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Lyons

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[54] **CASSEGRAIN ANTENNA MOUNTED IN AIRCRAFT NOSE CONE**

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[73] Assignee: **Hawker Siddeley Aviation Limited,** Surrey, England

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[21] Appl. No.: **114,320**

[30] **Foreign Application Priority Data**

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[52] **U.S. Cl.** **343/708,** 343/756, 343/781, 343/837

[51] **Int. Cl.** **H01q 19/14**

[58] **Field of Search**...............343/756, 781, 837, 708

[56] **References Cited**

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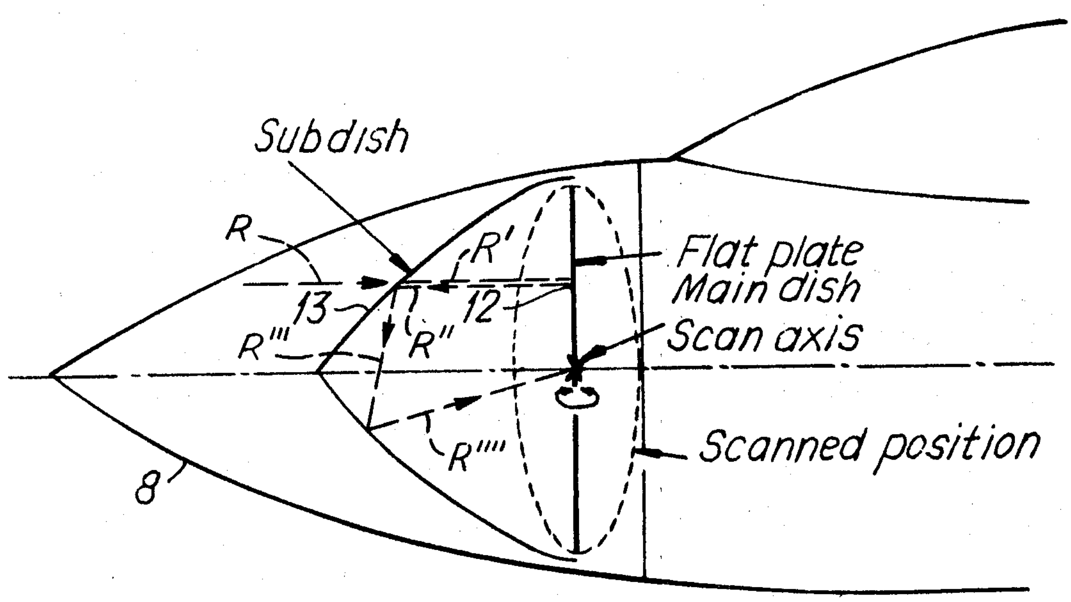
[57] **ABSTRACT**

A forward-facing aircraft antenna of modified Cassegrain configuration, having a flat plate main dish and a sub-dish which has a reflecting surface chosen from among surfaces of revolution that require two or more reflections to bring a wave parallel to the axis of revolution to a substantial point focus.

9 Claims, 10 Drawing Figures



PRIOR ART

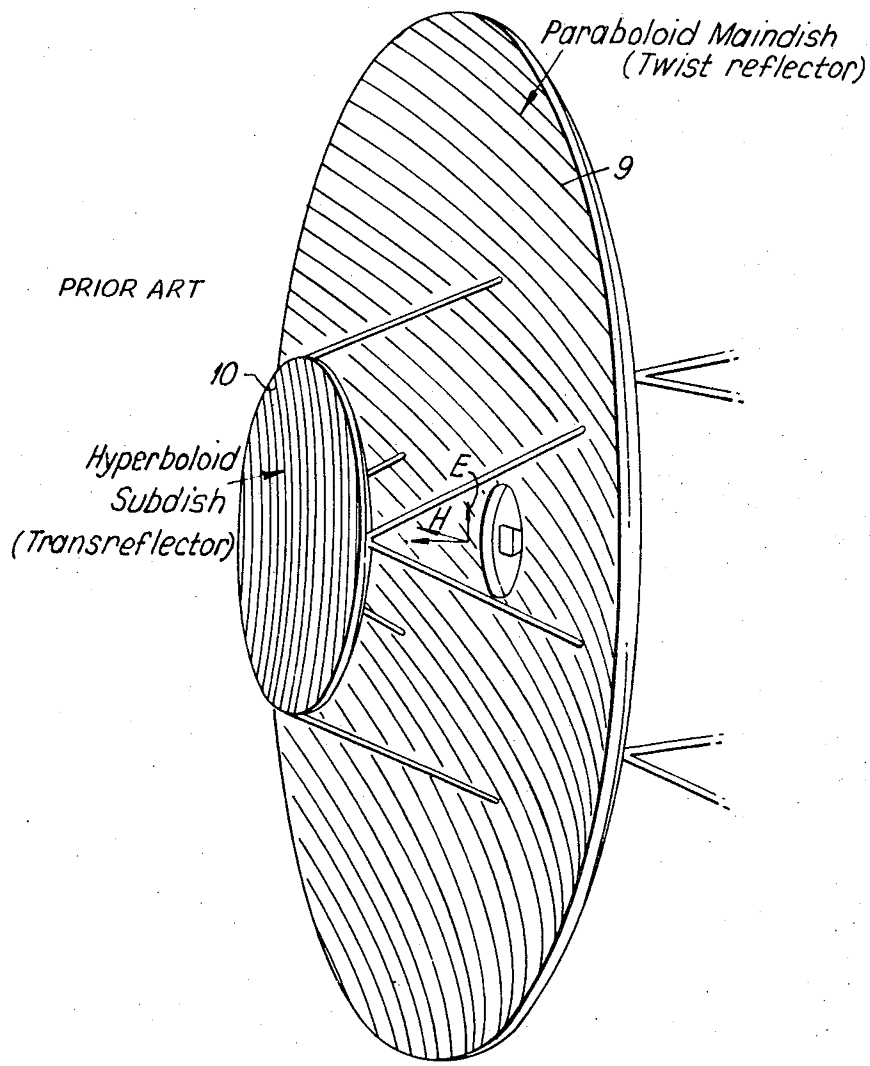


Fig.1.

