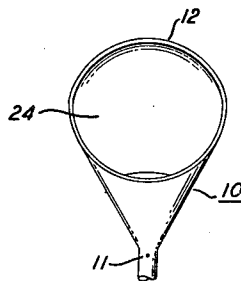


3,195,137

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3,195,137

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FIG. 3A

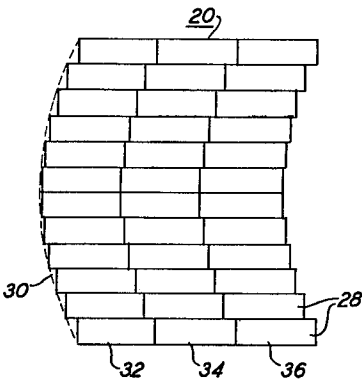


FIG. 3B

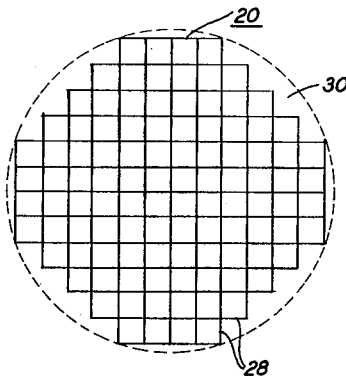
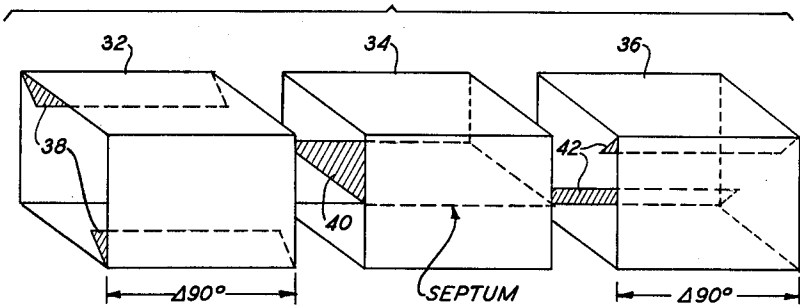


FIG. 3C



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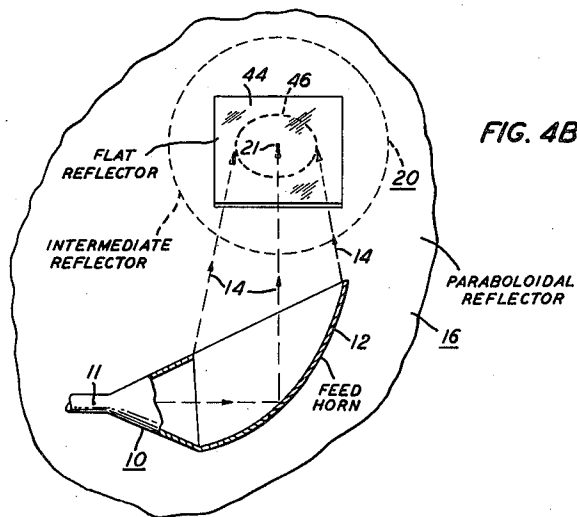
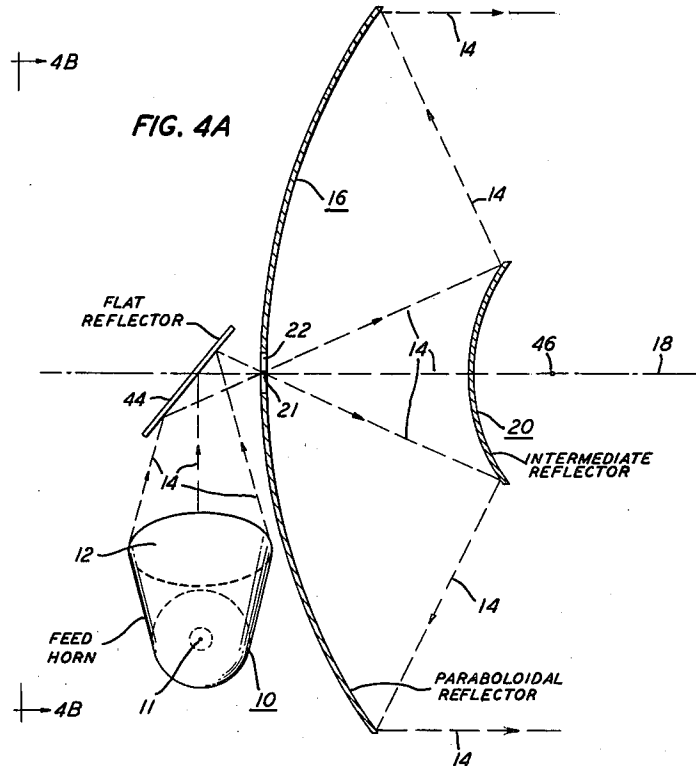
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CASSEGRAINIAN ANTENNA WITH APERTURE BLOCKING CORRECTION

