Dec. 17, 1968 B. L. LEWIS ET AL 3,417,398

MODULATED RETRODIRECTIVE CORNER REFLECTOR

Filed April 12, 1966

FIG. 1

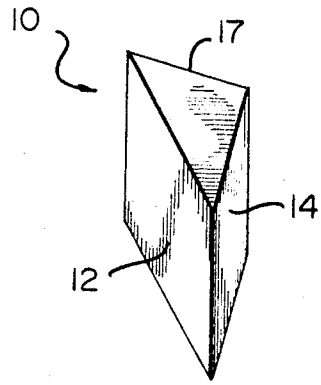
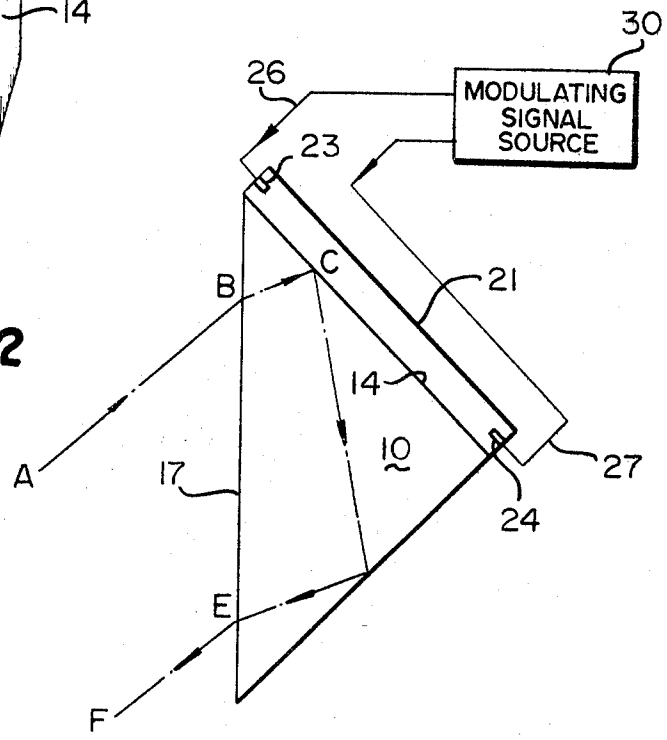


FIG. 2



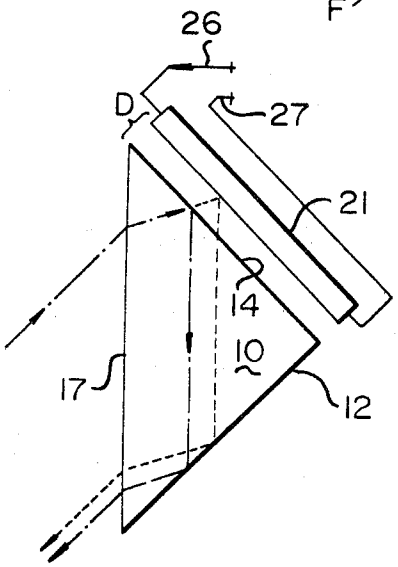


FIG. 3

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MODULATED RETRODIRECTIVE CORNER REFLECTOR

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7 Claims. (Cl. 343—18)

The present invention relates generally to corner reflectors, and more particularly to an improved dielectric corner reflector capable of receiving microwave radiation and returning it to the source with any desired phase or amplitude modulation.

The conventional metallic wall or wire-type corner reflectors have found use in a variety of communications and radar systems, for such purposes as improving the directivity of the radiating system, simulating or providing large cross-section radar targets, and operating as ground markers for aircraft-mounted systems. Despite such utility and its general capability of reflecting radiation arriving within a fairly wide range of angles, the conventional corner reflector is nevertheless limited to an unnecessary extent by the manner in which the reflection is accomplished, viz. by the use of solely conductive reflecting surfaces.

Improvements by way of increasing the limiting angles may be achieved by the use of a material having a dielectric constant greater than that of air, as a filler for the void formed by the metallic walls.

