

Aug. 12, 1952

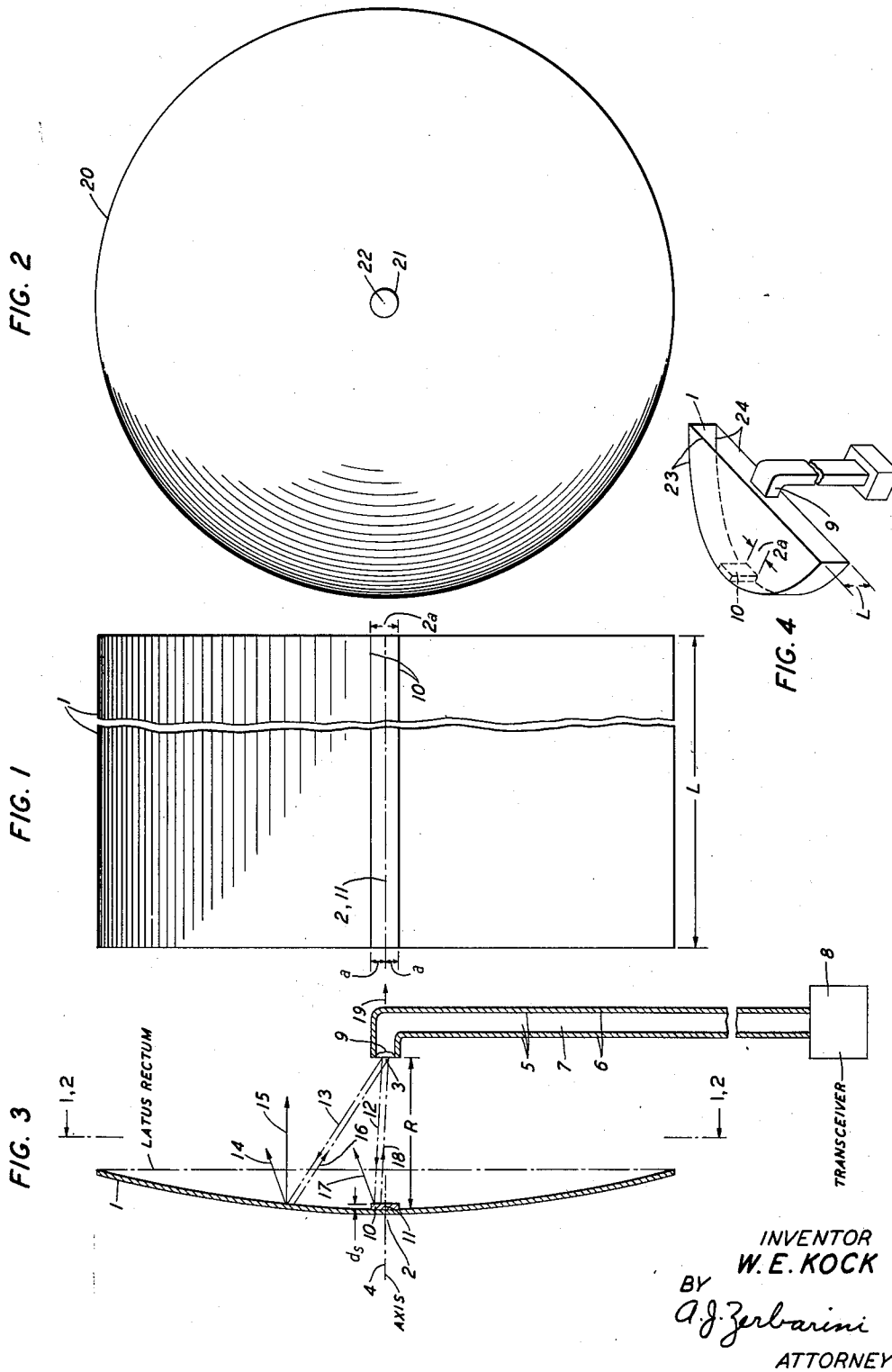
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2,607,010

WAVE GUIDE · ANTENNA SYSTEM

Filed April 23, 1945

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WAVE GUIDE ANTENNA SYSTEM

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FIG. 5

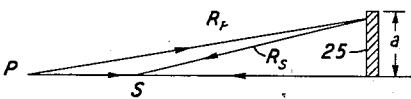


FIG. 6

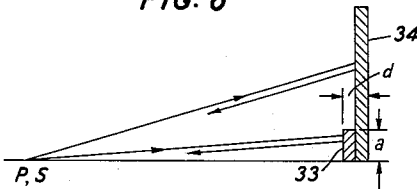


FIG. 7

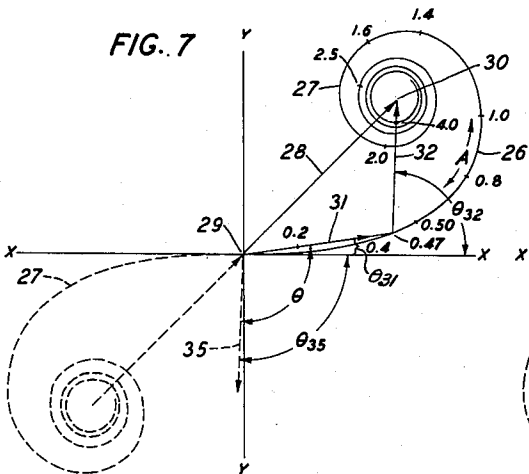


FIG. 12

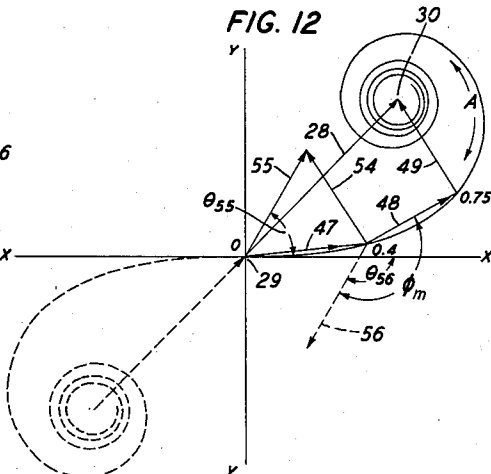
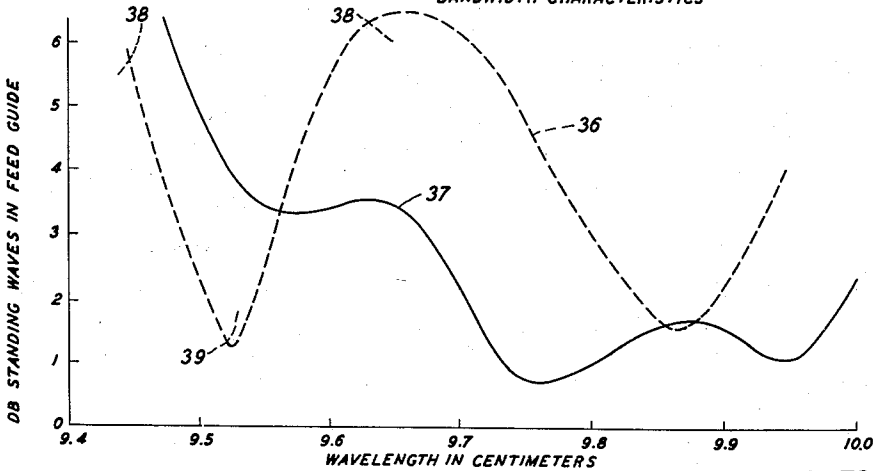