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CASSEGRAINIAN ANTENNA WITH APERTURE BLOCKING CORRECTION

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This invention relates to antenna systems and more particularly to an improved, low-noise temperature Cassegrainian antenna.

Paraboloidal reflectors are frequently employed to convert spherical electromagnetic wave fronts to plane electromagnetic wave fronts, and vice versa. Directional antennas in which an active feed element is located at the focus of a paraboloid have found wide application in radio communications as cheap and convenient means of intercepting and radiating directional signals. Such antenna systems are, however, subject to distinct shortcomings which become more serious as the technology of the communications art advances. For example, in order to illuminate the paraboloid efficiently, an appreciable amount of energy is radiated or intercepted by the active feed element directly without reflection from the paraboloid. This "spillover," as it is commonly called, causes an increase in the noise temperature in receiving antennas and accounts for a wasteful radiation of energy in a transmitting antenna. Moreover, since the active feed element must be located at the focus of the paraboloid, the active components which are connected to the feed must normally be placed in the path of the antenna beam. These obstructions cause an increase in side lobe level of the antenna radiation pattern.

An attempt to reduce the number of obstructions in the antenna beam path has resulted in the application of the Cassegrainian telescope principle to paraboloidal antennas. In the resulting antenna the feed is located at the vertex of the paraboloid and radiates signals to or intercepts signals from an intermediate reflector located in front of the paraboloid. From the intermediate reflector, signals are conveyed to or from the paraboloid. Consequently, the active components may be located behind the paraboloid and the obstructions in the path of the beam may be reduced if the intermediate reflector is either very small or transparent to the antenna beam. Spillover may be just as pronounced in the Cassegrainian antenna, however, as in the conventional paraboloid.

The conventional horn reflector antenna with a paraboloidal reflector eliminates both the problems of obstructions in the path of the beam and spillover. The price paid for its advantages, however, are not small. A horn reflector having some desired gain is by necessity much more expensive and larger in size and weight than a paraboloidal antenna having a comparable gain.

It is easy to see how a vicious cycle may develop in attempting to choose one of the above antenna types by compromising all the various factors in antenna design mentioned above. To gain advantages of low or reduced spillover, for example, great expense and increased size and weight must be tolerated. To acquire an antenna having the largest possible gain at the lowest cost and least weight and size requires a degradation in noise temperature properties of the antenna.

Hence, it is an object of the present invention to combine in a single antenna the desirable characteristics of both the Cassegrainian paraboloidal antenna and the horn reflector antenna.

It is a more particular object to reduce the noise temperature of paraboloidal receiving antennas, specifically, by decreasing spillover.

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It is a further object to eliminate opaque obstructions from the path of the antenna beam which might increase the side lobe level of the antenna radiation pattern.

It is still a further object to effect a good impedance match between the active feed element and the passive reflectors of a Cassegrainian antenna.