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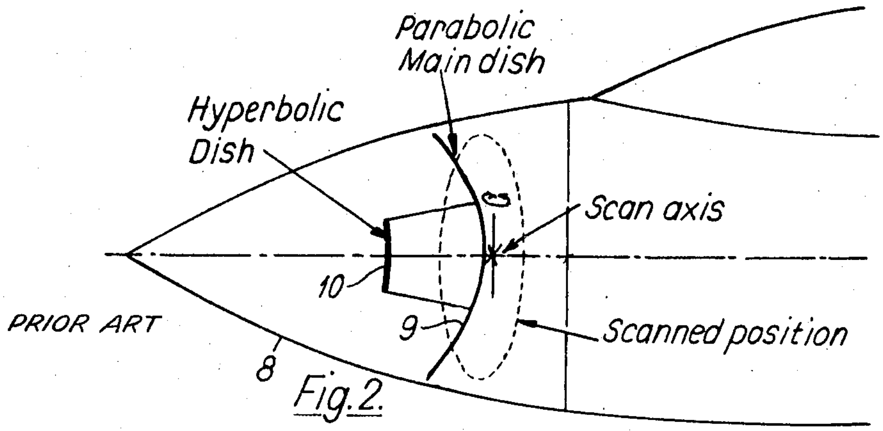

Fig.2.

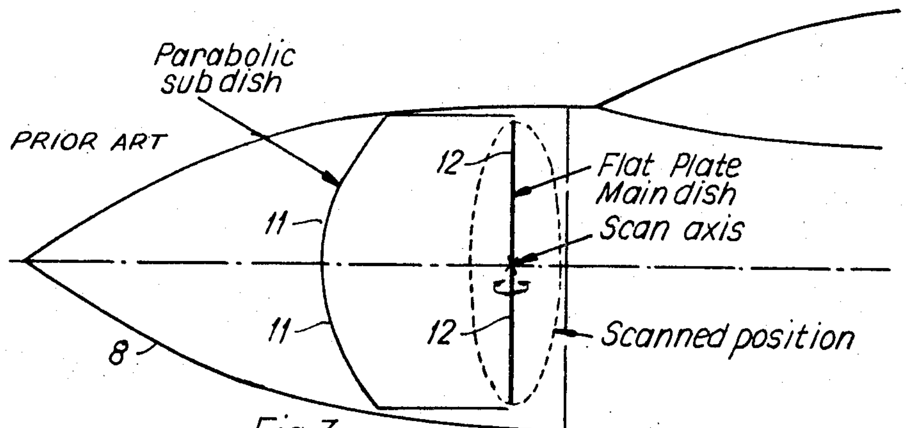

Fig.3.

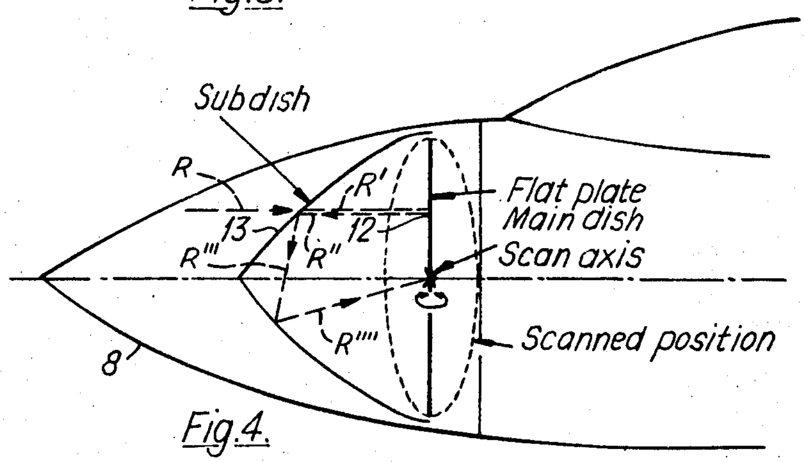

Fig.4.

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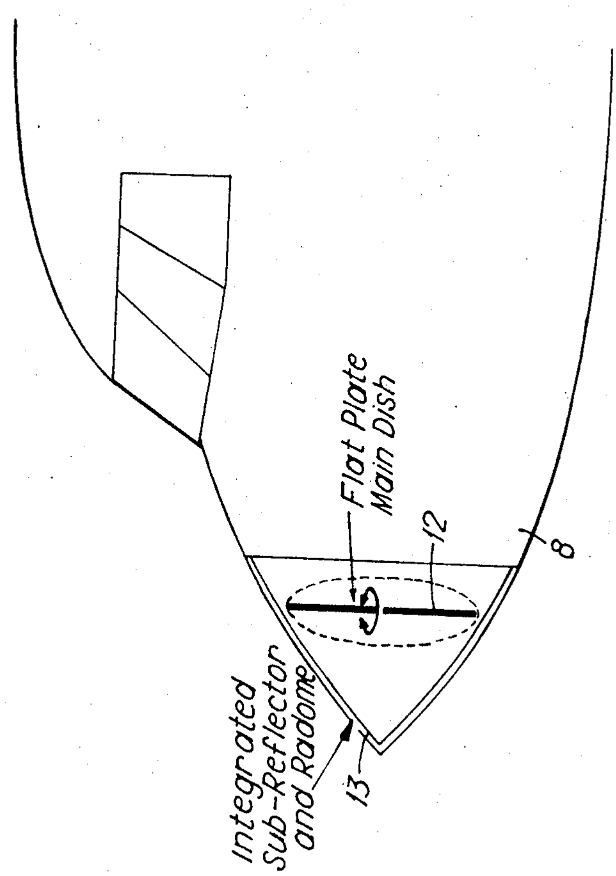
Fig. 5



