

June 24, 1958

C. E. McCLELLAN
REFLECTING SURFACES

2,840,819

Filed June 20, 1950

2 Sheets-Sheet 1

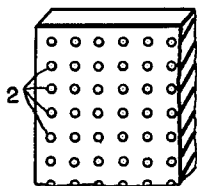


Fig. 1.

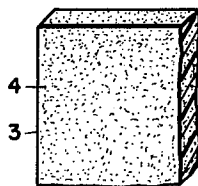


Fig. 2.

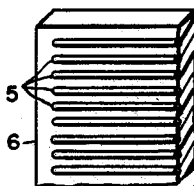


Fig. 2a.

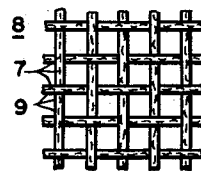


Fig. 2b.

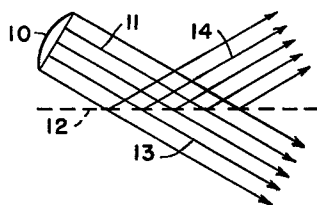


Fig. 3.

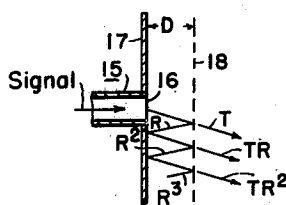


Fig. 4.

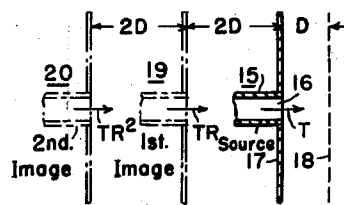


Fig. 5.

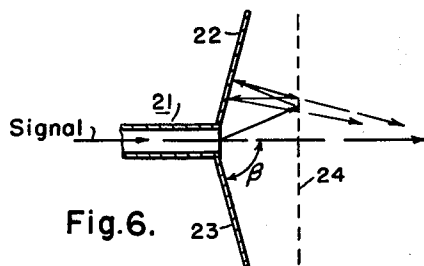


Fig. 6.

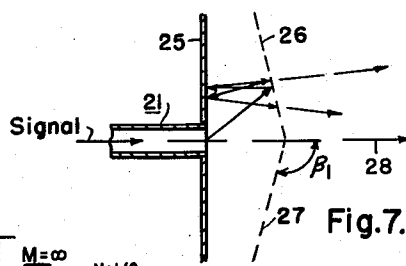


Fig. 7.

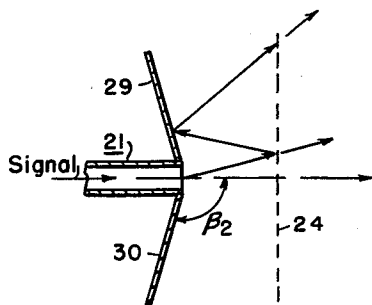


Fig. 8.

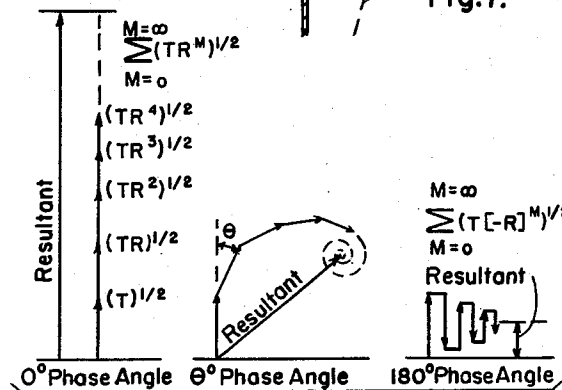


Fig. 9.

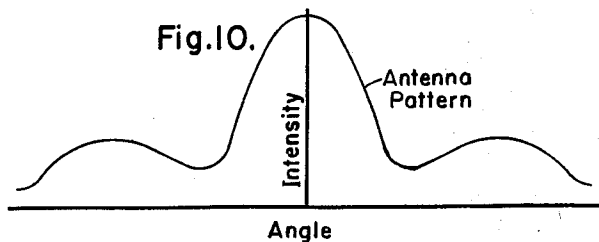


Fig. 10.