In accordance with the above objects, the antenna system of the present invention employs the classic Cassegrainian telescope principle. A feed horn of relatively small size and having an ellipsoidal reflecting surface provides a source and collector of radio signals. In construction this feed horn is identical to the conventional horn reflector with the exception of the ellipsoidal reflector here substituted for the paraboloidal reflector. This feed horn is located behind a large paraboloidal reflector and the foci of the ellipsoidal surface coincide with the paraboloid vertex and feed horn apex, respectively. Due to the nature of ellipsoidal surfaces, signals radiated from the apex of the feed horn converge on and focus at the vertex of the paraboloid, and vice versa, making transmission possible through a very small hole cut in the vertex of the paraboloid. Consequently, only the directly radiated signals are permitted to pass through the hole in the paraboloid and a good impedance match between the feed horn and the passive reflectors results.

An intermediate reflector is located in front and centered about the axis of the paraboloid. Its surface exhibits a curvature which creates at the paraboloidal focus a virtual source or collector of signals to signals reflected from it, so that conversion of the signal to and from a plane wave front may be achieved. In the case of transmission, after the radio signal radiated from the feed horn passes through the hole in the paraboloid it diverges and impinges upon the intermediate reflector from whence it is reflected, as though originating at the parabolic focus, toward the paraboloid. A plane wave front is then developed by the paraboloid. (For reception the converse occurs.) The beam radiated or intercepted by the feed horn is well defined for much the same reasons that the conventional horn reflector radiates and intercepts with such high directivity. Because the beam of the feed horn is so well controlled, very little energy is radiated or intercepted directly from beyond the periphery of the paraboloid and, hence, little spillover occurs. Still the antenna beam is developed by the paraboloid, however, and the advantages of size and cost derived therefrom are fully utilized.

If circularly-polarized waves are accommodated by the antenna system, the intermediate reflector may be made transparent to the ultimate antenna beam while performing its function of reflection between the feed horn and paraboloid. The invention takes advantage of the fact that the rotation of the direction of polarization of circularly-polarized signals reverses upon reflection from the paraboloid. Hence, the rotation of the direction of polarization of the ultimate antenna beam signal is opposite that of the beam emerging from or collected by the horn. The intermediate reflector is constructed to reflect circularly-polarized signals having one direction of rotation and to transmit signals having the opposite direction of rotation as though the intermediate reflector were not present, with the result that no shadow is created by the intermediate reflector.

In detail, the intermediate reflector may comprise three regions. A region which reflects linearly-polarized signals of a given orientation and transmits linearly-polarized signals of the quadrature polarization lies between a pair of linear-to-circular polarization converters. Circularly-polarized signals impinging upon the surface of the intermediate reflector are converted to linearly-polarized signals oriented in one of the two directions depending upon their original direction of rotation. Accordingly, the

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linearly-polarized signals oriented in the given direction are reflected by the center region and reconverted to circularly-polarized signals having the original direction of rotation. The linearly-polarized signals of the quadrature polarization are transmitted through the center region and also reconverted to circularly-polarized signals of their original direction of rotation.

An additional feature of the invention, designed to conserve space, provides that the aperture of the feed horn be placed at right angles to the hole in the paraboloid and close to the paraboloid. A flat plate, then, directs the radio signal between the feed horn and the hole.

The above and other features of the invention will be considered in detail in the following specification taken in conjunction with the drawings in which:

FIG. 1 is a side section of the complete antenna system of the invention;

FIG. 2 is a front elevation of the feed horn illustrated in FIG. 1;

FIGS. 3A, 3B and 3C show the detailed construction of the intermediate reflector; and

FIGS. 4A and 4B illustrate a modification of the antenna system of FIG. 1 intended to save space.

In explaining the details of the invention, it will be considered as a transmitting antenna to facilitate a visualization of operation. The antenna of the invention may, of course, receive signals as well in a manner reciprocally related to transmission and it is, in fact, as a receiving antenna that many features of the invention are fully exploited.