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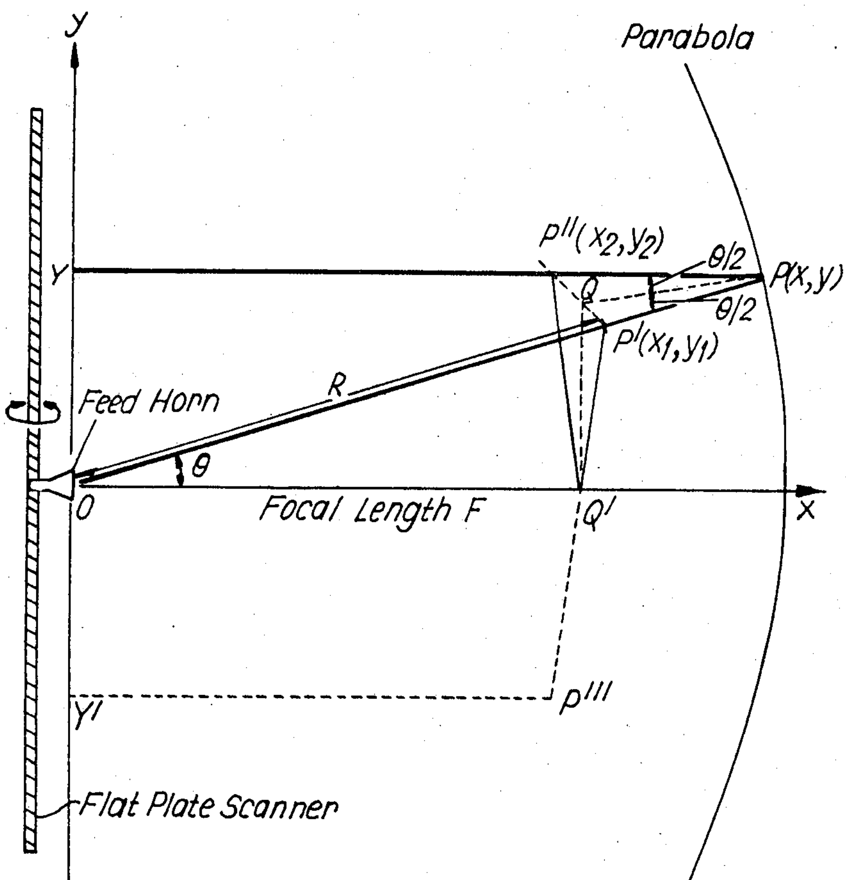

Path of ray for 1 reflection - OPY
Path of ray for 2 reflections - $OP^{I}OP^{III}Y^{I}$
The required curve is the locus of P^{I} and P^{III}

Fig. 6.

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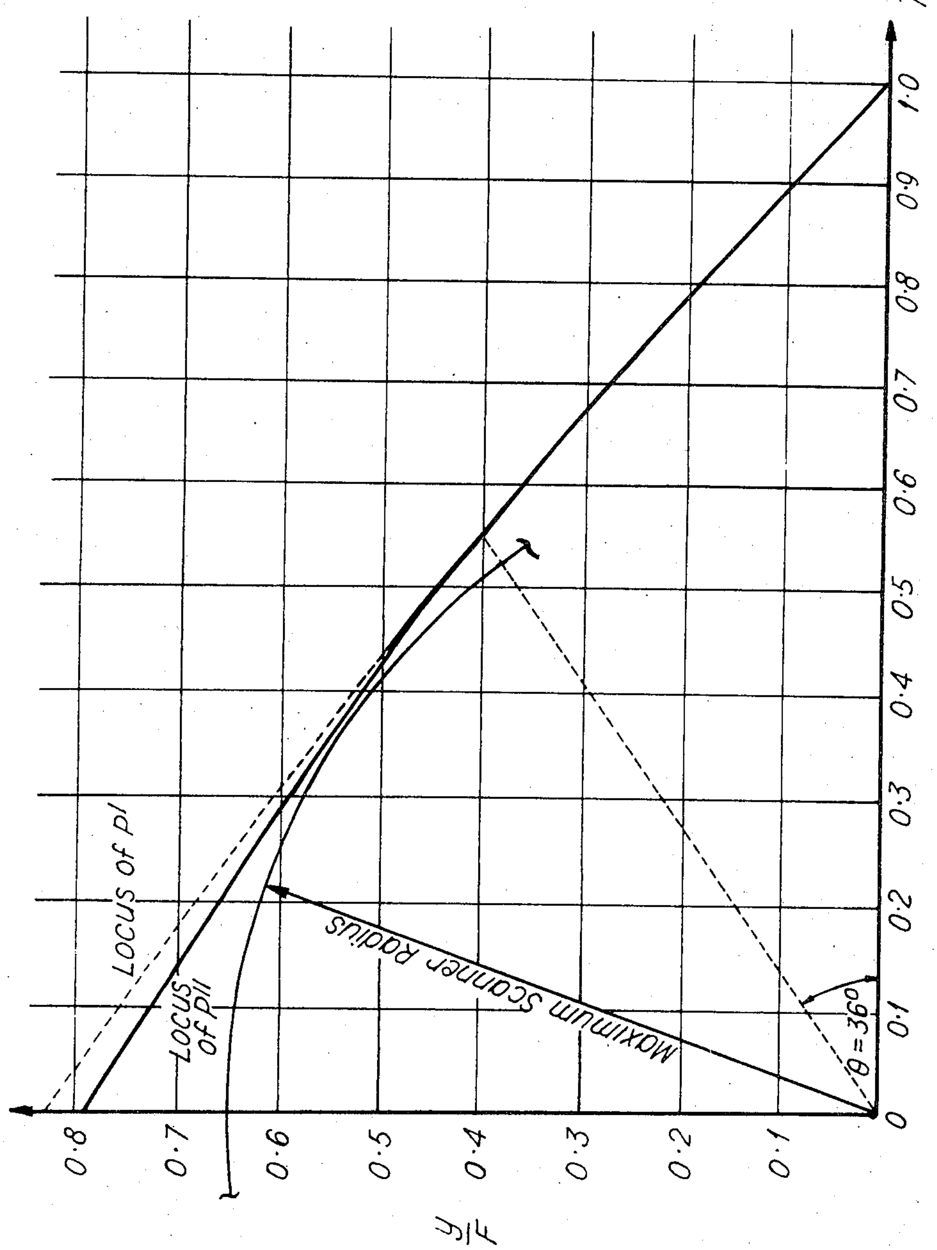
Fig. 7



