

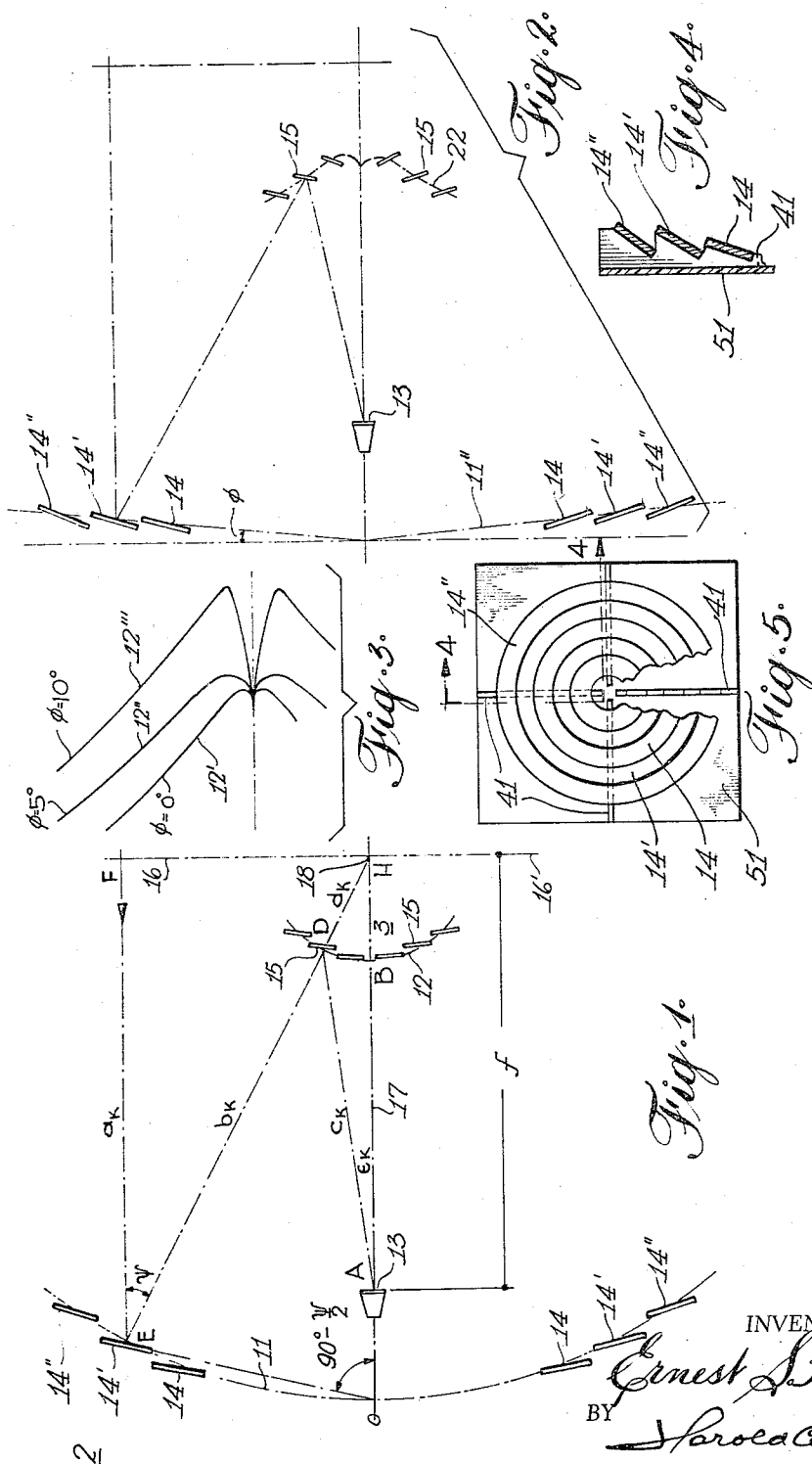
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DOUBLY REFLECTING LATTICED ANTENNA

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DOUBLY REFLECTING LATTICED ANTENNA
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This invention relates to microwave high gain antennas and, in particular, to a broadband microwave antenna using two latticed reflectors.