FIG. 1 illustrates the location of the three principle elements of the invention—a feed horn 10, a paraboloidal reflector 16 and an intermediate reflector 20. Feed horn 10 is similar to the conventional paraboloidal horn reflector with an ellipsoidal reflector 12 replacing the paraboloidal one. (FIG. 2 shows feed horn 10 in front elevation.) Paraboloidal reflector 16 is of the conventional type. Its surface is generated by rotating a parabola about an axis 18. Feed horn 10 is situated behind reflector 16, as shown in FIG. 1, so that its axis 17 lies perpendicular to and intersects axis 18. An aperture 24 in the wall of feed horn 10 passes through axis 18 and faces the vertex of paraboloidal reflector 16. Further, the focii 11 and 21 of ellipsoidal section 12 are located at the apex of feed horn 10 on axis 17 and the vertex of reflector 16 on axis 18, respectively.

An ellipse is characterized as the locus of a point the sum of whose distances from a pair of focii is a constant. When feed horn 10 is excited by a signal each signal ray emanating from the throat of feed horn 10 at focus 11, and reflected from ellipsoidal reflector 12, no matter what its direction of propagation, passes through focus 21, and passes through focus 21 in time phase with every other ray from focus 11. The envelope of the beam thus radiated from feed horn 10 has a biconical form as represented by the dashed signal ray lines 14. The beam passes through a hole 22 cut in reflector 16 at its vertex. Because the radiating beam converges at focus 21, an extremely small diameter hole 22 will serve to couple energy through paraboloidal reflector 16. Therefore, very little energy is reflected back to feed horn 10 after the initial propagation through hole 22 and a good impedance match results. As the feed horn beam diverges away from hole 22 it impinges upon a surface 30 of an intermediate reflector 20 centered about axis 18. Surface 30 is curved so as to produce at focus 46 a virtual radiator of the signal reflected from it. Stated another way, the signals reflected from intermediate reflector 20 have a spherical wave front concentric about focus 46. Depending upon the position of intermediate reflector 20 the curvature of surface 30 may vary. Although the most practical location of intermediate reflector 20 is probably between focus 46 and paraboloidal reflector 16 there is no restraint on placing it beyond focus 46. The radio

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signal propagating in a spherical wave front from intermediate reflector 20 is finally reflected from paraboloidal reflector 16 in a plane wave front forming an antenna beam propagating in the direction of axis 18.

The characteristics of feed horn 10, as in the analogous case of conventional paraboloidal horn reflectors, permits a great deal of control over the radiated signal. As a result, the beam emanating from feed horn 10 is sharply defined and very little energy strays from the path of the beam. It can be seen from FIG. 1 that if the sizes of paraboloidal reflector 16 and intermediate reflector 20 are selected so that all of the biconical beam radiated from feed horn 10 is reflected from both reflectors 16 and 20, as indicated by ray lines 14, negligible energy is radiated in the form of spillover. In a receiving antenna the significance of this feature of the invention is that very little thermal energy is collected from the surroundings and the effective noise temperature of the antenna contributed to the receiver system is small.

Moreover, the advantages of the horn reflector and paraboloidal antennas are fully utilized, while eliminating the shortcomings of each. Feed horn 10 is relatively small and paraboloidal reflector 16 large so that the cost and size of feed horn 10 in comparison to the gain associated with the paraboloidal reflector 16 is reasonable. The well-defined beam of feed horn 10 accounts for a small spillover not attainable with conventional paraboloidal antennas.

Although feed horn 10 and the cross section of surface 30 are circular in the embodiment of FIG. 1, they may both be rectangular as may be aperture 24, for ease of construction, in which case the envelope of the beam from feed horn 10 would be pyramidal. It is evident that this does not provide as efficient an illumination of paraboloidal reflector 16 as the embodiment of FIG. 1.

If the signals of the source exciting feed horn 10 are circularly polarized, intermediate reflector 20 may be made transparent to the antenna beam so that no shadow exists in the local antenna beam as would normally be expected from the presence of an obstruction such as intermediate reflector 20. This facet of the invention takes advantage of the fact that circularly-polarized signals upon reflection from a conducting surface (in this instance paraboloidal reflector 16) reverse their direction of rotation of polarization. Intermediate reflector 20 is capable of discriminating between circularly-polarized signals whose polarization is rotating in different directions in that signals rotating in one direction are reflected and signals rotating in the opposite direction are transmitted.