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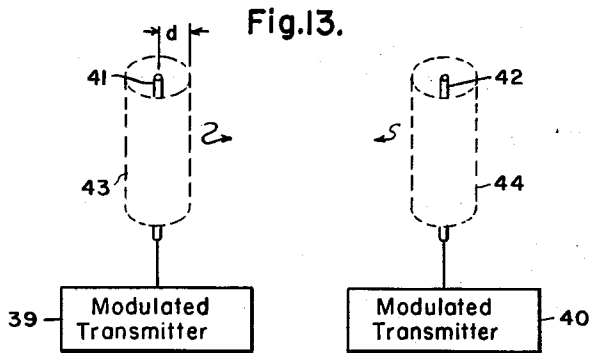
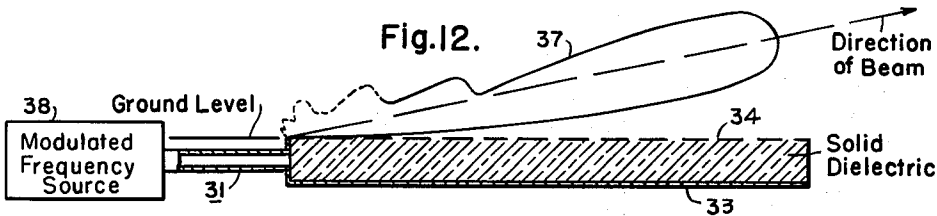
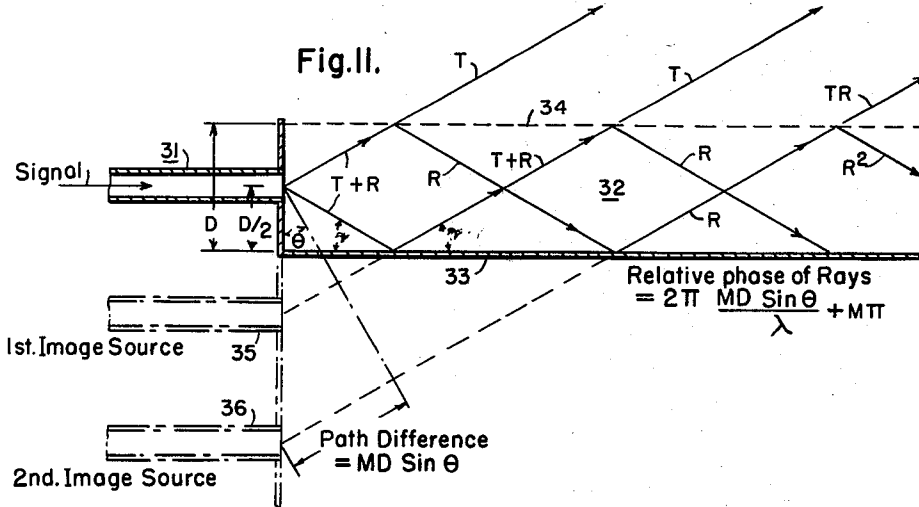
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WITNESSES:

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2,840,819

REFLECTING SURFACES

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Application June 20, 1950, Serial No. 169,250

10 Claims. (Cl. 343—781)

This invention relates generally to devices for controlling radiant energy, and more particularly to systems for applying to the control of radiant energy, devices which partially reflect radiant energy and which partially transmit radiant energy, as distinguished from devices which partially absorb and partially transmit radiant energy, such devices finding particular, though not exclusive, application in the art of directing radio waves.

There has been, in the recent past, considerable development of novel devices for directing electromagnetic wave energy, especially by means of metallic and dielectric lenses, at ultra-high frequencies. There has further been considerable development in the field of controllable absorbing devices for wave energy at ultra-high frequencies. The present invention, in radical contradistinction to devices of the character indicated, depends upon a novel principle, i. e., that of controlling radiant energy by means of devices which are partially reflective and partially transmissive of radiant energy, and in which energy absorption plays at most an insignificant role.