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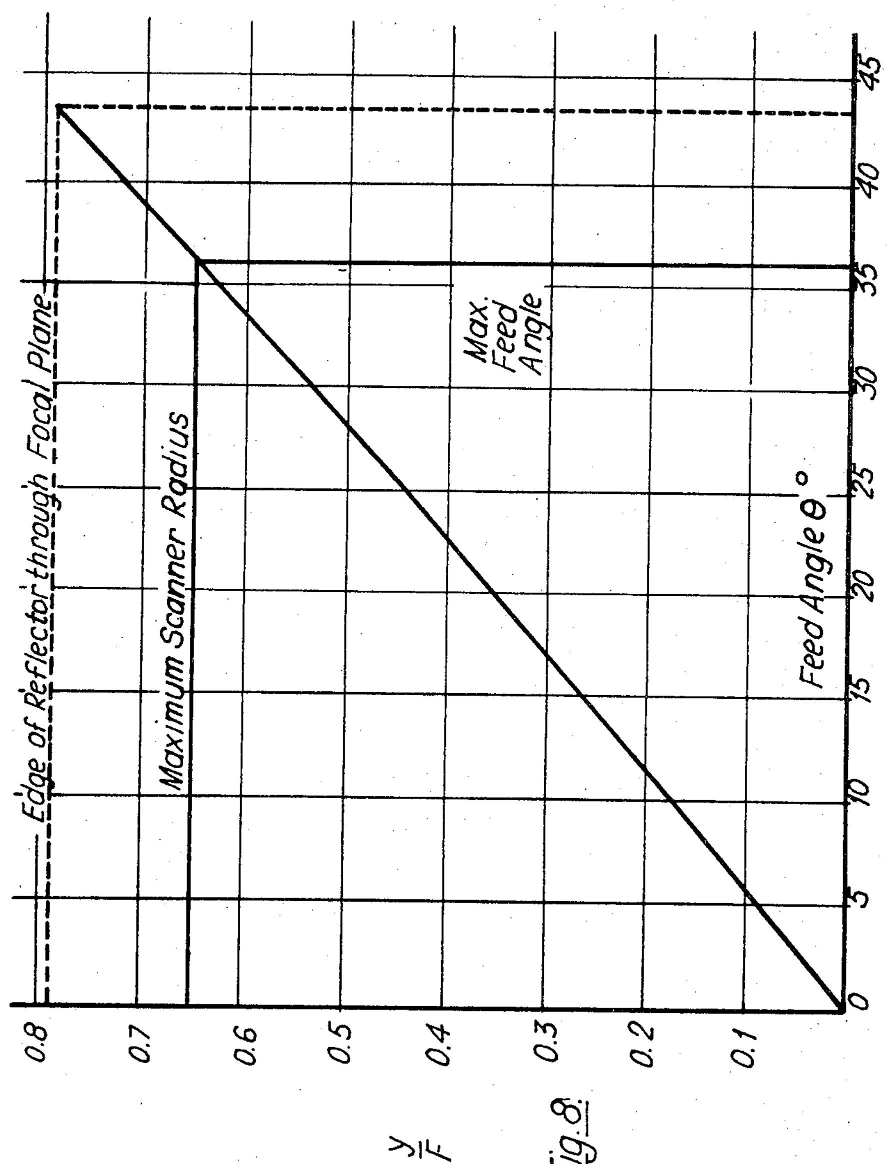

Fig.8.

