal primary reflector radiates signals to or intercepts signals from an intermediate secondary reflector smaller than the primary reflector and which is located between the vertex and the focal point of the primary reflector. The secondary reflector, which usually assumes a hyperboloidal configuration, has a focal point essentially coincident with the focal point of the primary reflector.

Although the Cassegrain design is able to substantially reduce the amount of spillover energy past the primary reflector, a problem of spillover past the secondary reflector exists. This secondary reflector spillover also results in loss of power, and for antenna beams at low elevation angles an appreciable portion of this spillover energy is intercepted by the earth, resulting in an increased noise temperature.

In addition, since the angular extent, termed "feed angle," of the main beam portion of the radiation pattern from the feed element employed in a conventional Cassegrain antenna varies inversely with the frequency of the energy being radiated or received, such an antenna can be operated with optimum efficiency over only a very narrow frequency range. For example, if the frequency of operation is reduced below the optimum frequency, the feed angle will be increased, resulting in excessive spillover. On the other hand, if the frequency of operation is increased to above the optimum value, the feed angle will be decreased, which results in inefficient illumination of the reflector surfaces. Thus, the bandwidth over which conventional Cassegrain antennas are operable is severely limited.

Accordingly, it is an object of the present invention to provide a multiple reflector antenna of the Cassegrain type which achieves high efficiency, low noise operation over a wider range of frequencies than has heretofore been afforded.

It is a further object of the present invention to provide a multiple reflector antenna of the Cassegrain type in which the amount of spillover energy is substantially less than with prior art antennas of this type.

It is a still further object of the present invention to provide an antenna the noise temperature of which is sub-

stantially less than that of prior art antennas when the antenna is aimed at low elevation angles.

It is still another object of the present invention to provide an antenna feed arrangement for illuminating the secondary reflector of a Cassegrain antenna with a feed pattern having a beamwidth which is essentially independent of frequency over at least an octave bandwidth.

In accordance with the objects set forth above, an antenna in accordance with the present invention includes a primary reflector the intersection of which with a given plane defines essentially a first parabola having a focal point in the given plane, a secondary reflector the intersection of which with the given plane defines essentially a second parabola having a focal point essentially coincident with the focal point of the first parabola, and a feed reflector the intersection of which with the given plane defines essentially a segment of an ellipse having first and second focal points. The first focal point of the ellipse is essentially coincident with the common focal points of the first and second parabolas, and a feed element oriented so as to face the feed reflector is disposed essentially at the second focal point of the ellipse.

Additional objects, advantages and characteristic features of the present invention will become readily apparent from the following detailed description of preferred embodiments of the invention when considered in conjunction with the accompanying drawings in which:

FIG. 1 is a sectional view illustrating an antenna in accordance with one embodiment of the present invention;

FIG. 2 is a sectional view illustrating the feed arrangement (feed element and feed reflector) of the antenna of FIG. 1, including radiation pattern diagrams and a feed reflector aperture distribution diagram;

FIGS. 3(*a*), (*b*) and (*c*) are diagrams illustrating respective radiation patterns from an ideal feed element, a conventional feed element, and a feed arrangement in accordance with the present invention;

FIGS. 4–8 are sectional views, similar to FIG. 1, illustrating respective antennas in accordance with further embodiments of the invention; and

FIG. 9 is a sectional view, similar to FIG. 2, showing an antenna feed arrangement in accordance with a still further embodiment of the invention.

Referring with greater particularity to FIG. 1, a multiple reflector antenna according to one embodiment of the invention may be seen to include a paraboloidal primary, or main, reflector **10** the surface of which may be generated by rotating a parabola about an axis **12**. The paraboloidal reflector **10** has a vertex at **14** and a focal point at **16**. A paraboloidal secondary, or sub, reflector **18** substantially smaller than the primary reflector **10** is spaced from the primary reflector **10** along the axis **12** and has its convex surface facing the concave surface of the reflector **10**. The secondary reflector **18**, the surface of which may be generated by rotating a parabola about the axis **12**, has a focal point essentially coincident with the focal point **16** of the primary reflector **10** and has a vertex **19** which intersects the axis **12**.

