

March 15, 1949.

C. G. SMITH
METHOD AND MEANS FOR CONTROLLING THE
POLARIZATION OF RADIANT ENERGY

2,464,269

Filed June 12, 1942

2 Sheets-Sheet 1

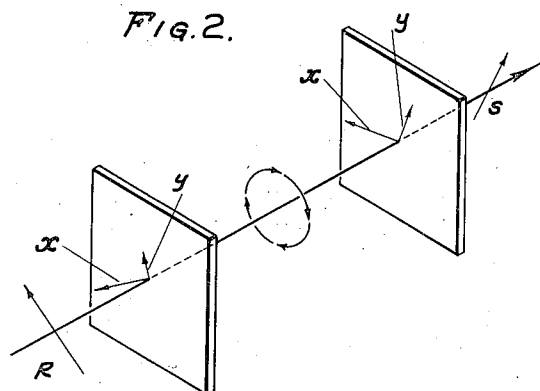
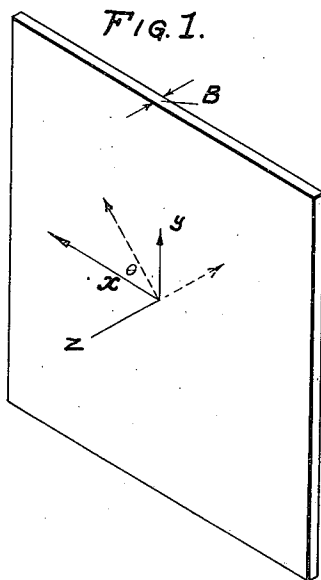
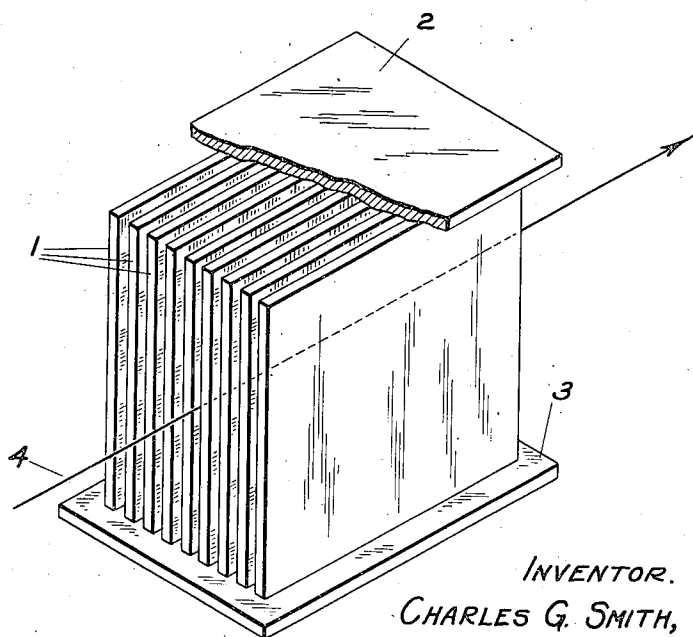


Fig. 3.



INVENTOR.
CHARLES G. SMITH,
BY *Elmer J. Gorn*
ATTY.

March 15, 1949.

C. G. SMITH
METHOD AND MEANS FOR CONTROLLING THE
POLARIZATION OF RADIANT ENERGY

2,464,269

Filed June 12, 1942

2 Sheets-Sheet 2

FIG. 4.