FIG. 8
BANDWIDTH CHARACTERISTICS



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FIG. 10

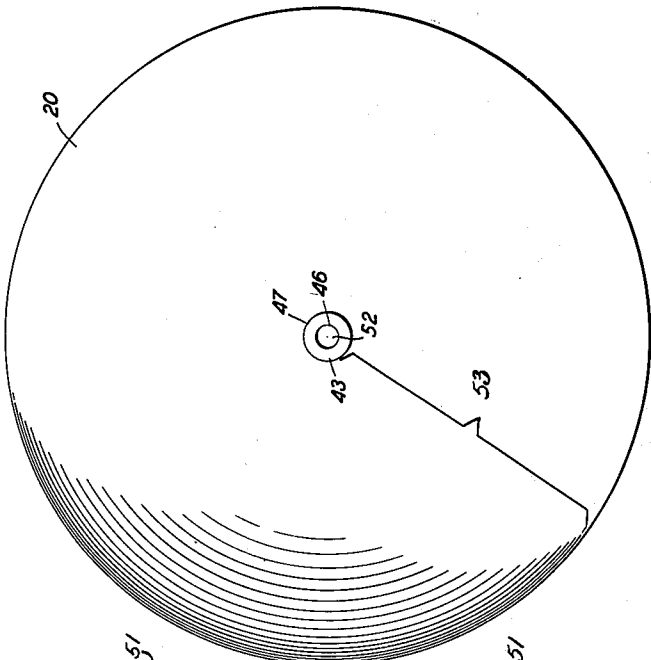


FIG. 9

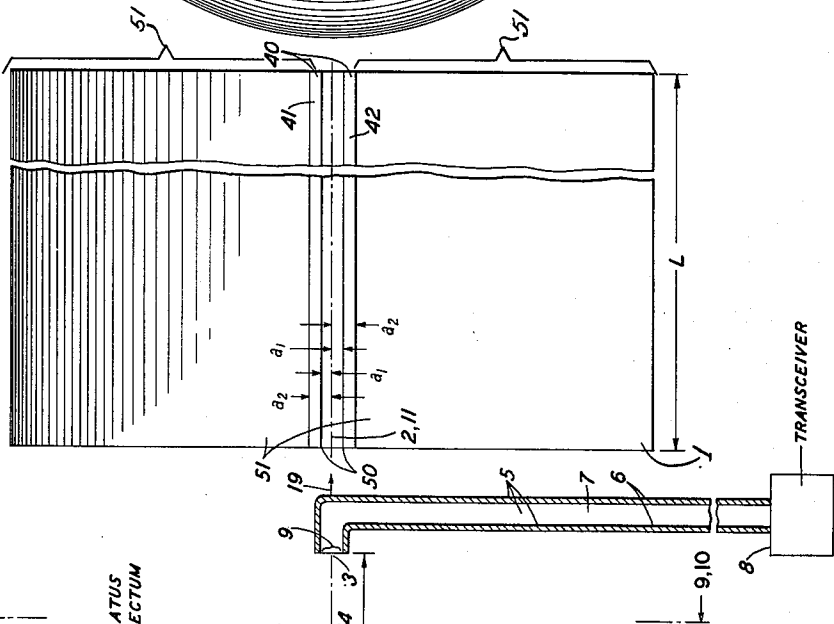
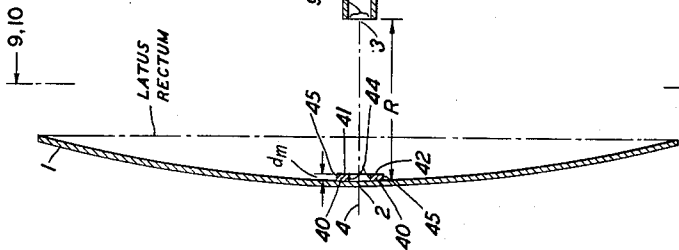


FIG. 11



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WAVE GUIDE ANTENNA SYSTEM

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Application April 23, 1945, Serial No. 589,899

4 Claims. (Cl. 250—33.65)

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This invention relates to means for preventing bilateral coupling between a pair of spaced antenna elements, and more particularly to means for preventing, in a directive transmitting radio system comprising a passive reflector and a primary antenna, reverse or feedback coupling, that is, detrimental energization by the reflector of the primary antenna and associated line or guide.

As is known, directive antenna systems comprising parabolic reflectors and air-filled dielectric guide feeds therefor are widely used in microwave systems, especially radar systems. In general, in these systems, radio waves having a given operating or design frequency are conveyed along the dielectric guide from the transmitter to the antenna aperture at the remote end of the guide, and thence radiated towards the reflector. While most of the energy impinging upon the reflector is propagated in the desired direction, a certain amount is reflected back to the antenna aperture by the reflector, whereby a detrimental mismatch or reverse coupling effect is obtained and undesired standing waves are established in the guide. Also, while some reduction of the standing wave may be realized at the design or mean frequency, and at the frequencies closely adjacent thereto, satisfactory reduction at other frequencies in the design band has not been accomplished and the actual bandwidth of the system is therefore relatively narrow. Accordingly, it appears desirable to eliminate completely the mismatch effect at the mean frequency and to substantially reduce the reverse coupling over a relatively wide band of frequencies.

It is one object of this invention to eliminate standing waves, at all frequencies in a wide band, in a dielectric guide connected to a source of energy.

It is another object of this invention to prevent, in a directive radio system comprising an active or primary antenna element and a passive or secondary antenna element, reverse or feedback coupling of said primary element to said passive element.