When a resonant dipole is placed in an electromagnetic field, absorption and re-radiation create a considerable disturbance in the field. As the dimensions of the disturbing element are reduced below one-half wave length, the magnitude of the disturbance decreases rapidly, and may be made as small as desired by suitably reducing the dimensions of the conductor. Energy loss in the conductor due to current flow may be made small, and for practical purposes is negligible in a good conductor.

When a large number of electrically conducting particles or elements are disposed, more or less uniformly, in a surface, and with the spacing of adjacent particles only a fraction of a wave length, the surface can be caused to vary in its properties from perfect transparency with respect to radio waves to complete opacity and reflectivity, by properly selecting the sizes and distribution density of the particles or elements. The present invention concerns itself primarily with the intermediate property, wherein a predetermined fraction of the wave energy impinging on a surface is transmitted, and the remainder reflected. Surfaces having the latter property are hereinafter referred to as partially reflecting surfaces, or as being partially reflective and partially transmissive.

In general, partially reflecting surfaces may consist of a layer of non-conducting material, utilized as a supporting structure for a large number of reflecting or conductive particles, or other small reflecting or conductive objects. For example, a large number of tiny discs, or particles, of copper or aluminum foil may be secured to a sheet of plastic material, such as Plexiglas, or conducting particles may be molded integrally with a plastic medium. Alternatively, the partially reflecting surface may be fabricated of cloth woven from threads containing metallic fibers, placed intermittently along the length of the thread. Further, partially reflecting surfaces may be fabricated of metallic conductors, comprising, for example, a large number of parallel rods or wires, oriented

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with their lengthwise dimensions perpendicular to the electric vector component of the electromagnetic wave, and with their spacings and thicknesses in the direction of that vector, and suitably selected.

Partially reflecting surfaces may be constructed in various shapes, configurations and sizes, and with varying densities and distributions of reflecting particles, to provide various degrees of reflection and transmission. Also, in a given surface the distribution of reflecting particles may be various, or their dimensions may be various, at different portions of the surface, to provide a spatially non-uniform reflection coefficient, or a different reflection coefficient at different angles of wave incidence.

Partially reflecting surfaces may be utilized to provide radar camouflage, as by interposing semi-reflecting netting between a military objective and a radar equipment, to effect blending of the objective with the surrounding countryside. Such surfaces may be employed, additionally, in the construction of dummy radar targets.

A more generally useful application may reside in utilizing a partially reflecting surface for splitting or dividing a beam of electromagnetic radiation, emanating from a single directive transmitting antenna, into a plurality of directions, with any desired division of the available energy in the several directions, and with control of directivity.

As a further embodiment of the present invention and a further application of the principles thereof, a plane partial reflector and a plane total reflector may be arranged parallel with one another, or at any desired mutual angle, and wave energy introduced therebetween, as by means of a wave guide having its end extending through the total reflector, or the partially reflecting surface. If the energy transmitted by the partial reflector be T and the energy reflected be R , with $R+T=1$, the reflected energy R will be re-reflected from the total reflector, and again be partially reflected and partially transmitted by the partial reflector. The radiation pattern of a system of this character, where the surfaces are parallel, will be, in accordance with known principles, that which would be generated by an array consisting of the wave guide and a series of images thereof, one behind the other with a separation between adjacent images of $2D$, where D is the spacing between the surfaces, and effective signal strengths sequentially of TR , TR^2 , TR^3 , ... If the spacing D is chosen to equal a whole number of half wave lengths, the signals normal to the reflecting surfaces, and deriving from the images, will all be in-phase. For certain angles the signals will tend to cancel, and a directional pattern will be generated. This pattern may be modified in various ways in accordance with further embodiments of the invention, as by varying the angle between the planes, the spacing of the planes, and the shapes of the planes. A plurality of wave energy sources may be utilized with various relative positions, and the energy may be initially transmitted at various angles with respect to the surfaces.