Still further improvements are achieved by use of a wholly dielectric corner reflector as disclosed in the copending application of Bernard L. Lewis, entitled "Modulated Corner Reflector," Ser. No. 539,078, filed Mar. 31, 1966 and commonly assigned herewith. In the Lewis application, there is further disclosed means by which the dielectric corner reflector may be provided with modulated retrodirective reflection capability. Specifically, there is printed on one or more of the reflecting surfaces (dielectric interfaces providing total internal reflection) an array of electrical components each having at least one voltage variable parameter, such as capacitance (varactors) or conductance (diodes or transistors), by use of conventional printed circuit or microminiaturization techniques. The driving or exciting voltage for these components is varied in accordance with information to be returned to the station from which the original (incident) radiation was transmitted, causing a corresponding variation in the voltage variable parameter of each electrical element of the printed array and, thereby, a variation of the R-F reflection coefficient of the reflecting surface or surfaces on which the elements are deposited. This, in turn, modulates the reflected R-F wave which is effective as a high frequency carrier for the modulation intelligence.

Certain advantages may be achieved over the modulatable dielectric corner reflectors disclosed in the aforementioned Lewis application by utilizing a completely different means, which will be described presently, to produce the desired modulation of the reflected carrier.

It is, accordingly, a primary object of the present invention to provide an improved modulatable dielectric corner reflector.

It is another object of the present invention to provide a dielectric corner reflector for collecting microwave radiation and retrodirectively reflecting it back to its source, and in conjunction with an improved modulating means, to provide the reflector with the capability of producing any desired phase modulation or amplitude modulation of the reflected wave.

Briefly, according to the present invention, a solid

dielectric corner reflector, which may have any of the usual polyhedral reflecting surface shapes, such as dihedral, trihedral, or square corner (square trihedral) configuration, is arranged and adapted to provide retrodirective reflection of rays incident thereon. By virtue of its solid dielectric composition and appropriate selection of index of refraction, the corner reflector is capable of providing extended coverage, i.e. retrodirective reflection of rays incident at angles up to $\pm 90°$ with respect to the axis of symmetry of the reflector. Phase modulation of the reflected signal is achieved by provision of a gas-filled tube or tubes placed in contact with one of the reflecting faces of the corner, and ionization of the gas in accordance with ionizing voltages applied to the tube electrodes. Amplitude modulation of the reflected signal is obtained by positioning the gas tube or tubes a predetermined distance away from the reflecting face (i.e., the dielectric interface), dependent upon wavelength of the waves in question, and parallel therewith, and thereafter modifying the reflection coefficient of the face by varying the state of ionization of the gas in the discharge tubes.

It is therefore a further object of the present invention to provide a modulated microwave corner reflector comprising a solid dielectric polyhedron and at least one gas discharge tube positioned adjacent a dielectric interface thereof, variation of the state of ionization of the gas producing the desired modulation of the reflected wave.

The above and still further objects, features, and attendant advantages of the present invention will become apparent from a consideration of the following detailed description of certain exemplary embodiments thereof, especially when taken in conjunction with the accompanying drawings, in which:

FIGURE 1 is a perspective view of a modulated microwave corner reflector embodying the principles of the present invention;

FIGURE 2 is a top view of the corner reflector of FIGURE 1 arranged to provide phase modulation of waves reflected therefrom; and

FIGURE 3 is a top view of the corner reflector of FIGURE 1 arranged to provide amplitude modulation of waves reflected therefrom.

Referring now to the drawings, wherein like reference numerals are used to designate like elements in the several views, and with particular reference to FIGURE 1, the corner reflector **10** comprises a solid dielectric mass of any polyhedral shape conventionally employed for corner reflectors. For purposes of illustration, the reflector is shown as having a dihedral reflecting surface configuration, but it will be appreciated that other configurations may be employed, as desired. Reflecting faces (dielectric interfaces) **12** and **14** form a 90-degree angle therebetween although this may vary according to well known principles in the art. The corner reflector is positioned in any convenient and conventional manner to receive and reflect waves arriving at angles of incidence within a predetermined angular range relative to the axis of symmetry, depending upon the dielectric constant of the reflector material and the geometry of the reflector.

Retrodirective reflection of rays incident at entrance face **17** at angles up to ± 90 degrees with respect to the axis of symmetry of the corner reflector (coinciding, in this example, with a normal to the entrance face) is achieved in accordance with principles set forth in detail in the aforementioned Lewis application. For the sake of clarity and completeness, however, a brief review of the relevant criteria will be set forth herein.