It is another object of this invention to prevent, in a directive transmitting antenna system comprising a reflector and a primary antenna element, therefor, the wave components reflected by the reflector from producing detrimental effects at the primary antenna.

It is a further object of this invention to eliminate, in an antenna system comprising an active or primary antenna element and a passive or secondary antenna element, energization of the ac-

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tive element by the passive element, without affecting the energization of the passive element by the active element.

It is still another object of this invention to prevent, in a directive antenna system comprising a parabolic reflector associated with a dielectric guide having an antenna aperture facing the reflector, and at all frequencies in a very wide frequency band, the formation in the guide of standing waves resulting from the waves reflected by the reflector.

As used herein, the term "wave guide" generically includes a conventional line or "conductive guide" and an air-filled or dielectrically loaded "dielectric guide"; the term "parabolic reflector" generically includes a "paraboloidal reflector" and a "cylindrical-parabolic reflector"; the term "focus" applies generically to the "focal point" of a paraboloidal reflector and the "focal line" of a cylindrical parabolic reflector; the term "vertex" applies generically to the "vertex line" of a cylindrical-parabolic reflector and to the "vertex point" of a paraboloidal reflector; the term "radar" signifies a radio device used for detecting an object or target and for determining its direction and its distance or range; and the term "transceiver" signifies a device comprising a transmitter and a receiver and used in a radar system. Also, as used herein, the term "circular front" or "circular wave front" denotes an arcuate line along which the wavelets have the phase angle.

In accordance with one embodiment of the invention, a small auxiliary single-strip reflector is positioned between a large main cylindrical-parabolic reflector and the primary antenna aperture in the dielectric feed guide. The small reflector may be flat or parabolic and is symmetrically positioned relative to the axial plane of the large reflector. The small reflector is preferably, but not necessarily, attached to the vertex of the large reflector. The dimension of the small reflector, as measured perpendicular to the axis of the large reflector and in the plane of curvature of the large reflector, and therefore the area of the small reflector, are related to the area or opening dimension of the large reflector and is such that the amplitude of the vector resultant of the wavelets reflected back into the primary antenna aperture by the small reflector is equal to the amplitude of the vector resultant of the wavelets fed back into the aperture by the large reflector. Also, the difference in the distances between the primary antenna aperture and the two reflectors is such that the aforesaid vector re-

sultants have opposite phase angles at the primary antenna aperture. Hence the feedback components from the small and large reflectors mutually cancel at the antenna aperture and the formation of standing waves is avoided in the guide. In more detail, the aforesaid dimension a of the small reflector is mathematically related to the mean wavelength of the system, the focal length of the large reflector, and the parameter of the cornu spiral representing the integrated amplitudes and phases of the components in the circular wave front established by the primary antenna aperture. The separation of the reflective faces of the two reflectors is such as to produce mutual cancellation of the wavelets returned to the primary antenna by the large reflector and the auxiliary reflector.

In accordance with a second embodiment, a paraboloidal reflector and a disk or plate auxiliary reflector are used, respectively, in place of the cylindrical-parabolic reflector and the single-strip reflector. In accordance with a third embodiment, a single-strip reflector is used in conjunction with a "pill-box" antenna comprising a cylindrical-parabolic reflector equipped with parallel end plates. In accordance with a fourth embodiment, the main reflector has a cylindrical-parabolic contour and a double strip auxiliary reflector is attached to the vertex of the main reflector; and in accordance with a fifth embodiment the antenna system comprises a main paraboloidal reflector and an annular or ring reflector.

The invention will be more fully understood from a perusal of the following specification taken in conjunction with the drawing on which like reference characters denote elements of similar function and on which:

Fig. 1 is a sectional front view of a first embodiment of the invention comprising a cylindrical-parabolic reflector and a single auxiliary linear strip reflector;

Fig. 2 is a sectional front view of a second embodiment comprising a paraboloidal reflector and an auxiliary circular plate or disk reflector;

Fig. 3 is a sectional side view of the above-mentioned first and second embodiments;

Fig. 4 is a perspective view of a third embodiment comprising a cylindrical-parabolic reflector, end plates therefor and a single-strip reflector;

Figs. 5 and 6 are explanatory diagrams used in explaining the invention;

Fig. 7 is a cornu spiral and vector diagram used in determining the size of the auxiliary reflectors included in the embodiments of Figs. 1, 2 and 4;

Fig. 8 illustrates the measured bandwidth curves for the embodiment of Fig. 4 and a prior art system without the auxiliary reflector;

Fig. 9 is a sectional front view of a fourth embodiment comprising a cylindrical-parabolic reflector and a pair of strip reflectors;

Fig. 10 is a sectional front view of a fifth embodiment comprising a paraboloidal reflector and an auxiliary ring reflector;

Fig. 11 is a sectional side view of the fourth and fifth embodiments, and

Fig. 12 is a cornu spiral and vector diagram used in determining the dimensions of the auxiliary reflectors included in the embodiments of Figs. 9 and 10.

Referring to Figs. 1 and 3, reference numeral 1 denotes a large cylindrical-parabolic reflector having a vertex line 2, a focal line 3, a focal length R , a longitudinal dimension L and an

axis or axial plane 4. Numeral 5 designates a dielectric guide comprising the metallic walls 6 and the air dielectric 7. The guide 5 is connected at one end to the transceiver 8 and has at its other end an antenna aperture 9. The mid-point or center line of the antenna aperture 9 is on the focal line 3 of reflector 1 and faces the reflector. Numeral 10 denotes a linear strip reflector attached to reflector 1 and having a length L , a thickness d_s , a dimension or width $2a$ in the plane of the parabolic contour of reflector 1, and a centerline or longitudinal axis 11 included in the axial plane 4.