For example, if a circularly-polarized signal having a counterclockwise rotation as viewed by facing in the signal's direction of propagation is radiated from feed horn 10, this signal is reflected from intermediate reflector 20, as shown, also rotating counterclockwise as viewed by facing in the signal's changed direction of propagation. Reflection from paraboloidal reflector 16 reverses the direction of rotation of polarization so that the signal polarization is rotating in a clockwise direction. Since the signal polarization is rotating clockwise rather than counterclockwise, the portion of the signal falling upon intermediate reflector 20 is transmitted through it to form a shadow-free beam both in the path of intermediate reflector 20 as well as outside of that path.

For consideration of the detailed structure of intermediate reflector 20 attention is directed to FIGS. 3A, 3B and 3C. FIGS. 3A and 3B are side and front elevations, respectively, of reflector 20. Section 20 is composed of square wave guide sections, as typified by wave guide sections 28, the cross sections of which are staggered in position to form an approximate spherical surface 30. This approximation is valid because the wavelength of the signal employed is normally large compared to the dimensions of the discontinuities of surface 30. Each of sections 28 is composed of three regions as shown in FIG. 3C. Linear-to-circular polarization converter regions

32 and 36 are connected by a middle region 34 which reflects linear-polarized signals oriented in a given direction and transmits linear-polarized signals oriented in the quadrature direction.

Specifically, regions 32 and 36 are $\Delta 90$ -degree sections with fins 38 and 42 oriented along opposite diagonals in regions 32 and 36, respectively. Middle region 34 has a horizontal septum 40 placed therein. In operation, counterclockwise-rotating circularly-polarized signals impinging upon intermediate reflector 20 are converted to linearly-polarized signals oriented in a horizontal direction after transmission through region 32. When these signals reach region 34 they are reflected therefrom and reconverted to counterclockwise-rotating circularly-polarized signals after the return trip through region 32, and radiated from surface 30. If, on the other hand, clockwise signals are introduced into section 32, they are converted to linearly-polarized signals oriented in a vertical direction during transmission through region 32. The vertically-polarized signals are transmitted through section 34 to section 36 in which they are reconverted to clockwise-rotating circularly-polarized signals and radiated as a portion of the antenna beam. To bring the signal transmitted through intermediate reflector 20 into time phase with the remainder of the antenna beam the length of region 34 is adjusted to effect a time lead through intermediate reflector 20 as a whole with respect to free space which is an integral number of wavelengths of the signal.

Rotating region 34 by ninety degrees reverses the discriminatory characteristics of intermediate section 20. Section 20 would then reflect clockwise-rotating circularly-polarized signals and transmit counterclockwise circularly-polarized signals.

In FIG. 4 feed horn 10 is positioned at right angles to hole 22. A flat reflector 44 directs the signals emanating from feed horn 10 through hole 22. This modification of the embodiment in FIG. 1 conserves space by situating feed horn 10 closer to reflector 16.

What is claimed is:

1. In an antenna system for radiating and receiving circularly-polarized signals, a paraboloidal reflector having a focus and a vertex, said paraboloid having a hole located at said vertex, a horn reflector located behind said paraboloid, said horn reflector having an ellipsoidal reflecting surface with one focus near the apex of said horn reflector, and a second reflector facing said paraboloid and located to create a virtual source and collector of signals at said focus of said paraboloid, said second reflector reflecting without changing the direction of rotation circularly-polarized signals rotating in one direction and transmitting circularly-polarized signals rotating in the opposite direction, said horn reflector oriented to permit coupling of signals between it and said second reflector through said hole.

2. In an antenna system for radiating and receiving circularly-polarized signals, a paraboloidal reflector having a focus and a vertex, said paraboloid having a hole located at said vertex, a horn reflector located behind said paraboloid and directed in a line perpendicular to the axis of said paraboloid, said horn reflector having an ellipsoidal reflecting surface with one focus near the apex of said horn reflector, and a second reflector facing said paraboloid and located to create a virtual source and collector of signals at said focus of said paraboloid, said second reflector reflecting without changing the direction of rotation circularly-polarized signals rotating in one direction and transmitting circularly-polarized signals rotating in the opposite direction, and a flat reflector located behind said paraboloid to direct signals between said horn reflector and said hole.