In accordance with still a further embodiment of the invention, a source of electromagnetic wave energy radiates into a space between a partially reflecting surface and a totally reflecting surface and in a direction parallel to the surfaces. In such case the system operates as would a wave guide having considerable leakage from one wall and provides a narrow beam at a very small angle with respect to the plane of the surfaces. A beam of this character may be employed as a localizer beam for blind flying or landing of aircraft and may be varied in directivity by frequency modulating the impressed wave energy to provide a more accurate indication of the directivity of the beam aboard the aircraft. Since a wave guide of the character described may be filled with solid dielectric, the radiating system may be built into and be part of a landing runway.

It has been determined that partially reflecting surfaces, when combined with totally reflecting surfaces in the manner above indicated, provide extremely effective transmitting antennae, since except for losses all the energy applied to the radiating system is ultimately radiated. On the other hand, when the system is employed for reception, a large part of the received energy is reflected by the partially reflecting surface, while that part which passes through the partially reflecting surface is largely reflected and passes out through the partially reflecting surface to be re-radiated.

The last-described property—that of effective transmission and ineffective reception—finds extended and valuable application where a plurality of transmitters are operative in a given vicinity. In the conventional system of this character, signals transmitted by one of the transmitters and impinging on the antenna system of another find their way into the amplifier stage of the latter and there modulate the output of the latter. Once this has taken place, the two signals cannot be separated in a receiver. In accordance with the present invention, transmission may take place from antennae of a plurality of transmitters through partially reflecting surfaces, which serve effectively to shield each antenna from waves transmitted by the others, thereby to prevent intermodulation of the outputs of the transmitters.

It is, accordingly, a broad object of the present invention to provide surfaces which are partially reflective and partially transmissive of electromagnetic wave energy and which are substantially lossless.

It is a further broad object of the invention to provide novel systems for the directive propagation of radio waves, employing partially reflecting surfaces.

It is another object of the invention to provide a system for splitting a directed beam of radiant energy into a plurality of directed beams, dividing the energy in the original beam among the plurality of directed beams in any desired ratio.

It is still another object of the invention to provide a wave guide having one wall fabricated, at least in part, of a partial reflector extending longitudinally of the wave guide to enable transmission of energy from the wave guide along its entire length.

It is a further object of the invention to provide a flexible surface of woven fabric which is partially reflective and partially transmissive of electromagnetic wave energy in any desired ratio and which is substantially free of energy loss.

It is still a further object of the invention to provide a wall, molded or rolled, of plastic material, which shall be partially reflective and partially transmissive of electromagnetic wave energy and which is substantially free of loss.

A further object of the invention resides in the provision of a space partially enclosed by a partially reflective surface and partially by a totally reflective surface between which energy transmitted into the space is constrained, with continual leakage of energy from the partially reflective surface.

It is still another object of the invention to provide a communication system involving a plurality of transmitters in which each of the transmitters is protected from modulation in response to energy radiated by any other of the transmitters by shielding the antennae by means of a shield comprising at least in part a partially reflecting surface.

The above and still further objects, features and advantages of the present invention will become apparent upon consideration of the following detailed description of various embodiments thereof, especially when taken in conjunction with the accompanying drawings, wherein:

Figure 1 is a view in perspective of a portion of a wall which is partially reflective and partially transmissive;

Figure 2 is a view in perspective of a modification of the structure of Figure 1, in which conducting particles are distributed through a binding material;

Figure 2a is a view in perspective of a modification of the structure of Figures 1 and 2, utilizing extended rods as conductive elements;

Figures 2b is a view in plan of a modification of the structure of Figures 1, 2, 2a, utilizing metallic filaments woven into threads of a fabric as conductive elements;

Figure 3 is a schematic representation of a beam splitting arrangement utilizing a partial reflector;

Figure 4 is a schematic representation of a directive transmitter utilizing a partially reflective surface and a fully reflective surface to generate a directive radiation pattern;

Figure 5 is a view explanatory of electrical properties of the system of Figure 4;