In operation, microwaves of the given or design frequency are supplied by the transceiver 8 and conveyed over guide 5 to the antenna aperture 9, and thence emitted towards the main and auxiliary reflectors 1 and 10. The arrows 12 and 13 represent typical directions for the wavelets radiated by aperture 9. The front of the emitted wavelets, in the plane of the parabolic contour of reflector 1, is substantially circular. The wavelets impinging upon reflectors 1 and 10 are reflected or reradiated, as well understood in the art, in diverse directions illustrated, by way of example, by arrows 14, 15, 16, 17 and 19; and maximum radio action occurs in direction 19 included in the axial plane 4. The main beam of the antenna system 9, 1 is relatively wide in the axial plane 4 and relatively narrow in the plane of the parabolic contour, or *latus rectum* plane, so that the system constitutes a fan-beam antenna. As shown by arrows 16 and 18 some of the wavelets reflected by the large reflector 1 and by the small reflector 10 are returned to the aperture 9 and guide 5. Assuming for the moment that the strip reflector 10 is omitted, the wavelets fed back by reflector 1 have in guide 5 a propagation direction opposite to that of the waves supplied by the transmitter in device 8 and, as a result, pronounced standing waves are established in guide 5. Stated differently, the guide 5, or more accurately the aperture 9, is mismatched or miscoupled to its load reflector 1, whereby detrimental reflection occurs. In accordance with the invention, the strip reflector 10 is utilized and, as will now be explained, its thickness d_s and width $2a$ are such that the energies fed back by the two reflectors 1 and 10 mutually cancel at aperture 9, whereby the formation in guide 5 of standing waves resulting from undesired feedback by reflector 1 is prevented. In other words, in transmission, the large reflector 1 is coupled to, or sees, the feed aperture 9, but the feed aperture is in effect not coupled to, or does not see, the large reflector 1; and the strip reflector is in a sense a decoupler for preventing bilateral, while permitting unilateral, coupling of the active or primary antenna element 9 and the passive or secondary antenna element 1.

The embodiment of Figs. 2 and 3 is structurally the same as that of Figs. 1 and 3 except that a main paraboloidal reflector 20 and an auxiliary disk reflector 21 are employed in place of the cylindrical parabolic reflector 1 and the strip reflector 10. Also, the main beam of the antenna system 9, 20 is relatively narrow in all planes containing the axis 22 of reflector 20 so that the system constitutes a point-beam antenna. The reflector 20 and the disk 21 are coaxially disposed. The thickness d_s and diameter $2a$ of the disk reflector 21 are the same as the thickness and the width of the strip reflector 10. In operation, the disk reflector functions to cancel the energy returned by the main reflector 20 to the

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primary antenna aperture 9, whereby standing waves are eliminated in guide 5.

The embodiment of Fig. 4 comprises a cylindrical-parabolic reflector 1 and a single-strip auxiliary reflector 10 and therefore resembles the embodiment of Figs. 1 and 3 in certain respects. The longitudinal dimension L of the reflector 1 in the system of Fig. 4 is very short as compared to that of reflector 1 in Figs. 1, 3; and in Fig. 4 the guide 5 extends perpendicular to the latus rectum of reflector 1 whereas in the embodiment of Figs. 1, 3 it is parallel to the latus rectum. Also, in the system of Fig. 4, the reflector 1 is equipped with a conductive top end plate 23 and a conductive bottom end plate 24 which, together with the transverse ends of reflector 1, form a rectangular or substantially linear antenna aperture. The secondary antenna comprising the cylindrical-parabolic reflector 1 and the end plates 23, 24 constitute a so-called "pill-box", "cheese-box" or "parallel plate" antenna reflector. A conventional pill-box antenna reflector is illustrated on page 840 of the textbook "Radio Engineers Handbook" by F. E. Terman.

In general, the operation of the embodiment of Fig. 4 is the same as described above for the cylindrical-parabolic system of Figs. 1 and 3, and a fan-beam is obtained. The plates 23, 24 function as guide members for the energy emanating from the primary antenna aperture 9 so that the illumination or energization of reflector 1 is relatively intense and a high gain is secured. The parallel plates also undesirably increase, at least to some extent, the feedback, or reflection from reflector 1 towards the primary antenna aperture 9. Hence, the utilization of a strip reflector 10, for the purpose of cancelling the feedback energy, is in a sense of more significance in the case of the system of Fig. 4 than in the system of Figs. 1, 3.

Referring to Figs. 5, 6 and 7 the method of determining the dimensions d and $2a$ of the strip and disk reflectors 10, 21 will now be explained. First of all, the amplitude of vibration at a point P, Fig. 5, of the waves received from a source S via a reflector 25, the point P and source S being at the respective distances R_P and R_S from the surface 25, may be represented by the upper half 26 of a cornu spiral 27, Fig. 7, as explained in the textbook "Theoretical Physics" by Georg Joos, pages 376-378. Thus, if the width or height of surface 25 were infinite, the amplitude at point P may be represented by the vector 28, Fig. 7, extending from the origin 29 to the asymptotic point 30, that is, between the opposite terminals, of the half spiral 26. The length dimension of vector 28 represents the resultant or integrated amplitude of the wavelets originating at S and impinging on the surface 25; and the angle between the vector 28 and the XX axis represents the integrated phase of these wavelets. If the width a of the surface 25 is finite and has a dimension corresponding to an intermediate point on the spiral A, that is, corresponding to a selected value of the parameter A of the spiral 26, an amplitude is obtained at the receiving point P which may be represented by the vector 31 extending from the origin 29 to the intermediate point. If the surface 25 begins at an intermediate point, Fig. 7, corresponding to the selected value of the parameter A and extends to infinity, the amplitude at point P may be represented by the vector 32 extending from the intermediate point to the asymptotic point 30.

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Applying the above theory to the embodiments of Figs. 1, 2 and 4, the source S and point P correspond to the aperture 9 so that $R_P=R$, Fig. 3, the focal length of reflector 1, Figs. 1 and 4, or reflector 20, Fig. 2. Also the parabolic curvatures of reflectors 1 and 20 are such that these reflectors reasonably approximate the flat surface 25, Fig. 5. It is apparent from the above that the surface 25, Fig. 5, may be divided into two parts 33 and 34, Fig. 6, which have somewhat critical widths and which produce two vectors 31 and 32 having equal lengths and therefore equal amplitudes. Moreover, the thickness d or difference in the lengths of the paths extending between the source S or point P and the two parts 33 and 34 may be selected so that vector 31 assumes a position devoted by numeral 35 and extending in a direction opposite to that of vector 32, whereby the integrated amplitude of vibration at point P of the waves received from S is zero.