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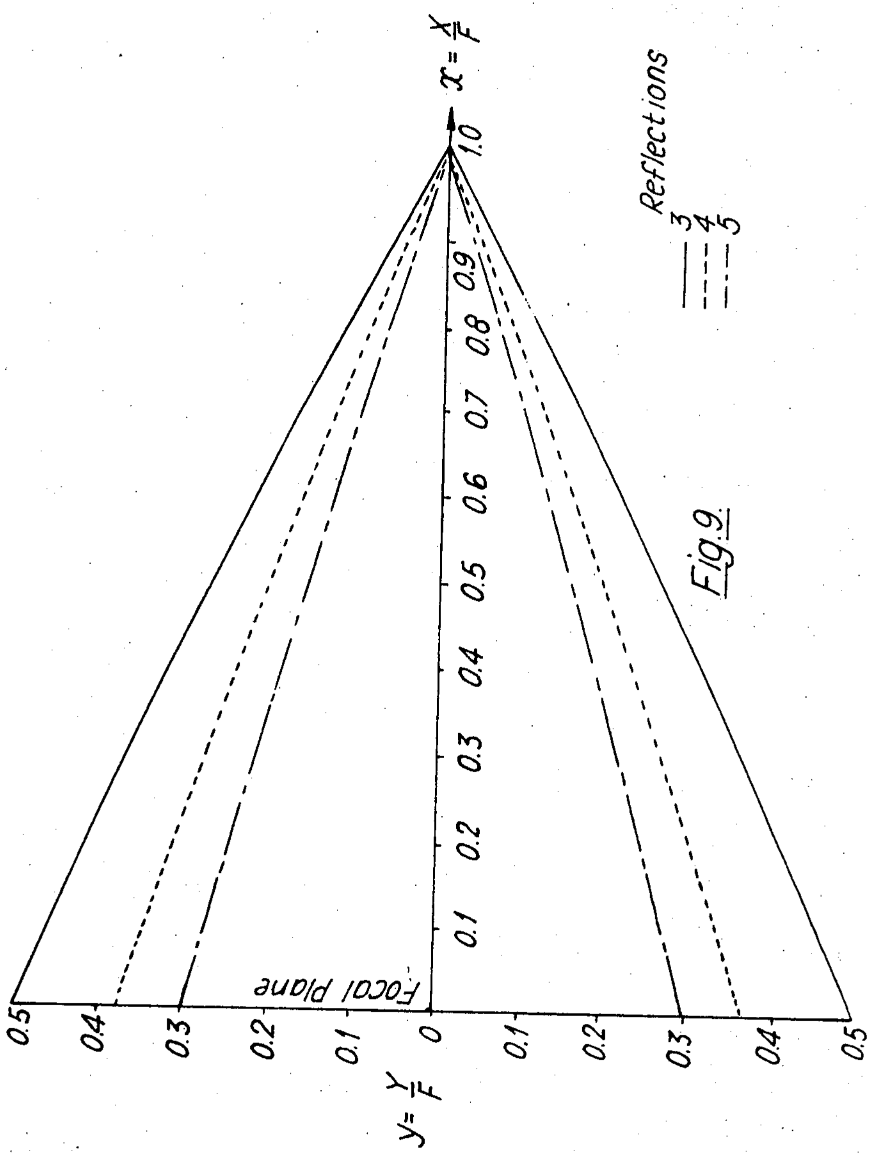

Fig.9

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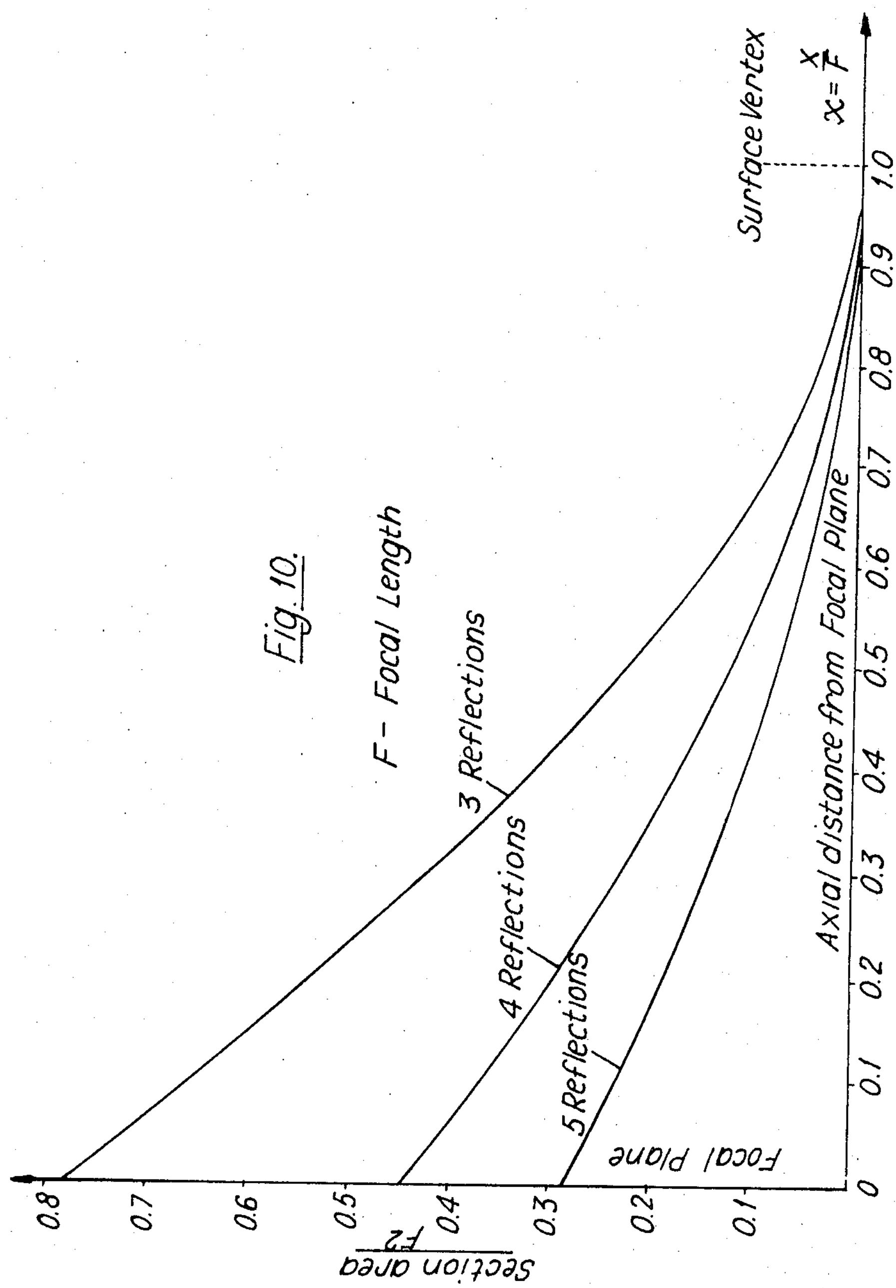

Fig. 10.