A tertiary, or feed reflector **20** is disposed between the primary reflector **10** and the secondary reflector **18** to reflect energy emitted from a feed element **22** toward the secondary reflector **18**, as well as to reflect energy from the reflector **18** toward the feed element **22**. The feed reflector **20** has the configuration of a segment of an ellipsoid **24** which, in the embodiment of FIG. 1, has its major axis coincident with the axis **12**. The ellipsoid **24** has a first focal point essentially coincident with the focal point **16** of the reflectors **10** and **18**, and has a second focal point **26** at which the feed element **22** is located. The ellipsoidal segment defining the location of the feed reflector **20** is symmetrically disposed about the major axis of the ellipsoid **24** at its end adjacent the primary reflector **10**. The feed reflector **20** may be mounted on the primary reflector **10** adjacent its vertex **14** by means of a supporting element **28**.

The feed element **22** may be a conventional source feed device, such as a pyramidal or conical horn for example, having its radiating aperture disposed in a plane through the focal point **26** and perpendicular to the axis **12**. It is pointed out, however, that various types of feed elements other than a horn feed, for example a multi-aperture or multimode monopulse tracking type feed, may be employed. Nevertheless, the feed element should be selected so as to provide a radiation pattern having well defined sidelobes of desired amplitudes and widths, for example a first sidelobe having a power level around 13 db below the maximum power level of the main beam portion of the radiation pattern and a width half that of the main beam portion.

Electromagnetic wave energy, including the sidelobes, radiated by the feed element **22** is reflected first by the feed reflector **20**, then by the secondary reflector **18**, and finally by the primary reflector **10** from which it emanates in a form of a highly directional beam traveling in the direction of the axis **12**. Conversely, electromagnetic beams received from space are reflected first by the primary reflector **10**, then by the secondary reflector **18**, and finally by the feed reflector **20** to the feed element **22**.

The manner in which the feed element **22** and the feed reflector **20** function in accordance with the principles of the present invention to considerably reduce the spillover energy from that of conventional Cassegrain type antennas, as well as to provide an electromagnetic feed pattern having a beamwidth which is essentially independent of frequency, will now be discussed with reference to FIG. 2. As is shown in FIG. 2 the feed element **22** provides a radiation pattern (radiation intensity as a function of angular direction from the point of emission) designated generally by the numeral **30**. The radiation pattern **30** has a main beam portion **32** and sidelobes **34** which are larger in relation to the main beam portion than would normally be provided by a feed element for a Cassegrain antenna arrangement. The electromagnetic radiation emitted by the element **22** travels in a manner indicated by lines **35** to the surface of the ellipsoidal feed reflector **20**, from which it is reflected in a manner indicated by lines **36** to provide a desired reflector aperture distribution (the electric field intensity in a plane through the perimeter of the feed reflector **20** perpendicular to the axis **12**). This aperture distribution may be approximated mathematically by

$$\frac{J_1(ur)}{ur}$$

where $J_1(ur)$ is a Bessel function, u is a factor proportional to frequency, and r represents radial distance from the axis **12** in the aperture distribution plane. The projection of such an aperture distribution in a plane through the axis **12** is indicated by curve **37** of FIG. 2, the aperture distribution having a width W which is defined as the cross-sectional dimension of that portion of the radiation emanating from the reflector **20** due to the main beam portion **32** of the radiation pattern **30**. It is pointed out that for a feed reflector having a rectangular aperture instead of a circular aperture the resultant aperture distribution would be approximated mathematically by

$$\frac{\sin ux}{ux}$$

where u is a factor proportional to frequency, and x represents distance from the axis **12** along a line parallel to a side of the rectangular aperture.

As has been mentioned above, the feed angle (designated θ_0 in FIG. 2) of the main beam portion **32** of the radiation pattern from the feed element **22** varies inversely with the frequency of the energy emanating from the element **22**, and thus a conventional Cassegrain antenna which uses such a feed element to directly illuminate the secondary reflector can be operated with optimum efficiency over only a very narrow frequency range. With the arrangement of the present invention, the feed angle θ_0 of the main beam portion **32** of the radiation pattern from the feed element **22** will likewise vary inversely with frequency, causing the aperture distribution width W to vary inversely with frequency in terms of absolute dimension. However, since the wavelength of the emitted radiation is also a inverse function of frequency, the width W of the aperture distribution **37** is constant in terms of wavelength. The resultant radiation pattern **40** from the feed reflector **20** (radiation intensity as a function of angular direction from the vertex of the feed reflector **20**) is thus independent of frequency, enabling the antenna of the present invention to be operated with optimum efficiency over a considerable frequency range. The radiation pattern **40** may be seen to possess an essentially sector shaped main beam portion **42** which is capable of more uniformly illuminating the secondary reflector **18** than would a radiation pattern main beam portion such as **32**. The radiation pattern **40** may also be seen to possess sidelobe energy **44** which is substantially smaller in relation to the main beam energy **42** than the sidelobe energy **34** is relative to the main beam portion **32** of the radiation pattern **30**.