Doubly reflecting microwave antennas are known and generally comprise a main reflector and a sub-reflector. Such antennas can be used both for transmitting and receiving microwave energy. When used for reception, the main reflector intercepts the incident energy and reflects it to a sub-reflector which in turn reflects the energy to a microwave horn of relatively small dimensions forming the feed horn of the antenna system.

For a doubly reflecting antenna to be broadband in operation it must be so constructed that the path length of all rays from an incident plane wave front to the receiving horn is a constant. If the path lengths are unequal the various reflected rays will reinforce each other at some frequencies and destructively interfere at other frequencies. This property of constant path length is possessed by such known broadband doubly reflecting antennas as the Cassegrain antenna using a paraboloidal main reflector with a hyperboloidal sub-reflector, and the Gregorian antenna using a paraboloidal main reflector with an ellipsoidal sub-reflector. It is to be noted that these last-mentioned antennas require accurately shaped doubly curved reflectors.

A doubly reflecting broadband antenna using only singly curved reflectors has been described in Canadian Patent No. 674,742, Nov. 26, 1963 to E. S. Kelsey, assigned to the same assignee as this application. While this antenna has the advantage of using reflectors which are simple and economical to fabricate a large sub-reflector is required, equal in width to the incident beam, which must be offset from the main reflector to avoid serious blockage of the incident radiation.

It is therefore an object of this invention to provide a broadband doubly reflecting antenna which does not require doubly curved reflectors.

It is a further object of this invention to provide a broadband doubly reflecting antenna with a sub-reflector of small size relative to the main reflector.

It is a still further object of this invention to provide a broadband latticed doubly reflecting antenna in which the lattice elements forming the main reflector are arranged to lie on any arbitrarily chosen simple surface.

The antenna of this invention has a main reflector formed by ring elements of conical configuration arranged coaxially and located so that all the elements lie on a simple surface such as a plane or a cone. The angle of each conical lattice element is arranged to be the appropriate value to direct rays of an incident plane wave towards a small area surroundings a theoretical focal point on the common axis of the lattice elements. The sub-reflector is similarly formed by ring elements of conical configuration which are arranged coaxially with the main reflector lattice elements. The angle of each conical lattice element in the sub-reflector is arranged to reflect the rays from the main reflector towards a small area surrounding a second focal point, also on the common axis, where a microwave horn is situated. The surface along which the sub-reflector lattice elements are arranged is in a particular configuration according to the invention and is related to the simple surface along which the main reflector elements are arranged in such a manner that the path length between the antenna aperture and the feed

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horn is the same for all rays. This, of course, ensures that the antenna is broadband in operation. This arrangement provides a main reflector which is of an uncomplicated design and simple to manufacture while the smaller sub-reflector is of a more complex design.

Other features and objects of this invention will become apparent from the following description taken in conjunction with the accompanying drawings in which:

FIGURE 1 is a schematic view of an antenna according to this invention illustrating a typical ray path,

FIGURE 2 is a schematic view of an antenna according to this invention in which the main reflector lattice elements are arranged along a conical surface,

FIGURE 3 is a graphical plot of the generating curves for the sub-reflector positioning surfaces along which the lattice elements must lie when the main reflector lattice elements are arranged on a conical surface,

FIGURE 4 is a side elevation of a support useful in assembling the antenna reflectors, and

FIGURE 5 is a front elevation of an antenna reflector showing one manner of supporting the lattice elements.

In the schematic diagram of an antenna according to this invention illustrated in FIGURE 1, a plane wavefront 16, 16' is considered to be moving from the right to the left of the figure. This wavefront is intercepted by a main reflector, indicated generally at 2, consisting of a plurality of lattice elements designated generally as 14 with individual elements being designated 14', 14'' for ease of description. Each lattice element 14 is in the form of an annular ring of conical configuration arranged with a common axis 17. Elements 14 are of conducting material. The angles of the cones from which each lattice element is derived are selected so that all rays parallel to the axis 17 incident on lattice elements 14 are reflected towards a common focus 18. This angle, as measured from the cone axis should be 90° $\psi/2$ (see FIG. 1). The condition that all parallel axial rays incident on the lattice elements be reflected to a common focus 18 strictly requires that the cross-section of any lattice element 14 be a segment of a parabolic arc. In practice, the substitution of a conical element for a parabolic segment will introduce a negligible phase error provided that the difference in path length of rays reflected from the middle and the edges of the lattice element does not exceed a value of the order of $\lambda/20$, where λ is the shortest wave length with which the antenna is expected to operate. This difference in path length depends on the width of the lattice element and its distance from the focus and can be shown to be equal to:

$$\Delta C = \frac{W^2}{8p \sin^2 \frac{\psi}{2}}$$

Where W is the width of the lattice element, p, its distance from the focus, and ψ the angle between the vector from the focus to the lattice element and the axis of symmetry.

If C is assigned the limiting value, $\lambda/20$, this equation, when solved for W, gives

$$W = \sqrt{0.4 p \lambda \sin \psi/2}$$

Since a conical ring is a developable surface the reflector elements are easily formed from flat metal strips avoiding the difficulties inherent in the production of accurately curved surfaces.

A main reflector positioning surface is shown in cross-section as generating curve 11 in FIGURE 1. This main reflector positioning surface or first surface is a surface of revolution formed by the rotation of generating curve 11 about axis 17. Lattice elements 14 are arranged to lie along the main reflector positioning surface, that is the

lattice elements are positioned so that they are bisected by this surface. In other words, the positioning surface defines the position of the lattice elements. The manner of supporting the lattice elements is not material to this invention and is not shown in FIGURE 1. A suitable form of supporting structure is discussed below in connection with FIGURES 4 and 5. It should be noted that the surfaces of the lattice elements 14 do not correspond to the main reflector positioning surface, rather the lattice elements are positioned so that they are intersected or bisected by the reflector positioning surface. This will result in surface discontinuities between the edges of adjacent lattice elements and will thus cause phase discontinuities between rays from these adjacent edges. The effect will be negligible if the offset of each lattice edge from the positioning surface is limited to a value of the order of $\lambda/40$. The following equation gives the magnitude of this offset, Δp , in terms of the width W and the angle of inclination, α , of the lattice element to its positioning surface.

$$\Delta p = \frac{W}{2} \sin \alpha = \lambda/40$$

The limitation on the width of the lattice element to meet this requirement, therefore, is:

$$W = \lambda/20 \operatorname{cosec} \alpha$$

A sub-reflector, indicated generally at 3, intercepts the rays reflected from the main reflector towards focus 18. Sub-reflector 3 is a lattice structure similar to but smaller than main reflector 2. Sub-reflector 3 comprises a plurality of lattice elements 15 which are again annular conducting rings of truncated conical form arranged coaxially with one another along axis 17. There are the same number of lattice elements 15 in the sub-reflector as there are lattice elements 14 in the main reflector and each lattice element 15 has a one-to-one correspondence with a lattice element 14. The angles of the cones from which lattice elements 15 are derived are selected so that all rays incident on sub-reflector 3 from the main reflector 2 are reflected to a common focus 13 on axis 17. This angle, as measured from the cone axis, should be

$$90^\circ - \frac{\Psi - \epsilon}{2}$$

A microwave horn antenna situated at focus 13 acts as a transmitting or receiving feed horn for the doubly reflecting antenna.

The sub-reflector positioning surface or second surface is shown in cross-section as generating curve 12 in FIGURE 1. The sub-reflector positioning surface is a surface of revolution formed by the rotation of generating curve 12 about axis 17. The lattice elements 15 are positioned in such a manner that they are intersected or bisected by the sub-reflector positioning surface. A suitable form of supporting structure for lattice elements 15 is discussed below in connection with FIGURES 4 and 5. As has been discussed in connection with the main reflector, the sub-reflector positioning surface need not exist physically in the antenna, it is sufficient that the lattice elements 15 are supported in position to define such a surface.