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CASSEGRAIN ANTENNA MOUNTED IN AIRCRAFT NOSE CONE

The present invention relates to aircraft antennas, more particularly forward-looking antennas.

The forward-looking antennas used in strike and interceptor aircraft over recent years have usually employed a Cassegrain configuration having a parabolic main dish and hyperbolic sub-dish, the whole unit being mechanically scanned. In some installations, polarization sensitive reflecting surfaces have been used in order to reduce the aperture blocking effect of the sub-dish to a minimum. Details of such a Cassegrain antenna can be found in the paper by P.W. Hannan: 'Microwave Antennas derived from Cassegrain Telescope,' I.R.E. Trans. A.P., March '61.

Although reasonably good performance is attainable, the arrangement has certain disadvantages. Because of the need to position the scan axis behind the main dish, the swept volume required by the antenna is such that the permissible dish diameter is a good deal less than the radome cross section thus resulting in a valuable loss of aperture area. Also the need to scan the antenna through large azimuth angles (possibly up to ± 60° in a search phase) requires that the radome be extended rearwards some distance behind the scanner pivot point thus increasing both the radome surface area and the shell strength requirements. As the antenna feeds are fixed relative to the scanning surfaces, rotating waveguide joints are necessary. When multi-channel and possibly multi-frequency feeds are employed the joints pose installational and mechanical problems and also introduce undesirable attenuation losses.

Ideally, one would like a fixed feed antenna with a simple low inertia main dish that is easily and quickly scanned. A parabolic sub-dish may be employed, the main dish being a simple flat plate. As the main dish acts essentially as a plane mirror, it only needs to be scanned through half the angle required to scan the radar beam. Although such an arrangement is attractive from both electrical and mechanical considerations, from the installational aspect it has a disadvantage, namely the large sub-dish. An antenna of this type, for a given aperture area, demands a larger radome than the conventional Cassegrain layout. This makes the arrangement extremely unattractive as far as aircraft design is concerned.

If, however, the sub-dish is made a more reasonable shape then the antenna will fit into a smaller radome and, at the same time, the use of a flat main dish will ensure that the radome diameter is fully utilized and swept volume requirements are minimized. The present parabolic sub-dish is, by definition, a surface which focusses in a single reflection a wave parallel to its axis to a point (the focus).

According to the present invention, we employ a surface which requires a plurality of reflections to achieve the necessary focussing, whereby the resulting surface of revolution possesses a shape more amenable to aircraft installation. For instance, a two-reflection surface exists, at least in an approximate form sufficiently accurate for practical purposes, and its derivation is hereinafter discussed.

Arrangements in accordance with the invention will now be described by way of example and with reference to the accompanying drawings, in which:

FIG. 1 is a pictorial view of a Cassegrain antenna,

FIG. 2 is a diagram of the antenna of FIG. 1 installed in an aircraft,

FIG. 3 is a similar diagram of a flat plate Cassegrain antenna,

FIG. 4 is a similar diagram showing a modified flat plate Cassegrain antenna according to the invention,

FIG. 5 is a diagram of such an antenna installed as an integrated structure in a large aircraft,

FIG. 6 illustrates the geometry of the device,

FIGS. 7, 8 and 9 are plots of various mathematical equations involved, and

FIG. 10 is a plot of the surfaces developed.

Referring to the drawings, FIG. 1 shows a prior art Cassegrain antenna with a paraboloid main dish **9** and a hyperboloid sub-dish **10**. FIG. 2 shows how such an antenna may be installed in the nose of an aircraft **8**.

In FIG. 3 a flat plate Cassegrain antenna is shown similarly installed. This has a parabolic sub-dish **11** and a main dish **12** in the form of a simple flat plate. Polarization sensitive reflecting surfaces are employed.

Coming now to the modified flat plate Cassegrain antenna according to the invention, a scheme employing the two-reflection case is shown in FIG. 4. As will be seen, the general shape of the two-reflection surface **13** resembles that of typical nose radomes. However, for high speed aircraft, the included angle at the vertex of the surface, 90°, is too large for this surface to be used as an external radome. For larger, slower aircraft, the shape is almost ideal when faired into the aircraft fuselage lines, as shown in FIG. 5. Thus in applications of this type, the antenna sub-dish **13** also becomes the external aircraft radome. As we have now eliminated one dielectric surface in front of the antenna, the losses and phase errors associated with such a surface have also been eliminated and therefore improvements in antenna performance can be expected.

To illustrate more clearly the operation of the embodiment of FIG. 4, the path of a typical ray is shown at R. This ray path has a section R′ parallel to the fore-and-aft axis of the system and striking the flat plate main dish **12**, whence it is reflected back along a parallel path R″ to strike the sub-dish **13**. The ray is then reflected across the bowl of the sub-dish **13** along a path R‴ to strike it again on the opposite side of the fore-and-aft axis, where there is a second reflection from the sub-dish directing the ray along path R⁗ to the feed horn substantially at the center of the flat plate main dish **12**.