A ray, incident upon the corner at entrance face **17** at an angle θ relative to the normal thereto, is refracted on entering the dielectric as a result of the difference in index

of refraction of the dielectric material of which the corner is composed and of the medium in which the corner is immersed (normally air). The angle of refraction is equal to arc sin

$$\left(\frac{\sin\theta}{\sqrt{\epsilon}}\right)$$

where ϵ is the relative dielectric constant of the corner with respect to the surrounding medium. For air, $\epsilon_{air}=1$, so that the relative dielectric constant ϵ is simply the dielectric constant of the corner. If the angle at which the ray is incident on each of the dielectric interfaces encountered thereby (i.e., the reflecting surfaces forming the corner polyhedral, and specifically faces **12** and **14** forming the dihedral in the embodiment of FIGURE 1) is greater than the critical angle θ_{cr}, for that boundary, then total internal reflection will occur at each interface and the ray is redirected toward the entrance face on which it was initially incident. The critical angle will, of course, have the same value at each interface between the same more dense medium and the same less dense medium, such as exists at all faces of the polyhedral reflector of FIGURE 1.

If the ray, which has undergone multiple reflections within the corner, is now incident on the entrance face at an angle less than θ_{cr}, it will pass therethrough at an angle of refraction, relative to the normal, equal to the initial angle of incidence of the ray. Hence, the ray is sent back in the direction from which it came.

It will thus be apparent that if the value of the relative dielectric constant ϵ is selected such that angles of refraction for rays (alternatively termed waves, radiation, or signals) incident on the front face of the corner at angles within a predetermined range (i.e., a predetermined solid angle) result in angles of incidence on the reflecting faces of the corner greater than the critical angle, and in an angle of incidence on the front face, after the multiple reflection, less than the critical angle, then extended coverage is achieved with higher efficiency than the limited angular coverage possible using conventional metal wall or wire-type corners. This increased efficiency is attributable in part to the absence of conductive walls used in conventional reflectors and the decrease in power loss in the reflected signal which would otherwise occur as a result of the heating currents set up in the conductive walls. The limited effective area of the non-dielectric corner reflector is a consequence of the absence of refraction of a wave incident on the corner.

For the 90-degree dihedral configuration of the embodiment of FIGURE 1, the aforementioned criteria may readily be demonstrated, from ray tracing techniques and a consideration of the geometry involved, to require a value of dielectric constant for the corner reflector material greater than 6.4, or, equivalently, an index of refraction of 2.52, in order that solid angle coverage be attained over at least $\pm 45°$ relative to the axis of symmetry of the corner. The required index of refraction may be obtained by use of any of such materials as Rutile, Sphalerite (ZmS), strontium titanate, arsenic trisulfide, glass amorphous selenium, germanium, and Pyrite, to name a few. Smaller values of ϵ are usable but will result in retrodirective action only over a solid angle less than 90-degrees. Similarly, retrodirective action over solid angles greater than 90° may be achieved by use of corner reflector materials having an index of refraction greater than 2.52. Since refraction at the front face of the corner increases the angle of incidence on the reflecting faces, the corner can theoretically approach a solid angle coverage of 180-degrees.

Another distinct advantage of the dielectric corner reflector over the prior art metal corner types is that the reflectivity is modulatable by perturbation of the space in the vicinity of one or more of the reflecting interfaces. According to the present invention gas discharge tubes are disposed adjacent and parallel to a reflecting interface, in contact therewith to produce phase shift of the reflected signal, and displaced therefrom by a distance dependent upon the wavelength of the signal to produce amplitude modulation of the reflected signal.

An exemplary embodiment of the invention adapted to produce phase modulation of the reflected wave is shown in FIGURE 2. A single gas discharge tube **21** (or a plurality of such tubes) is positioned in contact with a reflecting surface (e.g. **14**) of the dielectric corner reflector **10**, the tube (or tubes) conforming with the shape and general dimensions of that surface. The envelope of tube **21** may be filled with any well-known gaseous ionizable medium, such as neon, and is provided with a pair of electrodes **23** and **24** across which the modulating voltage from a source **30** thereof is to be applied via conductive leads **26** and **27**.