It will have been noted that the form of the main reflector and sub-reflector positioning surfaces has not yet been specified. These surfaces are selected so that the path length of all rays from the plane wave front 16, 16' to the microwave horn at focus 13 is constant, that is they are chosen to ensure broadband operation. As will be demonstrated below any one of these surfaces can be arbitrarily selected after which the form of the remaining surface can be calculated. Mechanical considerations make it desirable to select a simple shape for the main reflector positioning surface, such as a plane or a cone. This requires a less simple shape for the sub-reflector positioning surface, but as the sub-reflector is much smaller

the manufacturing complications are much less than they would be for the main reflector.

The required relationship between the main reflector and sub-reflector positioning surfaces will now be derived referring to the ray diagram in FIGURE 1. A ray FE from the plane wave front 16, 16' is incident on main reflector lattice element 14. It is reflected as ray ED which is intercepted by sub-reflector lattice element 15 and reflected to focus 13 as ray DA. Were the sub-reflector not present, the ray ED would intersect axis 17 at focal point H and all rays reflected from lattice element 14 would converge towards a small area surrounding H.

The distance FE will be denoted by a_k , the distance ED by b_k , the distance DH by d_k , the distance DA by e_k and the angle FED by ψ_k . The subscript K is used to indicate that one pair of associated lattice elements 14 and 15 is being considered. The condition for broadband operation of the antenna is that the total path length of all rays should be constant, that is

$$a_k + b_k + e_k = C \quad (1)$$

where C is any constant.

It is convenient to denote the distance EH by p_k , that is

$$p_k = b_k + d_k \quad (2)$$

Now, because $a_k = p_k \cos \psi_k$.

Equation 1 may then be expressed as

$$C = e_k - d_k + p_k(1 + \cos \psi_k) \quad (3)$$

The constant C can be expressed in terms of the axial dimensions of the antenna by considering a hypothetical axial ray. Denoting the values of distance along the axis by the subscript 0 Equation 3 becomes

$$C = e_0 - d_0 + 2p_0 \quad (4)$$

Instead of the set of equations relating the positions of the associated pairs of lattice elements such as Equation 3 it is convenient to consider the corresponding relationship between the two reflector positioning surfaces containing the center lines of the lattice elements. Expressed in general terms of the two positioning surfaces Equation 3 becomes

$$C = e - d + p(1 + \cos \psi) \quad (5)$$

where the value of C may still be determined from Equation 4.

If the shape of the main reflector positioning surface is arbitrarily specified, then p may be expressed in terms of ψ for this arbitrary surface as these values are independent of the sub-reflector positioning surface. Equation 5 may then express the relationship between e and d which determines the sub-reflector positioning surface. Conversely if the shape of the sub-reflector positioning surface is arbitrarily specified e and d can be expressed in terms of ψ and Equation 5 may then express the relationship between p and ψ which determines the main reflector positioning surface.

It is of interest to note that in the particular case which occurs when both $(e-d)$ and $p(1+\cos \psi)$ are constants the equation can be separated into two parts

$$e - d = C_1 \quad (6A)$$

$$p(1 + \cos \psi) = C_2 \quad (6B)$$

where $C_1 + C_2 = C$

In this case Equation 6A defines a sub-reflector positioning surface which is a hyperboloid and Equation 6B defines a main reflector positioning surface which is a paraboloid. This corresponds to a latticed version of a Cassegrain type antenna with the lattice elements being tangential to the reflector positioning surfaces.

It is important to note that, with the exception of a few special cases such as the one which has just been considered, the antenna of this invention cannot be derived from known antennas having continuous reflecting surfaces by replacing the continuous surface by a latticed structure approximating thereto. In general in this inven-

tion, the conical lattice elements are not tangential to the reflector positioning surface which specifies only the location of the lattice elements. The angle between the lattice elements and the axis of the system is determined by the condition that the rays incident on the reflector be brought to a common focus.

Continuing with the derivation of the relationship between the main reflector and sub-reflector positioning surfaces, a further restriction is placed on Equation 5 in that d and e must form two sides of a triangle having a base AH of fixed length. This is implicit in the condition that all rays such as b_k come to a common focus at H . Denoting the distance AH by f we have

$$e^2 = f^2 + d^2 - 2fd \cos \psi \quad (7)$$

The f denotes the distance between the first focus 18 and the second focus 13 and is a known constant of the antenna structure.