Figures 6, 7 and 8 are schematic representations of modifications of the system of Figure 4 in which the partially reflective and totally reflective surfaces are not parallel;

Figure 9 provides vector diagrams explanatory of the action which takes place in the system of Figure 4 for various directive angles;

Figure 10 is a plot of a resultant radiation pattern with field intensity plotted against angle of bearing produced by the system of Figure 4;

Figure 11 is a schematic showing of a chamber having a totally reflecting wall and a partially reflecting wall with wave energy transmitted longitudinally of the wave guide and leaking through the partially reflecting wall along its entire length;

Figure 12 is a plot of a radiation pattern provided by the structure of Figure 11; and

Figure 13 is a schematic representation of a transmitting system comprising a plurality of adjacent transmitters protected from intermodulation by means of partially reflecting shields.

Referring now to the drawings, and particularly to Figure 1, there is illustrated a sheet of material, fabricated of insulating material, and to the surface of which is secured a large number of small, thin, metallic discs 2. The spacing between the discs 2 is a very small fraction of a wave length, and the size of the discs of the same order of magnitude or smaller. The surface so developed represents a simple example of a partially reflecting surface. As a further example of such a surface, powdered metal may be distributed throughout a plastic sheet 3, Figure 2, as by infusing the plastic material with metallic powder 4 while the material is plastic and before the sheet is formed, thereafter forming the sheet and causing the sheet to harden. This expedient enables utilization of extremely small metallic particles with minute spacings.

In Figure 2a is illustrated a further modification of the invention, wherein thin metallic wires or rods 5 are molded into a sheet 6 of plastic material, adjacent wires or rods having a spacing equal to a fraction of a wave length, and the diameters of the wires or rods 5 being of the same order of magnitude as the spacings or less. The construction illustrated in Figure 2a forms a partially reflecting surface with respect to electromagnetic waves having an electric vector E which is directed perpendicular to the lengths of the wires or rods 5, and parallel to the plane of the plastic sheet 6. When the vector E is parallel to the rods or wires 5, the sheet becomes totally reflective. Obviously, the plastic sheet may be dispensed with provided some other means be provided for supporting the rods or wires 5 and for maintaining their relative positions.

Other modes of fabricating partially reflecting surfaces are envisaged, as by incorporating short lengths of wire in fabric. I am aware that wire has heretofore been incorporated in fabric to provide a surface totally reflective to electromagnetic waves by weaving into the

fabric metallic thread and that there has been utilized for this purpose copper or aluminum wires. In accordance with an embodiment of the present invention, illustrated in Figure 2b of the accompanying drawings, the threads 7, of which is woven a fabric 8, may themselves each include many discrete short lengths 9 of flexible metal of high conductivity, such as copper or aluminum filaments, to provide the spaced conductive particles required. The use of continuous wires of sufficient density of distribution, as in the prior art, results in a totally reflecting surface, while use of wire particles results in a partially reflecting surface. If continuous wires are woven into cloth, but in one direction only, a variation of the structure of Figure 2a may be provided, which is totally reflecting for waves polarized parallel to the threads and partially reflecting for waves polarized in a direction perpendicular to the threads.

Referring now particularly to Figure 3 of the drawings, there is illustrated a system for splitting a beam of radiation generated by a directive antenna and providing thereby two directive beams. The relative intensities of the beams may be controlled by varying the characteristics of the partially reflecting screen, and the directions of the beams may be controlled by varying the angle which the plane of the partially reflecting surface makes with respect to the directivity of the original beam.

There is, accordingly, provided a directive antenna 10, which radiates a directed beam of wave energy 11. The latter impinges on the partially reflecting screen 12, part of the energy passing directly through the screen 12 to form a transmitted beam 13 and the remainder 14 being reflected therefrom. The directed beam 11 and the reflected beam 14 make identical angles with the plane of the partially reflecting screen 12 in accordance with known laws of optics, so that the directivity of the reflected beam 14 may be readily controlled without affecting the directivity of the transmitted beam 13.