The relation between the wavelength λ , the width a of the reflecting member 33, the distances R_P and R_S between the surface 34 and the point P and source S, is given as equation (35) on page 377 of the Joos textbook, and is

$$A = a \sqrt{\frac{2}{\lambda} \left(\frac{1}{R_P} + \frac{1}{R_S} \right)} \quad (1)$$

or, since in Fig. 3 $R_P=R_S=R$ (2)

$$A = a \sqrt{\frac{4}{\lambda R}} \quad (3)$$

or,

$$a = A \sqrt{\frac{\lambda R}{4}} = \frac{A}{2} \sqrt{\lambda R} \quad (4)$$

where λ is the mean or design wavelength and, as already indicated, A is a parameter of the cornu spiral. For plane or flat reflecting surfaces 33 and 34, and for the condition vector 31 equals vector 32, the value of A, as scaled from the cornu spiral 26 is

$$A = 0.47 \quad (5)$$

hence,

$$a = 0.235 \sqrt{\lambda R} \quad (6)$$

For one embodiment constructed in accordance with Figs. 1 and 3 and successfully tested,

$$\lambda = 3.94'' = 10 \text{ cm.} \quad (7)$$

and

$$R = 30.5'' = 77.5 \text{ cm.} = 7.75\lambda \quad (8)$$

so that

$$a = 2.62'' = 0.665\lambda \quad (9)$$

It follows from the above that the critical or optimum dimension $2a$ for the width of the flat strip reflector 10, Figs. 1, 3 and 4, used in the embodiments comprising a cylindrical parabolic reflector having a focal length of 30.5 inches, is 5.24'' or 1.33 wavelengths. For the comparable paraboloidal system, Figs. 2 and 3, the optimum diameter $2a$ of the flat disk reflector 21 is 5.24 inches. If the reflecting surface of the strip or disk reflector is parabolic, instead of flat, the parameter A is slightly larger than 0.47 as, for example, 0.6 and the dimension $2a$ is slightly greater than 5.24 inches.

The thickness d of the strip reflector 10, and of the disk reflector 21, may be determined from Fig. 7 by scaling the phase angles θ_{31} and θ_{32} , respectively, or vectors 31 and 32 and rotating vector 31 through an angle θ to the position

illustrated by vector 35 at which the sum of the phase angle θ_{35} and the phase angle θ_{32} is 180 degrees. The thickness d in wavelengths of each of reflectors 10 and 21 corresponds to one-half of the phase angle θ . As scaled from Fig. 7, θ equals about 103 degrees. In the tested embodiment of Figs. 1 and 3, the thickness

$$d = \frac{103 \text{ degrees}}{2} = 51.5 \text{ degrees} \quad (10)$$

or,

$$= \frac{\lambda}{7} = 0.565'' = 1.43 \text{ cm.} \quad (11)$$

was therefore utilized. The value $\lambda/7$ is not extremely critical since successful results are obtainable when d has any value included in the range of $\lambda/5$ to $\lambda/9$.

The transmitting and receiving directive patterns for the system of Figs. 1, 3, or for the system of Figs. 2 and 3, are the same, in accordance with the well-known reciprocity theorem. In the transmitting and receiving patterns, the top or peak of the major lobe is slightly depressed by reason of the front position of the primary antenna element. The primary element shadows the vertex portion of the main reflector and the attached auxiliary reflector, and the auxiliary reflector does not, therefore, appreciably affect either pattern. The mutual wave cancellation, however, obtained in transmission at the primary antenna and described above, differs considerably from that obtained in reception. The cancellation of the wavelets reflected by the main and auxiliary reflectors into the primary antenna or aperture 9, Fig. 3, is predicated on the assumption or condition that the outgoing wavelets travel along divergent radial paths of different length from the source S, Fig. 6, or aperture 9, and the components of the reflected waves return to the aperture 9 travel along convergent radial paths of different lengths. The cornu spiral, Fig. 7, and the associated equations (1) and (6) from which the value of dimension a of the auxiliary reflector is obtained, are based on the assumption or condition just described. This condition obtains in transmission but not in reception. As shown in Fig. 3, in transmission the wavelets outgoing from aperture 9 travel along the divergent radial paths 12 and 13 and the wavelets returned by the two reflectors to aperture 9 travel along the radial paths 16 and 18. In reception, however, while the wavelets incoming to, and reflected by, the two reflectors are propagated along radial paths to the aperture, the wavelets incoming from the distant station to the two reflectors travel along parallel paths of equal length. Accordingly, the cornu spiral does not represent the received energies and the dimension a of the small reflector is not such as to cause cancellation of the wavelets reflected by the two reflectors. Moreover, the auxiliary reflector is more or less shadowed by the primary antenna and its effect on the receiving operation is negligible.

Thus far, the operation of the three embodiments, Figs. 1, 3 and 2, 3, and 4 at only the mean or design frequency has been considered. Referring now to Fig. 8 and assuming the auxiliary reflector 10, Fig. 1 or 21, Fig. 2, is omitted and the transmitter frequency is changed or varied, the intensity of the standing wave pattern at a given point in the guide 5 passes through maximum and minimum values as the focal length R , in wavelengths, of reflector 1

or 20 passes successively through quarter wavelength values, that is, as the round trip distance $2R$ in wavelengths successively assumes values corresponding to a multiple of a half wavelength.

The greater the value of R , the closer in time or wavelength separation the successive maximum or minimum values are; and for a large value of R , such as $R=7.75$ wavelengths, the maximum values are very close together and a narrow frequency band is obtained. Stated differently, when the distance $2R$ is very large the difference in wavelengths between two waves producing, at the given point in the guide, adjacently successive maxima is a small percentage of the distance $2R$ whereas, when $2R$ is small, the aforesaid difference is a large percentage of the distance $2R$. When the auxiliary reflector is utilized the mismatch effect is not only corrected at the mean frequency but is minimized at substantially all frequencies in the band, since the thickness, $d=\lambda/7$, is a relatively small fraction of all wavelengths in the band.

Referring to Fig. 8, the dotted curve 36 and the full line curve 37 illustrate, respectively, the measured bandwidth characteristics, taken over the 9.45-10 centimeter band, for the system of Fig. 4 without, and with, the auxiliary reflector 10. As shown in this figure, in the central 9.5-9.85 centimeter portion of the band, the curve 36 for the prior art system contains the highly undesirable maximum standing wave peak 38 at 9.65 centimeters. The two minima 39 relatively close together and the two maxima 38 are relatively close together. The two usable portions or bandwidths, each centered on a minimum point 39 and extending below five decibels, are very narrow. On the other hand, the curve 37 is relatively flat over the wide band 9.5-9.9, and in the central region contains no maximum point, so that the system of the invention has a very wide operating bandwidth.