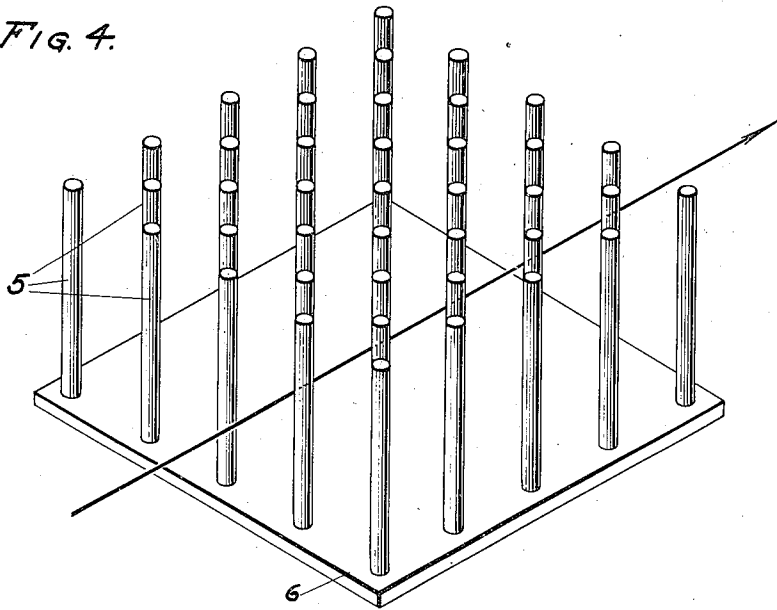
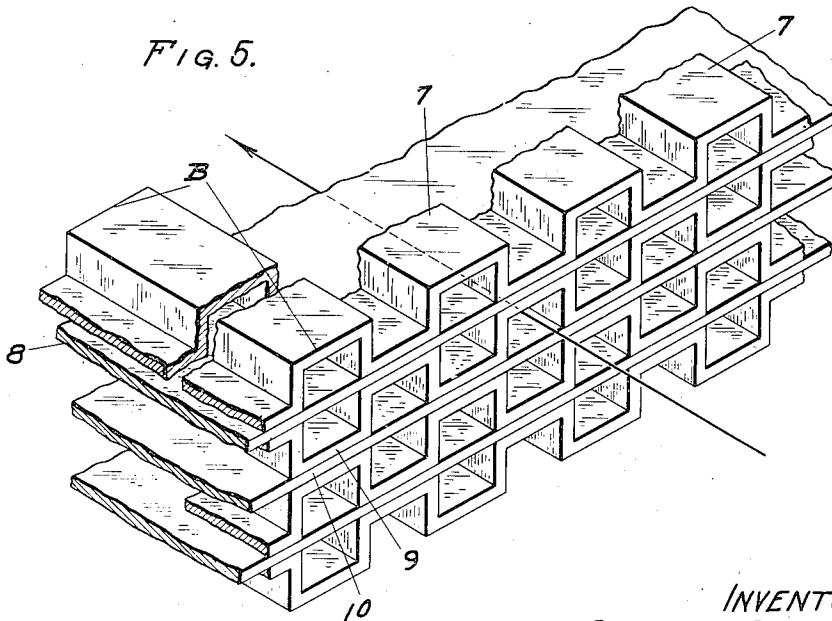


FIG. 5.



INVENTOR.
CHARLES G. SMITH,
BY Elmer J. Joen
ATTY.

UNITED STATES PATENT OFFICE

2,464,269

METHOD AND MEANS FOR CONTROLLING THE POLARIZATION OF RADIANT ENERGY

Charles G. Smith, Medford, Mass., assignor to Raytheon Manufacturing Company, Newton, Mass., a corporation of Delaware

Application June 12, 1942, Serial No. 446,847

10 Claims. (Cl. 250—33)

1

This invention relates to a method and means for controlling the polarization of radio waves. By the term "radio waves" as used in this specification and in the claims, I mean radiant energy having a wave length of the order of one millimeter or greater.

Although it has been long known that radio waves are plane-polarized when radiated from the usual radiator, very little use has been made of this fact. Even less attention has been paid to the advantages that may be obtained by controlling the plane of polarization. This has probably been due in part to the fact that no practical or simple method or means has been available for controlling the polarization of such waves.

An object of this invention is the provision of a method and means for controlling the polarization of radio waves.

Another object of the present invention is the provision of a means and a method for changing plane-polarized radio waves into circularly or elliptically polarized radio waves.

Still another object of the present invention is the provision of a means and method for changing circularly polarized radio waves into plane polarized radio waves.

A further object of the present invention is the provision of a method and means for controlling the plane of polarization of radio waves, as for example by determining the angle of said plane in relation to any other reference plane or by continuously rotating the plane of polarization.

Other and further objects and advantages of the present invention will become apparent and the foregoing will be best understood from the following description of exemplifications of my invention, reference being had to the drawings in which,

Fig. 1, is a schematic perspective drawing of a theoretical plate for changing the polarization of a radio wave;

Fig. 2 is a schematic diagram of a system for controlling the plane of polarization of a radio wave;

Fig. 3 is a perspective drawing of a structure embodying my invention;

Fig. 4 is a perspective drawing of another structure embodying my invention; and

Fig. 5 is a perspective drawing of still another structure embodying my invention.