In the system of Figure 4, electromagnetic wave energy is transmitted along a wave guide 15, which terminates with its open end 16 in a wall 17 fabricated of metal, and which is accordingly totally reflective. Spaced from the wall 17 by a predetermined distance D is a partial reflector 18.

If it be assumed that the total energy transmitted from wave guide 15 toward partial reflector 18 in any direction is unity and that the energy transmitted by the partial reflector 18 is T, and that reflected is R, so that $T+R=1$, it will be evident that energy will be transmitted of magnitude T in a given direction and that energy of magnitude R will be reflected back to the totally reflecting surface 17. The latter energy will be reflected in toto to partial reflector 18, which now transmits a quantity TR and reflects a quantity R^2 . The quantity R^2 is again reflected from the totally reflecting surface 17, and a quantity TR^2 is transmitted by the partial reflector 18. The process continues theoretically to infinity, and all the energy is eventually transmitted.

The total radiation pattern transmitted by the system of Figure 4 is the same as would be transmitted by a series of image transmitters 19, 20 . . . spaced successively behind the wall by distances 2D and transmitting energy at signal strengths TR, TR^2 , TR^3 . . . , as illustrated in Figure 5 of the accompanying drawings. If the distance D be chosen as a whole number of half wave lengths, say $\lambda/2$, the signals transmitted by the image transmitters will reinforce or be in phase in the direction normal to the reflecting surfaces; while at any angle which makes the path difference from successive images equal to an odd number of half wave lengths, cancellation will occur, and minima in the total radiation pattern will exist. The minima can never go to zero since the successive vectors contributing to the final result become smaller in amplitude, as shown for the angle θ in Figure 9. For zero phase angle with the stated spacing between reflecting surfaces, the vectors contributing to the

total radiation pattern are in phase, as shown in Figure 9, while for an angle of 180° , successive vectors are of opposite phase but of decreasing magnitude. The numerical value of the resultant vector depends upon the reflection coefficient of the reflecting surface and can vary over a wide range. The total radiation pattern is illustrated in Figure 10.

The radiation pattern of Figure 10 may be widely varied by varying the spacing D. Other modes of varying the radiation pattern produced by a system, generically of the character illustrated in Figure 4, are illustrated in Figures 6, 7 and 8 of the accompanying drawings.

In Figure 6 is illustrated a wave guide 21, terminated at two diverging and totally reflecting surfaces 22, 23 which make each an angle β of less than 90° with respect to the axis of the wave guide. A plane partially reflecting surface 24 is further provided, extending in a plane perpendicular to the axis of the wave guide. If the spacing of the partial reflector 24 from the mouth of the wave guide 21 be $\lambda/2$, or some integral multiple thereof, a maximum of radiation will occur in the direction of the axis of the wave guide. The fact that the walls 22, 23 make an angle β results, however, in a concentration of energy in the direction of this axis since energy reflected back by the partially reflecting surface tends to be re-reflected by the totally reflecting surface, at successively reduced angles for each successive reflection.

A similar result may be accomplished in the system of Figure 7 wherein the total reflector 25 extends perpendicularly to the axis of the wave guide 21, and where two partially reflecting surfaces 26, 27 making each an angle β_1 , with respect to the axis 28 of wave guide 21 are provided, $\beta_1 > 90^\circ$. The effect of the partial reflectors 26, 27 at angle β_1 is to direct energy, which tends to diverge in the system of Figure 4, by successive reflections always toward a line collinear with the axis of the wave guide. This action is particularly effective if only a small percentage of impinging energy is transmitted by the reflecting surfaces utilized so that a great many reflections take place, each of which involves considerable energy.

In the system of Figure 8, contrary to the results attainable by the system of Figures 4, 6, and 7, a widely divergent beam is generated by utilizing an angle β_2 of greater than 90° , for the totally reflecting walls 29, 30, the partial reflector 24 being plane.

Various additional combinations of relative spacings and angular relations may readily be envisaged to produce radiations of particular character by taking advantage of the general principles above explained and by modification of the specific structures illustrated and described.