Referring to Figs. 9, 10 and 11, the system of Figs. 9 and 10 is the same as that of Figs. 1 and 3 except that the auxiliary reflector 40 comprises two strip reflectors 41 and 42 which are attached to the reflector 1 in place of the single strip auxiliary reflector 10. The strip reflectors are spaced equally from the axial plane 4 and extend parallel to the vertex line 2 and focal line 3 of reflector 1. The system of Figs. 10 and 11 is the same as that of Figs. 2 and 3 except that a ring reflector 43 is used in place of the disk reflector 21, the ring reflector 43 and the paraboloidal reflector 20 being coaxially disposed. As explained below, the spacing a_1 and the spacing a_2 , Fig. 9, between the axial plane 4, Fig. 11, and the inner edges 44 and the outer edges 45, respectively, of the strip reflectors 41 and 42, and the thickness d_m of each strip reflector, are such as to suppress the standing wave established in guide 5 by the main reflector 1. Similarly the spacing a_1 and the spacing a_2 between the axis 22 of reflector 20 and the inner edge 46 and the outer edge 47 of the ring reflector 43, and the thickness d_m of reflector 43, are such as to cancel standing waves produced in guide 5 by the paraboloidal reflector 20.

Referring to Fig. 12, the manner of determining the dimensions a_1 and a_2 will now be explained. First, the three component vectors 47, 48 and 49, having equal lengths are disposed on the cornu spiral 27 so as to obtain two particular values A_1 and A_2 of the parameter A . The particular value A_1 corresponds to a_1 and is at the one-third point, and the particular value A_2 corresponds to a_2 and

primary antenna aperture 9, whereby standing waves are eliminated in guide 5.

The embodiment of Fig. 4 comprises a cylindrical-parabolic reflector 1 and a single-strip auxiliary reflector 10 and therefore resembles the embodiment of Figs. 1 and 3 in certain respects. The longitudinal dimension L of the reflector 1 in the system of Fig. 4 is very short as compared to that of reflector 1 in Figs. 1, 3; and in Fig. 4 the guide 5 extends perpendicular to the latus rectum of reflector 1 whereas in the embodiment of Figs. 1, 3 it is parallel to the latus rectum. Also, in the system of Fig. 4, the reflector 1 is equipped with a conductive top end plate 23 and a conductive bottom end plate 24 which, together with the transverse ends of reflector 1, form a rectangular or substantially linear antenna aperture. The secondary antenna comprising the cylindrical-parabolic reflector 1 and the end plates 23, 24 constitute a so-called "pill-box", "cheese-box" or "parallel plate" antenna reflector. A conventional pill-box antenna reflector is illustrated on page 840 of the textbook "Radio Engineers Handbook" by F. E. Terman.

In general, the operation of the embodiment of Fig. 4 is the same as described above for the cylindrical-parabolic system of Figs. 1 and 3, and a fan-beam is obtained. The plates 23, 24 function as guide members for the energy emanating from the primary antenna aperture 9 so that the illumination or energization of reflector 1 is relatively intense and a high gain is secured. The parallel plates also undesirably increase, at least to some extent, the feedback, or reflection from reflector 1 towards the primary antenna aperture 9. Hence, the utilization of a strip reflector 10, for the purpose of cancelling the feedback energy, is in a sense of more significance in the case of the system of Fig. 4 than in the system of Figs. 1, 3.

Referring to Figs. 5, 6 and 7 the method of determining the dimensions d and $2a$ of the strip and disk reflectors 10, 21 will now be explained. First of all, the amplitude of vibration at a point P, Fig. 5, of the waves received from a source S via a reflector 25, the point P and source S being at the respective distances R_P and R_S from the surface 25, may be represented by the upper half 26 of a cornu spiral 27, Fig. 7, as explained in the textbook "Theoretical Physics" by Georg Joos, pages 376-378. Thus, if the width or height of surface 25 were infinite, the amplitude at point P may be represented by the vector 28, Fig. 7, extending from the origin 29 to the asymptotic point 30, that is, between the opposite terminals, of the half spiral 26. The length dimension of vector 28 represents the resultant or integrated amplitude of the wavelets originating at S and impinging on the surface 25; and the angle between the vector 28 and the XX axis represents the integrated phase of these wavelets. If the width a of the surface 25 is finite and has a dimension corresponding to an intermediate point on the spiral A, that is, corresponding to a selected value of the parameter A of the spiral 26, an amplitude is obtained at the receiving point P which may be represented by the vector 31 extending from the origin 29 to the intermediate point. If the surface 25 begins at an intermediate point, Fig. 7, corresponding to the selected value of the parameter A and extends to infinity, the amplitude at point P may be represented by the vector 32 extending from the intermediate point to the asymptotic point 30.

Applying the above theory to the embodiments of Figs. 1, 2 and 4, the source S and point P correspond to the aperture 9 so that $R_P=R$, Fig. 3, the focal length of reflector 1, Figs. 1 and 4, or reflector 20, Fig. 2. Also the parabolic curvatures of reflectors 1 and 20 are such that these reflectors reasonably approximate the flat surface 25, Fig. 5. It is apparent from the above that the surface 25, Fig. 5, may be divided into two parts 33 and 34, Fig. 6, which have somewhat critical widths and which produce two vectors 31 and 32 having equal lengths and therefore equal amplitudes. Moreover, the thickness d or difference in the lengths of the paths extending between the source S or point P and the two parts 33 and 34 may be selected so that vector 31 assumes a position devoted by numeral 35 and extending in a direction opposite to that of vector 32, whereby the integrated amplitude of vibration at point P of the waves received from S is zero.

The relation between the wavelength λ , the width a of the reflecting member 33, the distances R_P and R_S between the surface 34 and the point P and source S, is given as equation (35) on page 377 of the Joos textbook, and is

$$A = a \sqrt{\frac{2}{\lambda} \left(\frac{1}{R_P} + \frac{1}{R_S} \right)} \quad (1)$$

$$\text{or, since in Fig. 3 } R_P = R_S = R \quad (2)$$

$$A = a \sqrt{\frac{4}{\lambda R}} \quad (3)$$

or,

$$a = A \sqrt{\frac{\lambda R}{4}} = \frac{A}{2} \sqrt{\lambda R} \quad (4)$$

where λ is the mean or design wavelength and, as already indicated, A is a parameter of the cornu spiral. For plane or flat reflecting surfaces 33 and 34, and for the condition vector 31 equals vector 32, the value of A, as scaled from the cornu spiral 26 is

$$A = 0.47 \quad (5)$$

hence,

$$a = 0.235 \sqrt{\lambda R} \quad (6)$$

For one embodiment constructed in accordance with Figs. 1 and 3 and successfully tested,

$$\lambda = 3.94'' = 10 \text{ cm.} \quad (7)$$

and

$$R = 30.5'' = 77.5 \text{ cm.} = 7.75\lambda \quad (8)$$

so that

$$a = 2.62'' = 0.665\lambda \quad (9)$$

It follows from the above that the critical or optimum dimension $2a$ for the width of the flat strip reflector 10, Figs. 1, 3 and 4, used in the embodiments comprising a cylindrical parabolic reflector having a focal length of 30.5 inches, is 5.24'' or 1.33 wavelengths. For the comparable paraboloidal system, Figs. 2 and 3, the optimum diameter $2a$ of the flat disk reflector 21 is 5.24 inches. If the reflecting surface of the strip or disk reflector is parabolic, instead of flat, the parameter A is slightly larger than 0.47 as, for example, 0.6 and the dimension $2a$ is slightly greater than 5.24 inches.