The improvement which the present invention achieves in providing a more ideal feed radiation pattern may be better appreciated by making reference to FIG. 3 wherein the radiation intensity I is shown as a function of angular direction θ for an ideal feed element, a conventional feed element, and a feed element and reflector arrangement in accordance with the present invention. An ideal feed radiation pattern, illustrated by the curve **50** of FIG. 3(*a*), may be seen to have an essentially constant radiation intensity within a desired feed angle θ_1 and no radiation outside of the angle θ_1. A feed radiation pattern used to illuminate the secondary reflector of a conventional Cassegrain antenna is illustrated by the curve **52** of FIG. 3(*b*) wherein the energy radiated outside of the feed angle θ_1, i.e., the spillover energy, is designated by cross-hatching. The radiation pattern provided by feed element **22** and feed reflector **20** of the antenna of the present invention is shown by the curve **54** of FIG. 3(*c*), the spillover energy again being designated by cross-hatching. It may be seen that the feed radiation pattern **54** produced in accordance with the present invention more closely resembles the ideal feed pattern **50** than does the conventional feed pattern **52**, not only in providing a more constant radiation intensity within the feed angle θ_1, but also in considerably reducing the spillover energy outside of the feed angle θ_1.

In accordance with a further embodiment of the present invention, illustrated in FIG. 4, an offset Cassegrain antenna arrangement may be provided. The embodiment shown in FIG. 4 is similar to that illustrated in FIG. 1, and elements in the embodiment of FIG. 4 which correspond with elements in the embodiment of FIG. 1 are designated by the same reference numerals as their counterpart elements except for the addition of the prefix numeral "1." In the embodiment of FIG. 4, however, the major axis **113** of ellipsoid **124** is not coincident with axis **112**, but rather is disposed at a predetermined angle α with respect to the axis **112** so that the axis **113** intersects the primary reflector **110** at a point **115** below the primary reflector vertex **114**. Feed reflector **120** is mounted on the primary reflector **110** adjacent the intersection point **115**. Also, vertex **119** of the secondary reflector **118** is located along the ellipsoid axis **113** rather than along the axis **112** which intersects the primary reflector vertex **114**. The embodiment of FIG. 4 is particularly useful when it is desired to provide beams at low elevation angles because its design minimizes the amount of secondary reflector spillover energy which intercepts the ground, thereby reducing the antenna noise temperature.

In accordance with a still further embodiment of the present invention, illustrated in FIG. 5, an antenna arrangement having an offset feed reflector may be provided. The embodiment of FIG. 5 is also similar to that of FIG. 1 and includes elements which, on account of their similarity with elements in the embodiment of FIG. 1, are designated by the same reference numerals as their counterpart elements except for the addition of the prefix numeral "2." In the embodiment of FIG. 5 ellipsoid **224** assumes the same location as the ellipsoid **24** of FIG. 1. However, the portion of the ellipsoid **224** defining the location of feed reflector **220** is offset, i.e. is unsymmetrically disposed relative to the axis **212**. Also, the feed element **222** is angularly disposed so that a line **223** perpendicular to the radiating aperture of the element **222** which intersects the center of the feed reflector **220** is disposed at an angle β with respect to the axis **212**.

Features of the embodiments of FIGS. 4 and 5 may be combined to produce a still further embodiment, illustrated in FIG. 6, which employs both an offset Cassegrain arrangement and an offset feed reflector. Since the embodiment of FIG. 6 is similar to the embodiments of FIGS. 4 and 5, elements in the embodiment of FIG. 6 which correspond with elements in the embodiments of FIGS. 4 and 5 are designated by the same second and third reference numeral digits as their counterpart elements; however, in the embodiment of FIG. 6 the numeral "3" is used as the first reference numeral digit rather than the numeral "1" or "2." It should be noted that in an offset feed reflector arrangement the feed reflector need not intersect the major axis of the ellipsoid, and thus in the embodiment of FIG. 6 feed reflector **320** is located entirely on one side of the ellipsoid axis **313**. Moreover, in the embodiment of FIG. 6 the angle β between the ellipsoid axis **313** and line **323** perpendicular to the radiating aperture of the feed element **322** which intersects the center of the feed reflector **320** is made essentially equal to 90°.