Turning now to Figure 11 of the accompanying drawings, there is illustrated a wave transmission medium comprising a wave guide 31, which radiates into a space 32 between a fully reflecting surface 33 and a partially reflecting surface 34.

Energy directed toward fully reflecting surface 33 at an angle of incidence γ is reflected at an angle of reflection γ , the total energy being $T+R$. The reflected beam impinges on the partially reflecting surface 34, T units of energy being transmitted and R units reflected at the same angle of reflection γ . The energy R again suffers a total reflection at surface 33 to surface 34 where TR units are transmitted and R^2 units reflected. The process continues until all this original energy has been dissipated. The effect at each angle γ is as if a succession of image sources of radiant energy existed as at 35, 36, which themselves generate the beams of energy T, TR For those angles for which the outputs of the image sources add, by reason of similar phases in the energy, an augmented beam exists. For angles at which phase opposition occurs, a diminished beam exists. The total effect, particularly when the reflectivity of the surface is great, is to spread the total energy along the surface 34 and to provide effective radiation from a tre-

mendously extended surface corresponding with 34. The transmission medium existing between the surfaces 33 and 34 may be solid dielectric, and the structure may be built into a runway of a landing field. The resulting system may then be employed for guiding aircraft to a blind landing, i. e., as a radio beacon in accordance with principles which are well understood per se.

In Figure 12 is provided a plot of the intensities of the radiant energy beam resultant from a structure of the character of that illustrated in Figure 11 for various angles of elevation from which may be perceived that a low angle, high intensity beam 37 is generated in which the radiated energy is largely concentrated in a single direction.

If desired, the energy provided to the wave guide 31 may be generated by a frequency modulated source 38. The directivity of the beam 37 is a function of the frequency of the carrier energy of the beam.

Accordingly, the beam 37 varies in directivity in synchronism with the modulations of the carrier, and this variation may be utilized in accordance with principles well understood per se aboard an aircraft in process of landing for following the beam 37 to a landing.

Referring now more particularly to Figure 13 of the accompanying drawings, there is illustrated schematically, two transmitters 39, 40 of modulated carrier frequency having antennae 41, 42, respectively, and which may be assumed to be close to one another so that the signal level at each of the transmitters due to the signal provided by the other is high. When operated in conventional fashion, it is found that each of the antennae 41 and 42 acts as a receiving antenna for transmissions from the other of the transmitters 39, 40. The received energy finds its way into the amplifier stage of the transmitter connected to the receiving antenna, and there modulates the output of the amplifier. The intermodulation signal with outputs of transmitters 39, 40, once it occurs, cannot be removed at a receiving station.

In accordance with the present invention, each of antennae 41, 42 may be surrounded with a partially reflecting shield 43, 44 preferably of relatively great reflective power. If antennae 41, 42 are vertical rod radiators, each rod may be surrounded by a partially conducting surface in the form of a cylinder. Since the cylinders are loss free, the energy transmitted by antennae 41, 42 is eventually radiated through the shields 43, 44, albeit after a plurality of reflections. On the other hand, energy originating at one of the antennae, say 42, and impinging on the shield 43 associated with the other of the antennae, say 41, is largely reflected therefrom. That portion of the energy deriving from antenna 42 which passes through partially reflecting shield 43 is in part intercepted by antenna 41 but is largely reflected by the interior surface of the partially reflecting shield 43 and eventually finds its way externally of the shield.

It will be clear that an optimum relation between the radius of each of the shields 43, 44, with respect to the wave length of the transmitted carrier, occurs when this distance d equals an integral number of wave lengths of the transmitted energy, since in such case the directly transmitted carrier energy, i. e., that transmitted without reflection and that transmitted only after one or more reflections, is in phase. The relationship stated should be understood to be optimum but not essential.

The pattern of radiation generated by an antenna 41 in conjunction with a surrounding reflecting shield 43 remains circular while the antenna 41 coincides with the axis of the shield 43 for all values of radius. The pattern of radiation may be caused to be non-circular by departing from this relation.