3. In an antenna system, a paraboloidal reflector having a focus and a vertex, a feed element accommodating circularly-polarized signals located near said vertex behind said paraboloid and directed to said focus of said paraboloid, and a second reflector facing said paraboloid

and located to create a virtual source and collector of signals at said focus of said paraboloid, said second reflector comprising means for converting between circularly-polarized signals and linearly-polarized signals, means for reflecting linearly-polarized signals having a given direction of polarization and transmitting linearly-polarized signals having a direction of polarization orthogonal to said given direction, and means for converting between linearly-polarized signals and circularly-polarized signals, said last three means being located one adjacent to the other in the order recited.

4. An antenna system comprising a paraboloidal reflector having a focus and a vertex, a hole in said paraboloid located at said vertex, a horn reflector located behind said paraboloid, said horn having an ellipsoidal reflecting surface with one focus near the apex of said horn reflector and the other focus at said vertex of said paraboloid and a second reflector facing said paraboloid and located to create a virtual source and collector of signals at said focus of said paraboloid, said horn reflector oriented to permit coupling of signals between it and said second reflector through said hole.

5. In an antenna system, a paraboloidal reflector having a focus and a vertex, a hole in said paraboloidal reflector located at said vertex, a horn reflector comprising a horn for conveying electromagnetic waves along a longitudinal axis, said horn having an apex aperture and a side aperture in its wall, an antenna axis passing through said side aperture, and an ellipsoidal reflector of electromagnetic waves facing both said apertures, the ellipsoidal foci lying upon said antenna axis and said longitudinal axis at said vertex of said paraboloidal reflector respectively, and a second reflector facing said paraboloid and located to create a virtual source and collector of signals at said focus of said paraboloid.

6. In combination, a source of radio signals the signals of which impinge upon a microwave circuit device comprising a plurality of waveguide segments stacked one on top of the other to form a surface upon which microwave signals may be directed, said segments each comprising, in the order named, a $\Delta 90$ -degree section, a septum section, and a $\Delta 90$ -degree section.

7. An antenna system comprising a first reflector having an opening through it, a feed element accommodating circularly polarized signals located behind said reflector and directed at said opening, and a second reflector facing said first reflector and located to couple signals between said source and said first reflector, said second reflector reflecting without changing the direction of rotation circularly polarized signals having a given direction of rotation and transmitting circularly polarized signals having a direction of rotation opposite said given direction.

8. In combination, a wave transmission circuit device and a source of circularly-polarized electromagnetic waves the polarizations of which are rotating in either of two directions, said source being directed to irradiate said wave transmission circuit device, said wave transmission circuit device comprising the following elements located in succession in the order recited: means for converting said circularly-polarized wave when its polarization is rotating in one direction into a linearly-polarized wave the polarization of which is oriented in a given direction and for converting said circularly-polarized wave when its polarization is rotating in the other direction into a linearly-polarized wave the polarization of which is oriented orthogonally to said given direction, means for transmitting said linearly-polarized wave when its polarization is oriented in said given direction and for reflecting said linearly-polarized wave when its polarization is oriented orthogonally to said given direction, and means for converting said linearly-polarized wave when its polarization is oriented in said given direction into a circularly-polarized wave the polarization of which is rotating in said one direction.

References Cited by the Examiner

UNITED STATES PATENTS

2,032,588	3/36	Miller	343—837
2,736,895	2/56	Cochrane	343—83 X
2,741,744	4/56	Driscoll	333—21
2,825,032	2/58	Alford	333—21
2,952,017	10/60	Easy	343—756
2,972,743	2/61	Svensson et al.	343—909 X

5

2,983,918	5/61	Parmeggiani	343—756
3,089,137	5/63	Pierce	343—756 X

FOREIGN PATENTS

898,352	7/44	France.
911,045	2/46	France.

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