Variations of the polarization of radio waves can be used for many purposes if such variations can be readily produced and controlled. For ex-

2

ample such variations may be used as a method of modulating a wave, and thus a new form of modulation in addition to amplitude and frequency modulation becomes available. This form of modulation has certain advantages over the others mentioned.

Radio waves tend to be plane-polarized. One way of varying the polarization of such waves is to change them into circularly-polarized waves. Therefore, I will now describe a method and means for transforming the usual plane-polarized radio wave into a circularly-polarized radio wave.

A circularly polarized wave may be considered as having along the azimuth of its direction of propagation two equal components at right angles to each other and differing in phase by 90° . Although in producing circularly-polarized waves two plane-polarized waves may be used to provide the two equal components, it may be difficult to match the waves to make them equal in amplitude and of proper phase relation. Therefore, it is preferable that a wave radiated from a single source be used to provide both components. The method of separating a single plane-polarized wave into two equal components at right angles to each other and differing in phase by 90° will next be described.

Referring now to Fig. 1, let us assume that the theoretical plane parallel slab of material there illustrated is a homogeneous but not isotropic body which presents unequal dielectric constants to a radio wave passing through said plate normal to the plane of the faces thereof. Let y be the direction of minimum dielectric constant and x , at right angles to y , the direction of maximum dielectric constant. Assume further that a plane-polarized radio wave travels through said plate in a direction z normal to the faces thereof with its plane of polarization making an angle θ with the x axis. The electrical vectors of this wave, which are under all conditions perpendicular to the direction of propagation of said wave, may be considered as having two components, one along the x axis and one along the y axis. Remembering that the velocity of a radio wave or of any of its components is dependent upon the dielectric constant of the material through which it is propagated and that the larger the dielectric constant the less the velocity of the wave or of any component thereof affected by said dielectric constant, it will be seen that the component along the y axis will travel faster than the component along the x axis because of the lesser dielectric constant along the y axis. If the radio wave has its plane polarized

3

so that said plane makes an angle of 45° with the x axis, that is if angle θ is 45° , then each of said components is equal. Assuming that the plate has the proper thickness, the component along the y axis will gain a $\frac{1}{4}$ wave length upon the component along the x axis when the wave leaves the rear face of the plate. The emerging wave now consists of two equal components at right angles to each other and differing in phase by 90° . The resultant wave is therefore circularly polarized.

From the foregoing, it will be seen that a plate having the characteristics such as those described in relation to Fig. 1 will be capable of changing plane polarized radio waves into circularly polarized radio waves.

It will also be apparent that a plate such as that in Fig. 1 is capable of changing circularly-polarized radio waves into plane-polarized radio waves. Assume that a circularly-polarized radio wave is passed through a plate similar to that shown in Fig. 1. The circularly-polarized radio wave may be considered as having two equal components at right angles to each other, one component lagging 90° behind the other. One component may be considered as lying along the x axis of Fig. 1, and the other component as lying along the y axis of Fig. 1. One of the two components of the radio wave entering said plate normal to the faces thereof will be shifted 90° in relation to the other. Thus, if the component along the x axis was the component 90° ahead of the other component, said first component will be retarded so that it will be in phase with said other component. Since these two equal components will emerge in phase, the resultant wave emerging from said plate will be plane-polarized. The plane of polarization of said emerging wave will make an angle of 45° with the axis of maximum dielectric constant, that is the x axis. It will therefore be seen that the direction of the x axis will determine the plane of polarization of the emerging wave. By rotating said plate about a line normal to its plane, the plane of polarization of the emerging wave will also be rotated.

Referring now to Fig. 2, a pair of plates having the theoretical characteristics of the plate of Fig. 1 are shown as arranged in series with each other along the path of propagation of a radio wave. The radio wave is initially plane-polarized in the plane indicated by the arrow R and enters the first plate in its path at an angle of 45° to the x axis of said plate. The emerging wave is therefore circularly-polarized. This circularly-polarized wave is then passed through a second plate and emerges therefrom as a plane-polarized wave. The finally emerging wave has its plane in the direction indicated by the arrow S, which is at an angle of 45° to the x axis of the second plate. Since the x axis of the second plate is at an angle to the x axis of the first plate, it will be seen that the plane of polarization of the finally emerging wave will be at an angle to the plane of polarization of the initial wave.