While I have described and illustrated various embodiments of my invention, it will be clear that vari-

ations in general arrangement and details of construction may be resorted to without departing from the true spirit of the invention as defined in the appended claims.

I claim as my invention:

1. A system for generating a directed beam of ultra-high frequency radio waves, comprising a wave guide having an output opening to which said ultra-high frequency waves are conveyed, a first wall totally reflective of incident ultra-high frequency radio waves, said wall extending transversely of the longitudinal axis of said wave guide and having a centered opening contiguous to the outer surface of said wave guide adjacent said output opening, a second wall extending transversely of the longitudinal axis of said wave guide, said second wall comprising mutually insulated conductive elements having cross-sectional sizes and spacings in planes of impinging wave energy equal to a fraction of the wavelength of said radio waves whereby the second wall will transmit part of said incident high frequency radio waves and reflect the remainder of said waves so that they will impinge on said totally reflective first wall to be re-reflected back to said second wall, said first and second walls being spaced apart by a predetermined spacing along the axis of said wave guide so that the output of said system results from interaction of said ultra-high frequency waves with said first and second walls.

2. The combination in accordance with claim 1 wherein said walls occupy parallel planes.

3. The combination in accordance with claim 1 wherein said first wall diverges with respect to the plane of said second wall on each side of a line falling on said longitudinal axis of said wave guide.

4. The combination in accordance with claim 1 wherein said first wall converges toward the plane of said second wall on each side of a line falling on said longitudinal axis of said wave guide.

5. The combination in accordance with claim 1 wherein the spacing between said first wall and said second wall is different for different distances perpendicular to said longitudinal axis of said wave guide.

6. The combination in accordance with claim 1 wherein said predetermined spacing is equal to an integral number of half wave lengths of said ultra-high frequency radio waves.

7. In combination, a source of electromagnetic waves of predetermined wave length, a first wall extending for a multiplicity of wave lengths of said electromagnetic waves, a second wall extending parallel to and displaced from said first wall, means for propagating said electromagnetic waves between said first and second walls, and in a direction parallel to said first and second walls, at least one of said first and second walls consisting of mutually insulated conductive elements having cross-sectional sizes and spacings in planes of impinging wave energy equal to a fraction of the wavelength of said electromagnetic waves to render said one wall partially reflective and partially transmissive of said electromagnetic waves.

8. A device for directing a beam of electromagnetic waves comprising a longitudinally extending portion of a plurality of walls which define a closed cross-sectional area, at least one of said walls comprising mutually insulated conductive elements having cross-sectional sizes and spacings in planes of impinging wave energy equal to a fraction of the wavelength of said electromagnetic waves to render said one wall partially reflective and partially transmissive of impinging electromagnetic waves, and means for feeding electromagnetic energy to the space defined by the inner periphery of said walls.

9. A system for generating a directed beam of ultra-high frequency radio waves, comprising a first totally reflecting wall, a second wall spaced from said first totally reflecting wall, said second wall comprising mutually insulated conductive elements having cross-sectional sizes

and spacings in planes of impinging wave energy equal to a fraction of the wavelength of said radio waves to render said second wall partially reflective and partially conductive of said ultra-high frequency radio waves, and a wave guide having an open end terminating in the space between said walls, said open end serving to introduce all of said ultra-high frequency waves directly into the space between said walls.

10. An antenna system comprising a first element designed to totally reflect impinging ultra-high frequency electromagnetic wave energy, a second element composed of mutually insulated conductive members having cross-sectional sizes and spacings therebetween in planes of impinging wave energy equal to a portion of the wavelength of said wave energy, said second element being spaced from said first element and designed to partially reflect and partially transmit impinging ultra-high frequency electromagnetic wave energy, a wave guide having an open end terminating in the space between said elements for feeding ultra-high frequency electromagnetic wave energy directly into said space from said end, the spacing between said elements being such that with a chosen configuration of said elements there will be reflective interaction between said elements to cause the out-

put electromagnetic energy to assume a predetermined wave pattern.

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