If, for brevity, the expression $C - p(1 + \cos \psi)$ is denoted by g , Equation 5 may be rewritten as

$$e = g + d$$

and hence Equation 7 becomes

$$f^2 + d^2 - 2fd \cos \psi = (g + d)^2$$

or

$$d = 1/2 \left[\frac{(f+g)(f-g)}{f \cos \psi + g} \right] \quad (8)$$

As has been stated mechanical considerations make it desirable to select a simple shape for the main reflector positioning surface and then to calculate the necessary shape for the sub-reflector positioning surface to ensure broadband operation. If, for example, the main reflector positioning surface is selected to be a plane then

$$p = p_0 \sec \psi$$

and hence

$$g = C - p_0 \sec \psi (1 + \cos \psi) \quad (9)$$

Thus a relationship for g expressed only in terms of ψ and known constants has been obtained. The value of g obtained from Equation 9 can be substituted in Equation 8 to provide an expression defining d in terms of ψ and known constants. This latter expression can be used to obtain the generating curve 12 for the sub-reflector positioning surface. An example of this curve for specific values of e_0 , d_0 and p_0 is shown at 12' in FIGURE 3.

If the main reflector positioning surface is a cone having as its generating curve a straight line 11'', as illustrated diagrammatically in FIGURE 2, then

$$p = p_0 \cos \phi \sec (\psi - \phi) \quad (10)$$

where ϕ is the angle of the cone as indicated in FIGURE 2. As before an expression for g can be obtained using the value of p obtained from Equation 10 expressing g in terms of ψ and known constants. The value of g obtained from this expression can be substituted in Equation 8 to provide an expression defining d in terms of ψ and known constants. This latter expression can be used to obtain the generating curve 22 for the sub-reflector positioning surface calculated.

As an example of antennas designed according to this invention the generating curves for sub-reflector positioning surfaces corresponding to a plane and two conical main reflector positioning surfaces have been calculated. The computed values for g and d are given in Table 1 and the generating curves for the three cases are shown in FIGURE 3.

The following axial parameters were selected for three cases

$$\begin{aligned} p_0 &= 1 \\ e_0 &= 0.85 \\ d_0 &= 0.05 \\ f &= e_0 + d_0 = 0.9 \end{aligned}$$

TABLE 1

ψ (deg.)	g			d		
	$\phi=0^\circ$	$\phi=5^\circ$	$\phi=10^\circ$	$\phi=0^\circ$	$\phi=5^\circ$	$\phi=10^\circ$
0	0.800	0.800	0.800	.0500	.0500	.0500
5	.796	.812	.827	.0491	.0441	.0360
10	.785	.815	.845	.0542	.0428	.027
15	.765	.812	.856	.0635	.0448	.022
20	.736	.799	.864	.0768	.0522	.018
25	.697	.778	.856	.0944	.0642	-----
30	.645	.750	.844	.1173	.0810	.030
35	.579	.708	.824	.1450	.1069	-----
40	-----	-----	.792	-----	-----	.061
45	-----	-----	.745	-----	-----	.098
50	-----	-----	.688	-----	-----	.133

FIGURES 4 and 5 illustrate one manner of supporting the conical rings to lie along a reflector positioning surface to form one of the reflectors of an antenna according to this invention. A support 41, constructed from any suitable structural material, has flat faces 42 adapted to receive the conical rings. Faces 42 have the correct inclination and position to locate the conical rings along the desired reflector positioning surface.

The complete reflector assembly shown in FIGURE 5 consists of a supporting structure 51, upon which are mounted four supports 41 of the type already discussed. The conical rings 14 forming the lattice elements of the reflector are mounted on the supports 41. This form of assembly is particularly suitable for the main reflector element, the sub-reflector element may advantageously be formed as a single unit.

Thus there has been described a novel microwave doubly reflecting antenna which is broadband in operation and uses reflector constructed from lattice elements in the form of conical rings. The arrangement of the antenna whereby the lattice elements in the main reflector may be arranged along a simple surface such as a plane or cone has also been described.