From the foregoing it will be apparent that the angle of the emerging wave will be varied by varying the angular relationship between the x axis of the first plate and the x axis of the second plate. Furthermore, it will be seen that by rotating the second plate, the plane of polarization of the emerging wave will also be rotated.

Referring now to Fig. 3, one form of a structure having the characteristics of the theoretical plate of Fig. 1 is illustrated there. This structure is made of a plurality of glass plates 1 arranged

4

parallel to each other and spaced a distance apart. These glass plates may be held in position by providing a cover 2 and a bottom 3 to which said plates are secured. The arrow 4 shows the direction in which the radio wave is propagated through said plates.

The dielectric constant of this structure along a horizontal axis is less than the dielectric constant along a vertical axis, as will be clear from the following: The dielectric constant of air is 1, while the dielectric constant of glass is approximately 8. The azimuthal components of wave 4 which lie along the horizontal axis are transverse to the length of the glass plates 1 and therefore are only affected by the thickness of such plates. The azimuthal components of wave 4 along the vertical axis are affected by the entire length of the glass plates. Therefore, the dielectric constant along the vertical axis is greater than the dielectric constant along the horizontal axis. In view of the discussion hereinbefore in connection with Fig. 1, it will therefore be apparent that the component along the vertical axis will travel more slowly than the component along the horizontal axis, and if the structure of Fig. 3 is of proper depth, the vertical component will emerge 90° behind the horizontal component. If it is desired that the emerging wave be circularly polarized, the plane of polarization of wave 4 as it enters the structure should make an angle of 45° with the horizontal plane so that the two components are equal.

It is preferred that the height and width of the structure of Fig. 3 should be several times the wave length of the radio wave to be controlled thereby. It is further preferred that the distance between plates 1 and the thickness of such plates each be considerably smaller than the wave length of said radio wave. It is preferred that the depth of the structure of Fig. 3 be several times the wave length of either of the components of said wave within said structure and that the total depth be such that the emerging components shall be 90° out of phase with each other.

Referring now to Fig. 4 another form of structure capable of changing plane polarized radio waves into circularly-polarized waves is there illustrated. This structure consists of a plurality of round glass tubes or rods 5 extending vertically and spaced from each other. These rods may be arranged in rows. Each succeeding row may be aligned with a prior row, or as shown in the figure may be arranged in staggered relation thereto. A top member (not shown) like the bottom member 6 may be used to hold the rods in position. From the explanation given hereinabove in connection with the structure of Fig. 3, it will be seen that the effective dielectric constant of this structure along a vertical axis will be greater than the effective dielectric constant along a horizontal axis. If the structure is made of the proper depth, a plane-polarized wave entering said structure with its plane of polarization at an angle of 45° to the horizontal axis will leave said structure as a circularly-polarized wave.

While in Figs. 3 and 4 I have disclosed the use of glass and air in structures presenting two different dielectric constants at right angles to each other, it will of course be readily understood that other materials might be employed. In Fig. 5 hereinafter a material other than glass is disclosed.

Referring now to Fig. 5, another structure em-

5

bodying my invention is there illustrated. This structure may be made of sheets of a plastic material which has a dielectric constant greater than air, such as for example the synthetic resin, polymethyl methacrylate. The honeycomb-like structure there illustrated may be made as follows. A sheet 7 of the above mentioned plastic having a width B is bent into a channel formation. Under this formation is arranged a flat sheet 8 of a similar material and having the same or a different width. Under sheet 8 another sheet 9 which has been bent into a channel formation similar to that of sheet 7 is next arranged. Under sheet 9 another flat sheet 10 similar to sheet 8 is next placed. In the same manner a large number of sheets are stacked, as illustrated, to form a box-like structure whose height may be equal to its width. These stacked sheets may be secured together by any suitable means which will be apparent to those versed in this art.