DERIVATION OF REFLECTION SURFACE FOR THE TWO-REFLECTION CASE

Consider the geometry of FIG. 6. The focus and hence the feed point is at O. Radiation from this point strikes a surface at P and is reflected parallel to the X axis to form a plane wavefront at the ordinate, Y. The locus of P, which is a parabola, is given by the equation:

$$Y = y_2 = 2F \tan \theta/2 \qquad (1)$$

where F is the focal length.

If we now fold the triangle OPY about line P′P″ such that QQ′ is parallel to the y-axis, then on unfolding the trapezoid OYP″ Q′ about the x-axis we can generate a surface which focusses radiation parallel to the x-axis, after two reflections, to a point θ. To find the equation of the surface, we need to derive expressions for the loci of P′ and P″. These should be identical if the required surface exits.

We derive first the locus of P′. From FIG. 6 we have the following relationships

$$y_1 = Y - PP' \sin\theta$$

$$y_1 = P'Q' \cos\theta/2 = P'P \cos\theta/2$$

$$y_1 = R \sin\theta$$

which give us in conjunction with equation (1)

$$R = 2F/[(1+\cos\theta)(1+2\sin\theta/2)] \quad (2)$$

The locus of P″ is more conveniently derived in x, y coordinates. We have the relationships

$$x_2 = x - PP''$$

$$y_2 = P''Q' \cos\theta/2 = P''P \cos\theta/2$$

Making use of the fact that the locus of P is a parabola, we have in addition

$$x/F = 1 - (y_2/2F)^2$$

From the above relationships and using equation (1) we arrive at

$$x_2/F = (1 - (y_2/2F)^2) - (y_2/F)\ \sqrt{1 + (y_2/2F)^2} \quad (3)$$

Equations 2 and 3 are plotted in normalized form in FIG. 7. It is seen that over the forward portion of the surface, the loci of P', P'' are identical. As x/F is reduced, however, the two curves diverge, showing that P' and P'' do not share a common loci for all values of θ. This is no disadvantage as far as the present application to antennas is concerned as will now be shown.

Equation (1) describes the relationship between the angular spread of the feed, θ, and the normalized aperture spread function y/F. As such this equation may be used to design a feed horn which will give a specified power distribution across the aperture. From FIG. 7, we see the maximum permissible normalized radius of a flat plate scanner pivoted at the feed point is about 0.65. From FIG. 8 which is a plot of equation (1), it is seen that this corresponds to a feed angle of 36° which is nearly the point at which the two loci curves diverge. Thus, if we define our required surface by equation (3) (locus of P″), then for feed angles less than 36° the required two-reflection, common locus curve exists.

By differentiating equation (3) and finding the slope of the curve at $x/F = 1$, it is readily shown that the included angle at the surface vertex is 90°.

To confirm the principle of the present invention two preliminary schemes were drawn. The first consisted of a retrofit installation of the proposed antenna in an already existing transonic strike aircraft and the second was an installation for a proposed lightweight interceptor aircraft. The present conventional Cassegrain antenna in the strike aircraft has a dish diameter of 26 inches. By replacing this with a flat plate scanner Cassegrain antenna, ½ inch can be added to the diameter. With the modified flat plate antenna, the diameter can be increased to almost 32 inches representing an aperture area increase of in excess of 45 percent. For the lightweight interceptor, comparing the flat plate scanner Cassegrain antenna and its modified form, utilization of the latter configuration enabled the dish diameter to be increased from 23¼ inches to 26½ inches, some 30 percent increase in aperture area.

Although antenna gain is directly proportional to aperture area, in assessing the overall antenna performance one must take into account the transmission and absorption losses which occur at each reflection on the sub-dish. With the antenna proposed here the extra reflection introduces an additional loss compared with the parabolic sub-dish antenna and hence this loss must be weighed against the extra gain derived from the allowable increase in aperture area. The techniques for designing the required gridded dielectric reflection surface are well documented, e.g. see the article by M.A. Teichman: 'Designing Wire Grids for Impedance Matching of Dielectric Sheets,' Microwave Journal, April '68. Good reflection properties are achievable over a wide range of angles of incidence and losses at each reflection can be kept as low as a few hundredths of a decibel. Thus, it is considered that the improved antenna performance achieved by the permitted aperture area increase far outweigh the effect of additional losses introduced by the second sub-dish reflection.

An additional feature of the proposed antenna is that the substantially conically shaped sub-dish, because of its reduced surface area, is somewhat lighter than that of the conventional flat plate Cassegrain antenna. For example,for the strike aircraft installation, the weight saving for this item was some 40 percent.

The salient features of the scheme herein may be summarized as follows:

1. A surface of revolution has been evolved which has the property of redirecting radiation from a point source feed, after two reflections, into a plane wavefront which propagation parallel to the surface axis.
2. The above surface has been used in conjunction with a flat plate scanner and polarization sensitive reflection surfaces to form an antenna suitable for nose mounting in aircraft.
3. Adoption of the above antenna in strike and interceptor aircraft allows improved utilization of radome cross sectional area enabling larger aperture antennas to be accommodated than are achievable with present designs.
4. For larger, slower aircraft the sub-dish of the present design can also become the external aircraft radome thus avoiding the requirement for a further dielectric surface.
5. The shape of the sub-dish required for the proposed antenna is such that significant weight savings are possible for the applications outlined in (3) and (4) above.
6. The invention is also of special benefit in the case of the small executive type of civil airliners where fuselage cross sections are small but the aircraft still requires the maximum possible size of scanner for its weather radar.