The thickness d of the strip reflector 10, and of the disk reflector 21, may be determined from Fig. 7 by scaling the phase angles θ_{31} and θ_{32} , respectively, or vectors 31 and 32 and rotating vector 31 through an angle θ to the position

illustrated by vector 35 at which the sum of the phase angle θ_{35} and the phase angle θ_{32} is 180 degrees. The thickness d in wavelengths of each of reflectors 10 and 21 corresponds to one-half of the phase angle θ . As scaled from Fig. 7, θ equals about 103 degrees. In the tested embodiment of Figs. 1 and 3, the thickness

$$d = \frac{103 \text{ degrees}}{2} = 51.5 \text{ degrees} \quad (10)$$

or,

$$= \frac{\lambda}{7} = 0.565'' = 1.43 \text{ cm.} \quad (11)$$

was therefore utilized. The value $\lambda/7$ is not extremely critical since successful results are obtainable when d has any value included in the range of $\lambda/5$ to $\lambda/9$.

The transmitting and receiving directive patterns for the system of Figs. 1, 3, or for the system of Figs. 2 and 3, are the same, in accordance with the well-known reciprocity theorem. In the transmitting and receiving patterns, the top or peak of the major lobe is slightly depressed by reason of the front position of the primary antenna element. The primary element shadows the vertex portion of the main reflector and the attached auxiliary reflector, and the auxiliary reflector does not, therefore, appreciably affect either pattern. The mutual wave cancellation, however, obtained in transmission at the primary antenna and described above, differs considerably from that obtained in reception. The cancellation of the wavelets reflected by the main and auxiliary reflectors into the primary antenna or aperture 9, Fig. 3, is predicated on the assumption or condition that the outgoing wavelets travel along divergent radial paths of different length from the source S, Fig. 6, or aperture 9, and the components of the reflected waves return to the aperture 9 travel along convergent radial paths of different lengths. The cornu spiral, Fig. 7, and the associated equations (1) and (6) from which the value of dimension a of the auxiliary reflector is obtained, are based on the assumption or condition just described. This condition obtains in transmission but not in reception. As shown in Fig. 3, in transmission the wavelets outgoing from aperture 9 travel along the divergent radial paths 12 and 13 and the wavelets returned by the two reflectors to aperture 9 travel along the radial paths 16 and 18. In reception, however, while the wavelets incoming to, and reflected by, the two reflectors are propagated along radial paths to the aperture, the wavelets incoming from the distant station to the two reflectors travel along parallel paths of equal length. Accordingly, the cornu spiral does not represent the received energies and the dimension a of the small reflector is not such as to cause cancellation of the wavelets reflected by the two reflectors. Moreover, the auxiliary reflector is more or less shadowed by the primary antenna and its effect on the receiving operation is negligible.

Thus far, the operation of the three embodiments, Figs. 1, 3 and 2, 3, and 4 at only the mean or design frequency has been considered. Referring now to Fig. 8 and assuming the auxiliary reflector 10, Fig. 1 or 21, Fig. 2, is omitted and the transmitter frequency is changed or varied, the intensity of the standing wave pattern at a given point in the guide 5 passes through maximum and minimum values as the focal length R , in wavelengths, of reflector 1

or 20 passes successively through quarter wavelength values, that is, as the round trip distance $2R$ in wavelengths successively assumes values corresponding to a multiple of a half wavelength.

The greater the value of R , the closer in time or wavelength separation the successive maximum or minimum values are; and for a large value of R , such as $R=7.75$ wavelengths, the maximum values are very close together and a narrow frequency band is obtained. Stated differently, when the distance $2R$ is very large the difference in wavelengths between two waves producing, at the given point in the guide, adjacently successive maxima is a small percentage of the distance $2R$ whereas, when $2R$ is small, the aforesaid difference is a large percentage of the distance $2R$. When the auxiliary reflector is utilized the mismatch effect is not only corrected at the mean frequency but is minimized at substantially all frequencies in the band, since the thickness, $d=\lambda/7$, is a relatively small fraction of all wavelengths in the band.

Referring to Fig. 8, the dotted curve 36 and the full line curve 37 illustrate, respectively, the measured bandwidth characteristics, taken over the 9.45-10 centimeter band, for the system of Fig. 4 without, and with, the auxiliary reflector 10. As shown in this figure, in the central 9.5-9.85 centimeter portion of the band, the curve 36 for the prior art system contains the highly undesirable maximum standing wave peak 38 at 9.65 centimeters. The two minima 39 relatively close together and the two maxima 38 are relatively close together. The two usable portions or bandwidths, each centered on a minimum point 39 and extending below five decibels, are very narrow. On the other hand, the curve 37 is relatively flat over the wide band 9.5-9.9, and in the central region contains no maximum point, so that the system of the invention has a very wide operating bandwidth.

Referring to Figs. 9, 10 and 11, the system of Figs. 9 and 10 is the same as that of Figs. 1 and 3 except that the auxiliary reflector 40 comprises two strip reflectors 41 and 42 which are attached to the reflector 1 in place of the single strip auxiliary reflector 10. The strip reflectors are spaced equally from the axial plane 4 and extend parallel to the vertex line 2 and focal line 3 of reflector 1. The system of Figs. 10 and 11 is the same as that of Figs. 2 and 3 except that a ring reflector 43 is used in place of the disk reflector 21, the ring reflector 43 and the paraboloidal reflector 20 being coaxially disposed. As explained below, the spacing a_1 and the spacing a_2 , Fig. 9, between the axial plane 4, Fig. 11, and the inner edges 44 and the outer edges 45, respectively, of the strip reflectors 41 and 42, and the thickness d_m of each strip reflector, are such as to suppress the standing wave established in guide 5 by the main reflector 1. Similarly the spacing a_1 and the spacing a_2 between the axis 22 of reflector 20 and the inner edge 46 and the outer edge 47 of the ring reflector 43, and the thickness d_m of reflector 43, are such as to cancel standing waves produced in guide 5 by the paraboloidal reflector 20.