In each of the foregoing embodiments the feed reflector has been shown as located in front of the primary reflector, i.e. between the primary reflector and the secondary reflector. However, the principles of the present invention are also applicable to antennas in which the feed reflector is located behind the primary reflector, for example by mounting the feed reflector in a recess in the surface of the primary reflector. Such a recessed antenna arrangement is illustrated in FIG. 7. The embodiment shown in FIG. 7 is similar to that illustrated in FIG. 1, and hence elements in the embodiment of FIG. 7 which correspond with elements in the embodiment of FIG. 1 are designated by the same reference numerals as their counterpart elements in the embodiment of FIG. 1 except for the addition of the prefix numeral "4." In the embodiment of FIG. 7 the feed reflector is mounted in a recessed portion **429** of the surface of the primary reflector **410**. It is pointed out, however, that the feed reflector may also be located so that its vertex is flush with the surface of the primary reflector.

The recessed feed reflector arrangement illustrated in FIG. 7 may be utilized in combination with any of the other variations discussed above. An example of an antenna arrangement combining the recessed feed reflector feature of FIG. 7 with the offset Cassegrain feature of FIG. 4 is illustrated in FIG. 8 wherein elements are designated by the same second and third reference numeral digits as their counterpart elements in FIGS. 4 and 7, except that the numeral "5" is used as the first reference numeral digit rather than the numerals "1" or "4."

In accordance with still another embodiment of the present invention, illustrated in FIG. 9, the feed arrangement may employ a rearwardly oriented feed element rather than a forwardly oriented feed element with respect to the feed reflector. Since features of the embodiment of FIG. 9 are readily illustratable by a drawing similar to FIG. 2, components of the feed arrangement of FIG. 9 and portions of the radiation pattern from the feed element thereof which have counterparts in FIG. 2 are designated by the same reference numerals as such counterparts except for the addition of a prime designation. In the embodiment of FIG. 9 the feed arrangement includes a waveguide portion **60** extending along major axis **12'** of the ellipsoid defining the location of feed reflector **20'** and a reflector portion **62** facing the feed reflector **20'**. The reflector portion **62** also faces end aperture **64** of the waveguide portion **60** and is spaced therefrom along the axis **12'**. The reflector portion **62** may be attached to the waveguide portion **60** by means of rods **66**, for example.

It is pointed out that while the specific embodiments of the present invention heretofore described employ primary and secondary reflectors having circular symmetry in planes perpendicular to the axis intersecting the vertex and the focal point of the primary reflector, the invention encompasses certain other antenna geometries which do not have such circular symmetry. For example, the principles of the invention could be utilized in constructing an antenna in which the primary and secondary reflectors have the configuration of parabolic cylindrical segments, i.e., segments the intersections of which with a plane (such as the plane of the paper) perpendicular to the segment surfaces define parabolas (such as indicated at **10** and **18** in FIG. 1), having a common focal line (such as a line perpendicular to the plane of the paper and intersecting it at **16**). The feed reflector in such an antenna arrangement could have the configuration of a segment of a cylindrical elliptical surface, i.e. a surface the intersection of which with a plane (such as the plane of the paper) perpendicular to the surface defines an ellipse (such as indicated at **24** in FIG. 1), having a pair of focal lines perpendicular to the plane of the ellipse and intersecting it at the focal points of the ellipse (such as at **16** and **26**). The common focal line of the parabolic cylindrical segments would be essentially coincident with one of the focal lines of the cylindrical elliptical segment, and the feed element would be located along the other focal line of the cylindrical elliptical segment. Such a cylindrical segment reflector could, of course, assume a "pillbox," or "cheese," configuration by making the parabolic cylindrical segments of a height much smaller than the minimum segment-to-focal line distance and by providing enclosing plates at the ends of the parabolic cylindrical segments in planes perpendicular to the cylindrical segments.