In the two-reflection case, the resulting surface, ogival in shape, although simplifying antenna installation, is not suitable for use as an external radome on supersonic aircraft. For this latter application, it is necessary to use a radome shape having a vertex included angle of 60° or less. By deriving surfaces which require more than two reflections to achieve the necessary focussing, radome shapes approaching those dictated by aerodynamic considerations can be obtained. We will now, therefore, discuss reflector shapes with 3, 4 and 5 reflections. The use of these surfaces enables the external aircraft radome to be utilized as the antenna sub-reflector thus forming an integrated antenna/radome installation.

We require to derive a surface shape which gives focussing properties sufficiently accurate for practical applications. As a unique solution to the derivation of a two-reflection surface was not achieved in the previous discussion it seems unlikely that such solutions are attainable for higher order reflection surfaces. Consequently, the approach adopted here is a semi-empirical one, in that the surface is assumed to be representable by a limited term polynomial equation. The equation coefficients are then determined by using certain gradient properties of the surface and the final remaining constant is determined by iterative methods.

From the results derived, it has been found that the two-reflection surface can be adequately approximated by a second order polynomial of the following form

$$y=A-Bx-Cx^2 \qquad (4)$$

where A, B, C are constants. On the assumption that the higher order reflection surfaces can also be represented by an equation of the same order we can rearrange equation (4) in more suitable form. If we consider x, y above to be in normalized units, i.e. each divided by the focal length of the focussing surface, then we have the following conditions; when $x=1$, $y=0$. Thus

$$y=B(1-x)+C(1-x^2)$$

We can write the coefficient C in terms of the slope of the curve at $x=1$ i.e. in terms of the vertex angle. Thus

$$y=B(1-x)-\tfrac{1}{2}[B+(dy/dx_{x=1})](1-x^2)$$

To find the constant B, we can rewrite the equation in terms of the intercept of the curve on the y axis, y_{max}. We now have our required equation.

$$y=[2y_{max}+(dy/dx_{x=1})](1-x)-[y_{max}+(dy/dx_{x=1})](\chi X^{\infty}) \qquad (5)$$

At the vertex of the required surface, the reflector system forms what is essentially a corner reflector. From geometrical considerations, it is easily shown that if n is the number of reflections required from the surface, then the included angle at the vertex is π/n. Thus

$$dy/dx_{x=1}=-\tan(\pi/2n)$$

It remains only to derive the value of y_{max} in equation (5). This is selected empirically to give as linear a wavefront as possible through the focal plane. For the results derived so far, phase errors corresponding to 0.1 percent of the focal length and angular errors less than ½° have been achieved. These errors are considered to be well within the limits acceptable for a practical antenna.

The following equations define the surface for **3**, **4** and **5** reflections

3 Reflections

$$y=1.4226(1-x)+0.0774(1-x^2)$$

4 Reflections

$$y=0.3358(1-x)+0.0392(1-x^2)$$

5 Reflections

$$y=0.2751(1-x)+0.0249(1-x^2)$$

These are plotted out in FIG. **9**. It is seen that the higher the number of reflections, the more slender is the nose section. The suitability of any particular surface for an aircraft nose section is more readily assessed in terms of its cross-sectional area. This is presented, in normalized form, in FIG. **10**. For supersonic applications, it is necessary that the nose cross-section blends smoothly with the remainder of the fuselage in order to keep drag to a minimum. From this point of view, it seems more likely that a 4 or 5 reflection surface would find application as an acceptable aerodynamic nose shape. From electrical considerations, however, the greater the number of reflections the greater are the losses incurred. Also, the higher incidence angles on the radome wall aggravate the problem of obtaining high transmission efficiency when the incident radiation is orthogonally polarized, i.e. after it has been reflected from the polarization twisting flat plate scanner.

Further factors which must be taken into account in assessing the suitability of this type of antenna for any particular application are, firstly, the manufacturing tolerances of the required shape and, secondly, the magnitude of the surface deflections which occur under aerodynamic and g - loadings.

Despite the above problems, however, it is considered that this type of antenna utilizes radome volume as efficiently as electronically-scanned antennas and an installation of comparable performance would cost considerably less than its more complicated counterpart.

What I claim is:

1. A forward-looking aircraft antenna of substantially Cassegrain configuration, comprising a main dish in flat plate form, and a sub-dish forward of the main dish with a reflecting surface in the form of a surface of revolution generated about a fore-and-aft axis passing through the center of the main dish, said sub-dish surface being chosen from the class of surfaces of revolution that require more than a single reflection at said sub-dish to bring a wave approaching from said main dish and parallel to said axis of revolution to a substantial point focus on said axis.

2. An antenna according to claim **1**, wherein the sub-dish also constitutes the external aircraft radome.

3. An antenna according to claim **1**, wherein the chosen surface requires two reflections to achieve a substantial point focus.

4. An antenna according to claim **3**, wherein the sub-dish surface has an equation of the form:

$$x/F=(1-(y/2F)^2)-(y/F)\sqrt{1+(y/2F)^2}$$

where F is the focal length.

5. An antenna according to claim **4**, wherein the angular spread of the feed to the sub-dish, measured from the axis of revolution of the sub-dish surface, is substantially 36°.

6. An antenna according to claim **1**, wherein the chosen surface requires more than two reflections to achieve a substantial point focus and has an equation of the form:

$$y = A(1-x) + B(1-x^2)$$

where A and B are empirically determined constants for any particular number of reflections.

7. An antenna according to claim 6, wherein the number of reflections is three, A = 1.4226 and B = 0.0774.

8. An antenna according to claim 6, wherein the number of reflections is four, A = 0.3358 and B = 0.0392.

9. An antenna according to claim 6, wherein the number of reflections is five, A = 0.2751 and B = 0.0249.

* * * * *