Referring to Fig. 12, the manner of determining the dimensions a_1 and a_2 will now be explained. First, the three component vectors 41, 48 and 49, having equal lengths are disposed on the cornu spiral 27 so as to obtain two particular values A_1 and A_2 of the parameter A . The particular value A_1 corresponds to a_1 and is at the one-third point, and the particular value A_2 corresponds to a_2 and

is at the two-thirds point, of the spiral. As scaled from the spiral, we have

$$A_1 = 0.40 \quad (12)$$

and

$$A_2 = 0.75 \quad (13)$$

Now, from equations (4), (7) and (8) we have

$$a_1 = \frac{A_1}{2} \sqrt{\lambda R} = 2.2'' = 0.554\lambda \quad (14)$$

and

$$a_2 = \frac{A_2}{2} \sqrt{\lambda R} = 4.2'' = 1.064\lambda \quad (15)$$

Hence, the widths of reflectors 41 and 42, and the radial width of the ring reflector 43, are each

$$a_2 - a_1 = 2'' = 0.510\lambda \quad (16)$$

The vector 48 corresponds to the wavelets reflected by the double auxiliary reflector 40, Fig. 9, and the vectors 47 and 49 correspond respectively to the wavelets reflected by the vertex or inner portion 50, Fig. 9, and the outer portion 51 of the cylindrical parabolic reflector 1. Also, vector 48 corresponds to the reflection from the ring reflector 43, Fig. 10, and the vectors 47 and 49 correspond respectively to the reflections from the vertex or inner portion 52 and the outer portion 53 of reflector 20. Vector 54 is identical with vector 49 and vector 55 represents the resultant of vectors 47 and 54. By selecting a proper thickness d_m for each of the strip reflectors 41, 42, or for the ring reflector 43, the vector 48 may be rotated clockwise through the angle θ_m to the position illustrated by vector 56, at which the sum of the phase angle θ_{56} of vector 56 and the phase angle θ_{55} of vector 55 equals 180 degrees. The physical thickness d_m of the reflectors 40 and 43, in wavelengths, is selected so as to correspond to one-half the scaled value of the angle θ_m . Since, from the curve, θ_m equals about 144 degrees, we have

$$d_m = \frac{144 \text{ degrees}}{2} = 72 \text{ degrees} \quad (17)$$

$$= \frac{\lambda}{5} = 0.787'' = 2 \text{ cm.} \quad (18)$$

It is thus apparent that, in the embodiment of Figs. 1 and 4, each comprising a cylindrical-parabolic reflector, the mismatch effect may be corrected by utilizing, in place of the single-strip reflector 10, the double-strip reflector 40, Fig. 9. In particular, the single-strip auxiliary reflector used in the tested embodiment described above and having a thickness of one seventh of the mean wavelength may be replaced by a dual-strip auxiliary reflector comprising two metallic strip reflectors 41 and 42, one on each side of the axial plane 4 and each having a thickness of a fifth of the mean wavelength. The reflectors 41 and 42 have their inner edges 44 at 0.554 wavelength from the axial plane 4 and each has a width of 0.510 wavelength. Similarly, in the comparable paraboloidal embodiment, Fig. 2, the mismatch may be eliminated by employing, in place of the disk reflector 21, a coaxial ring reflector 43 having a thickness in the order of $\lambda/5$, the inner and outer radii of the disk reflector being 0.554 and 1.064 wavelengths, respectively.

In the foregoing description it has been assumed that the main reflector has a very slight curvature corresponding to the curvature of a parabola having a very large focal length, and that the size or opening of the reflector is fairly small, com-

parable to the relatively flat portion of the aforesaid parabola in the region of its vertex or axis, whereby the main reflector may be regarded as flat, as shown in Fig. 6. If the focal length is very small the main reflector may have a pronounced curvature and, preferably but not necessarily, a slight correction for the curvature may be made. Again, in the case of reflectors having short focal lengths, the intensity of the illumination of the peripheral portions of the main reflector, and hence the intensity of the energies fed back to the primary antenna by these peripheral portions, is dependent upon the directional characteristic of the primary antenna. Consequently, preferably but not necessarily, a slight correction for the directional characteristic of the primary antenna may be made. These corrections are relatively small and may easily be made by one skilled in the art.

Although the invention has been explained in connection with specific embodiments it is to be understood that it is not to be limited to the embodiments described inasmuch as other apparatus and arrangements may be used in successfully practicing the invention. To illustrate, satisfactory results may be obtained by positioning the auxiliary reflector at a critical distance in back of the main reflector and providing a properly dimensioned and properly located aperture or window in the main reflector.

What is claimed is:

1. In combination, a primary antenna element for transmitting and receiving radio energy of a given wavelength, a large main reflector, a plurality of spaced small reflectors positioned at equal distances from said element and between said element and said main reflector, the spacing between said small reflectors and the reflective area of each small reflector being dependent upon said wavelength.

2. A combination in accordance with claim 1, the distance between said element and said main reflector being approximately 0.20 wavelength greater than the distance between said element and said plurality of small reflectors.

3. In combination, a large cylindrical-parabolic reflector having an axial plane and a vertex line, a dielectric guide having at one end an antenna aperture, said aperture extending perpendicular to and having its mid-point included in said axial plane, a plurality of parallel strip reflectors attached to the front of said large reflector, said strip reflectors being positioned on opposite sides of and at equal distances from said vertex line, the spacings between said aperture and said strip reflectors being equal and different from the spacing between said aperture and said large reflector, and a transmitter connected to the other end of said dielectric guide.

4. In combination, a large substantially flat reflector having a parabolic contour and a focal length R , a primary antenna element at the focus of said reflector for radiating waves having a wavelength λ and a circular wave front in the plane of said contour, a first small reflecting member included between said large reflector and said element, said small member being perpendicular to and spaced from the axis of the large reflector, the distance between said axis and the edge of said small member nearer to said axis being equal to

$$0.40 \sqrt{\frac{\lambda R}{4}}$$

and the separation between said axis and the edge

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of said small member farther from said axis being equal to

$$0.75\sqrt{\frac{\lambda R}{4}}$$

and a second small reflecting member included between said large reflector and said element, said second small member being positioned on the other side of and spaced from said axis, the distance between said axis and the edge of said second member nearest said axis being equal to the first mentioned distance and the separation between said axis and the edge of said second member farther from said axis being equal to said first mentioned separation.

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