The phase shift introduced into an electromagnetic wave by total internal reflection from a dielectric-air interface varies between zero and 180 degrees, depending upon the angle of incidence of the wave upon the interface. On the other hand, the phase shift introduced on reflection of the wave from an ionized gas is always 180 degrees. In both cases the phase shifts are independent of frequency. These phenomena are utilized to advantage in accordance with the invention to obtain broadband operation and phase modulation of the reflected wave. Assume, for example, that a plane wave in the microwave region of the R-F spectrum is incident on the corner **10**, the ray AB representing the normal to the H and E fields of the wave in the direction of propagation. Incidence upon the entrance face **17** of the corner **10** results in refraction of the ray along a path BC interiorly of the corner at an angle dependent upon the angle of incidence and the dielectric constant of the corner material. Absent ionization of the gas in tube **21** the ray is subjected to multiple reflections, at the dielectric interfaces **14** and **12**, and refraction at face **17**, so that the ray is reflected in the direction from which it arrived along the path EF, with a total phase shift equal to α (where α is the phase shift of the wave produced by the corner with no tube excitation).

By applying electrical control signals, from source **30** to the electrodes **23**, **24** of the tube **21**, of sufficient voltage amplitude to cause ionization of the gas, the wave reflected by the corner follows the same path as that shown but its phase undergoes a total shift of $\alpha+180$ degrees. Hence, the control signals from source **30** may be employed to modulate the phase of the reflected wave with any desired information.

Amplitude modulation of the reflected wave may be accomplished by the exemplary embodiment of FIGURE 3. Here, the apparatus deviates from that shown in FIGURE 2 only in the relative positions of tube **21** and dielectric interface **12**. Advantage is taken, in this embodiment, of the fact that electromagnetic waves propagate a relatively minute distance beyond the dielectric-air interface upon total internal reflection, i.e., there is a relatively slight refracted wave component in addition to the reflected wave at the interface. In order to utilize this phenomena, gas tube **21** is displaced from the interface by a distance D (exaggerated in the drawing) greater than zero but less than 0.175 λ, where λ is the wavelength of the incident wave. Under these conditions the phase of the refracted wave (indicated by the dotted line) that re-enters the interface is modified by controlling the state of ionization of the gas in tube **21**, in the aforementioned manner. Thereby, the refracted wave can be controlled to subtract from the directly reflected wave, in effect an amplitude modulation of the reflected wave in accordance with information to be impressed thereon, alteration of the reflection coefficient of the corner reflector being dependent upon the state of ionization of the gas in the discharge tubes.

While we have disclosed certain specific embodiments of our invention, it will be apparent that variations in the specific details of construction which have been illustrated and described may be resorted to without departing from

the spirit and scope of the invention, as defined in the appended claims.

We claim:

1. A retrodirective corner reflector for modulating high frequency R-F waves reflected therefrom, said corner reflector comprising a polyhedron composed of dielectric material having a preselected dielectric constant greater than that of the surrounding medium in which said reflector is to be used, said polyhedron having a plurality of intersecting faces forming the corner from which incident R-F waves are to be reflected interiorly of said dielectric material, and an enclosed gaseous ionizable medium disposed adjacent at least one of said intersecting faces and an opposing relation thereto.

2. The combination according to claim 1 including means for controlling the state of ionization of said gaseous medium to modulate R-F waves incident on said at least one face in accordance with the ionization control.

3. The combination according to claim 2 wherein said enclosed gaseous ionizable medium adjoins said at least one face.

4. The combination according to claim 2 wherein said enclosed gaseous ionizable medium is spaced from said at least one face by a distance on the order of 0.175 λ, where λ is the wavelength of the incident wave.

5. The combination according to claim 1 wherein said

corner has an axis of symmetry, and wherein the geometry of said polyhedron and the dielectric constant of said dielectric material are selected to produce total internal reflection of waves incident on any one or more of said intersecting faces forming said corner, when said waves arrive at said corner reflector within a predetermined solid angle of at least ± 45 degrees with respect to said axis of symmetry.

6. The combination according to claim 1 wherein said enclosed gaseous ionizable medium comprises at least one gas discharge tube.

7. The combination according to claim 6 including a source of control voltage for controlling the ionization of gas in said at least one tube to modulate the R-F wave incident on said at least one face in accordance therewith.

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ELI LIEBERMAN, *Primary Examiner.*

U.S. Cl. X.R.

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