It is preferred that the height and the length of the structure of Fig. 5 be several times the wave length of the wave to be propagated therethrough. It is further preferred that the cells of this honeycomb-like structure be at least less than half said wave length and preferably much smaller. The cells are preferably so small in comparison with the wave lengths that the structure may be considered as homogeneous in respect to waves having such a wave length. Unlike the structures of Figs. 3 and 4, the structure of Fig. 5 has its greater dielectric constant along a horizontal axis rather than a vertical axis, and thus the horizontal component of any wave propagated in the direction of the arrow shown in Fig. 5 would be retarded.

The dimension of any of the structures of Figs. 3, 4, and 5 along the direction of propagation of a radio wave should be such that, when a wave of a given frequency is propagated through said structure with its plane of polarization making an angle 45° with either of the axes the two components of such wave will emerge 90° out of phase with each other, that is the emerging wave will be circularly polarized. This dimension along the direction of propagation of a radio wave through any of these structures should preferably be approximately several times the length of the wave length of said wave.

The foregoing will be best understood after the following approximate calculations are considered in relation to Fig. 1, with reference to which the dielectric constant presented to the wave having electrical forces in the direction y is E_y , and in the direction x is E_x . Let C equal the velocity of light, and Z equal the direction of propagation of the radiation. Considering a radio wave travelling in the direction Z with electrical vectors along the y and x axes, these vectors will have different velocities. Let V_y equal the velocity of the waves along the x axis and V_x equal the velocity of the waves along the x axis, then

$$V_y = \frac{C}{\sqrt{E_y}}$$

Likewise

$$V_x = \frac{C}{\sqrt{E_x}}$$

Hence

$$\frac{V_y}{V_x} = \sqrt{\frac{E_x}{E_y}}$$

Let λ_y =wave length of the radiation whose electric vector is in the y direction; λ_y is measured in the dielectric along Z . Let λ_x =wave length of the

6

radiation whose electric vector is in the x direction; λ_x is measured in the dielectric along Z .

Consider a beam of plane-polarized radiation propagated along Z with its plane of polarization making an angle of 45° with the x axis.

Let

 f =frequency of the radiation. $\lambda f = C$ =velocity in free space, where λ =wave length in air.

$$\lambda_x f = V_x$$

$$\lambda_y f = V_y$$

$$\frac{\lambda_x}{\lambda_y} = \frac{V_x}{V_y} = \sqrt{\frac{E_y}{E_x}}$$

It is desired to make a plate or structure that will change plane-polarized radio waves into circularly-polarized radio waves or the reverse. We wish to make x and y components of such waves emerge from the plate 90° out of phase; that is, one component must fall $\frac{1}{4}$ wave length behind the other. Assuming that the structure has a thickness B along the direction of propagation thereof, this dimension B may be expressed in terms of the dielectric constant of the two axes, E_x and E_y , and in terms of the wave length or λ . Let a equal any arbitrary number, preferably more than 1; let b equal an odd integer.

Suppose

$$B = a\lambda$$

$$B = a\lambda_x + \frac{b\lambda_x}{4}$$

hence

$$a\lambda_y = a\lambda_x + \frac{b\lambda_x}{4}$$

and finally

$$a = \frac{b}{4 \left(\sqrt{\frac{E_x}{E_y}} - 1 \right)}$$

Let us assume that the value of the dielectric constant along the y axis, E_y , is 1.1, and along the x axis, E_x , is 1.5 then,

$$\frac{E_x}{E_y} = 1.36$$

Utilizing these dielectric constants, then

$$a = \frac{b}{4(1.17-1)} = \frac{b}{.68} \text{ approx.}$$

Let

$$b=3, \text{ an odd integer,}$$

$$a=4.41$$

$$B = a\lambda_y = 4.41\lambda_y$$

$$\frac{\lambda_y}{\lambda} = \sqrt{\frac{1}{E_y}}$$

hence

$$B = \frac{4.41\lambda}{\sqrt{E_y}} = \frac{4.41}{\sqrt{1.1}}\lambda$$

$$B = 4.2\lambda$$

From the foregoing it will be seen that the thickness of the plate or structure with the particular dielectric constants here chosen can be 4.2 times the wave length of the radiation in air.

From the foregoing it will be seen how the particular thickness of the structure can be obtained by measuring the dielectric constant along the axes of such structure and by calculating the desired thickness in terms of the wave length of the wave to be propagated through such structure.