Thus, although the invention has been shown and described with reference to particular embodiments, nevertheless various changes and modifications which are obvious to a person skilled in the art to which the invention pertains are deemed to lie within the spirit and scope of the invention as set forth in the appended claims.

What is claimed is:

1. An antenna comprising: a primary reflector the intersection of which with a given plane defines essentially a first parabola having a focal point in said plane, a secondary reflector the intersection of which with said plane defines essentially a second parabola having a focal point essentially coincident with the focal point of said first parabola, a feed reflector the intersection of which with said plane defines essentially a segment of an ellipse having first and second focal points, said first focal point being essentially coincident with the common focal points of said first and said second parabolas, and a feed element disposed essentially at said second focal point and facing said feed reflector.

2. An antenna comprising: a first reflector the intersection of which with a given plane defines essentially a first parabola having a focal point in said plane, a second reflector substantially smaller than said first reflector and having a convexly curved surface facing said first reflector, the intersection of said second reflector with said plane defining essentially a second parabola having a focal point essentially coincident with the focal point of said first parabola, a third reflector substantially smaller than said first reflector and having a concavely curved surface facing said second reflector, the intersection of said third reflector with said plane defining essentially a segment of an ellipse having first and second focal points, said segment being located nearer to said second focal point than to said first focal point, said first focal point being essentially coincident with the common focal points of said first and said second parabolas, and a feed element disposed essentially at said second focal point and facing said third reflector.

3. An antenna according to claim **2** wherein said third reflector is disposed between said first and said second reflectors.

4. An antenna according to claim **2** wherein said third reflector is mounted in a recessed portion of the surface of said first reflector.

5. An antenna according to claim **2** wherein an axis of said ellipse through said first and second focal points intersects said first parabola essentially at its vertex.

6. An antenna according to claim **2** wherein an axis of said ellipse through said first and second focal points intersects said first parabola at a point other than at its vertex.

7. An antenna according to claim **2** wherein said segment is symmetrically disposed about an axis of said ellipse through said first and second focal points.

8. An antenna according to claim **2** wherein said segment is unsymmetrically disposed relative to an axis of said ellipse through said first and second focal points.

9. An antenna according to claim **5** wherein said segment is symmetrically disposed about said axis.

10. An antenna according to claim **6** wherein said segment is symmetrically disposed about said axis.

11. An antenna according to claim **9** wherein said third reflector is disposed between said first and said second reflectors.

12. An antenna according to claim **9** wherein said third reflector is mounted in a recessed portion of the surface of said first reflector.

13. An antenna according to claim **5** wherein said segment is unsymmetrically disposed relative to said axis.

14. An antenna according to claim **6** wherein said segment is unsymmetrically disposed relative to said axis.

15. An antenna according to claim **2** wherein said feed element is a horn feed element having an aperture disposed in a plane through said second focal point perpendicular to said given plane, with a line in said given plane perpendicular to the plane of said aperture intersecting said segment at a point along the central portion thereof.

16. An antenna according to claim **2** wherein said feed element includes a reflector portion facing said third reflector and a waveguide portion having an aperture spaced from and facing said reflector portion.

17. An antenna comprising: an essentially paraboloidal primary reflector having a focal point, an essentially paraboloidal secondary reflector having a focal point essentially coincident with the focal point of said primary reflector, a feed reflector having essentially the configuration of a segment of an ellipsoid having first and second focal points, said first focal point being essentially coincident with the common focal points of said primary and said secondary reflectors, and a feed element disposed essentially at said second focal point and facing said feed reflector.

18. An antenna comprising: a first reflector of an essentially paraboloidal configuration having a focal point, a second reflector of an essentially paraboloidal configuration substantially smaller than said first reflector, said second reflector having a focal point essentially coincident with the focal point of said first reflector and being disposed with its convex surface facing said first reflector, a third reflector substantially smaller than said first reflector and having a concavely curved surface facing said second reflector, said third reflector having essentially the configuration of a segment of an ellipsoid having first and second focal points, said segment being located nearer to said second focal point than to said first focal point, said first focal point being essentially coincident with the common focal points of said first and said second reflectors, and a feed element disposed essentially at said second focal point and facing said third reflector.

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ELI LIEBERMAN, *Primary Examiner*.