I claim:

1. A doubly reflecting antenna comprising
 - a plurality of main reflector lattice elements, spaced from one another, positioned symmetrically with respect to a common axis at different distances, therefrom and positioned so that each element is intersected substantially along its centerline by a first positioning surface,
 - the surface of each of said main reflector lattice elements defining a cone making with said axis a conical angle,
 - each said main reflector lattice element having a conical angle providing on said axis a first common focus for rays parallel to said axis,
 - a sub-reflector lattice element for each main reflector lattice element each spaced from one another, positioned symmetrically with respect to said axis and positioned so that each element is intersected substantially along its centerline by a second positioning surface,
 - the surface of each of said sub-reflector lattice element defining a cone making with said axis a conical angle,
 - each said sub-reflector lattice element being positioned between a respective main reflector lattice element and said first common focus, and having a conical angle orienting the reflecting surface thereof for reflecting rays reflected by said respective main reflector lattice element from axially parallel rays to a second common focus on said axis, and antenna feed means positioned at said second focus,
 - said first and second surfaces being so shaped that the length of each doubly reflected ray path between said antenna feed means and a plane normal to said axis is a constant.
2. A doubly reflecting antenna comprising,
 - a plurality of main reflector lattice elements, spaced from one another, positioned symmetrically with respect to a common axis at different distances there-

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from, and positioned so that each element is intersected substantially along its centerline by a first positioning surface,

the surface of each of said main reflector lattice elements defining a cone making with said axis a conical angle,

each said main reflector lattice element having a conical angle providing on said axis a first common focus for rays parallel to said axis,

a sub-reflector lattice element for each main reflector lattice element each spaced from one another, positioned symmetrically with respect to said axis, and positioned so that each element is intersected substantially along its centerline by a second positioning surface,

the surface of each of said sub-reflector lattice element defining a cone making with said axis a conical angle,

each said sub-reflector lattice element being positioned between a respective main reflector lattice element and said first common focus, and having a conical angle orienting the reflecting surface thereof for reflecting rays between the respective main reflector lattice element and a second common focus on said axis, and antenna feed means positioned at said second focus,

said second positioning surface being defined in polar coordinates (d, ψ) with respect to said first focus by

$$d = \frac{1}{2} \frac{(f+g)(f-g)}{f \cos \Psi + g}$$

where f is the distance between said first and second focus,

p is the distance from said first focus to said first positioning surface measured at angle ψ ,

$$g = C - p (1 + \cos \psi)$$

and C is a constant.

3. A doubly reflecting antenna as defined in claim 2 in which said first positioning surface is a plane normal to said common axis so that

$$p = p_0 \sec \psi$$

where p_0 is the perpendicular distance between said plane and said first focus.

4. A doubly reflecting antenna as defined in claim 2

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in which said first positioning surface is the surface of a cone arranged coaxially with said common axis said surface making an angle ϕ with a plane normal to said common axis so that

$$p = p_0 \cos \phi \sec (\psi - \phi)$$

where p_0 is the distance between the apex of said cone and said first focus.

5. A doubly reflecting antenna comprising, a plurality of main reflector lattice elements having reflecting surfaces of substantially conical shape, first supporting means coaxially positioning said main reflector lattice elements with respect to a common axis at spaced apart locations defining a first surface bisecting said main reflector lattice elements, the conical angles of said main reflector lattice elements being such that all rays parallel to said common axis incident thereon are reflected as a first convergent beam having a first focus on said common axis, a plurality of sub-reflector lattice elements having reflecting surfaces of substantially conical shape, second supporting means positioning said sub-reflector lattice elements coaxially with said common axis at spaced apart locations defining a second surface bisecting said sub-reflector lattice elements, the conical angles of said sub-reflector lattice elements being such that said first convergent beam is reflected as a second convergent beam towards a second focus on said common axis, and antenna feed means positioned at said second focus, said second surface being defined in polar coordinates (d, ψ) with respect to said first focus by

$$d = \frac{1}{2} \frac{(f+g)(f-g)}{f \cos \Psi + g}$$

where f is the distance between said first and second focus,

p is the distance from said first focus to said first surface measured at angle ψ ,

$$g = C - p (1 + \cos \psi)$$

and C is a constant.

No references cited.

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