While the structures I have described in connection with Figs. 3 through 5 have been made of a material such as glass and Lucite having air spaces therein, it will of course be understood that

other materials may be substituted in place thereof, and furthermore, instead of using air spaces, the spaces in such structure might be filled with a solid, liquid, or a gaseous material. Whatever two materials are used to form such a structure, they must however have different dielectric constants. Furthermore, it is preferred that the dielectric constants of both materials used in such a structure be not too great, for if such dielectric constants are large they will produce too great a reflection of the radio wave entering said structure. On the other hand, the larger the dielectric constants of the materials, and particularly the larger the difference between the dielectric constants of the materials employed, the smaller the entire structure may be made in depth, that is the dimension along the line of propagation. Therefore, in selecting the materials for such structure and in determining the size thereof, the following are some of the factors that must be considered: the wave length of the wave to be propagated through said structure, the permissible amount of reflection of said wave, and the largest dielectric constants of the materials to be used which will enable the smallest structure to be made without causing too great a reflection of the radio wave.

While the structures I have described may be cubical, it will of course be apparent they may also be prismatic or spherical or have other configurations. Furthermore, while I have disclosed several different ways of constructing such a structure, it will be apparent from the foregoing descriptions that numerous other structures functioning in a manner indicated with Fig. 1 can readily be devised. Therefore, it is to be understood that the foregoing descriptions are by way of exemplification only and are not intended to limit the scope of this invention, it being intended that the appended claims be given a broad interpretation commensurate with the scope of this invention within the art.

What is claimed is:

1. A radio wave polarization structure for controlling the polarization of a radio wave propagated therethrough comprising a plurality of plane parallel plates made of a dielectric material having a dielectric constant greater than air, said plates being arranged parallel to each other and spaced a distance apart so as to present two effectively different dielectric constants to a radio wave which is propagated through said structure in a direction parallel to the faces of said plates, and which has component electrical vectors parallel to the axes of said different dielectric constants.

2. A radio wave polarization structure for controlling the polarization of a radio wave propagated therethrough comprising a plurality of plane parallel plates made of a dielectric material having a dielectric constant greater than air, said plates being arranged parallel to each other and spaced a distance apart so as to present two effectively different dielectric constants to a radio wave which is propagated through said structure in a direction parallel to the faces of said plates, and which has component electrical vectors parallel to the axes of said different dielectric constants, the distance between two adjacent plates being less than the wave length of the radio wave.

3. A radio wave polarization structure for controlling the polarization of a radio wave propagated therethrough comprising a plurality of plane parallel plates made of a dielectric ma-

terial having a dielectric constant greater than air, said plates being arranged parallel to each other and spaced a distance apart so as to present two effectively different dielectric constants to a radio wave which is propagated through said structure in a direction parallel to the faces of said plates, and which has component electrical vectors parallel to the axes of said different dielectric constants, the length and height of said plates being greater than the wave length of said radio wave.

4. A radio wave polarization structure for controlling the polarization of a radio wave propagated therethrough comprising a plurality of plane parallel plates made of a dielectric material having a dielectric constant greater than air, said plates being arranged parallel to each other and spaced a distance apart so as to present two effectively different dielectric constants to a radio wave which is propagated through said structure in a direction parallel to the faces of said plates, and which has component electrical vectors parallel to the axes of said different dielectric constants, the distance between two adjacent plates being less than the wave length of the radio wave, the length and height of said plates being greater than said wave length.

5. A radio wave polarization structure for changing a circularly polarized wave into a plane polarized wave, comprising a structure presenting two different dielectric constants to the electrical vectors of a circularly polarized wave propagated therethrough, the dimension of the structure along the direction of propagation being such that the electrical vectors of said wave emerge in phase.

6. A radio wave polarization structure for changing a plane polarized radio wave into a circularly polarized wave comprising a structure presenting two different dielectric constants, perpendicular to each other, to the electrical vectors of a plane polarized wave propagated through said structure, with the electric field thereof disposed at an angle to the direction of each of said dielectric constants, the dimension of said structure along the path of propagation being such that one of the electrical vectors of said wave emerges substantially 90° out of phase with another of said electrical vectors which is perpendicular thereto.

7. A radio wave polarization structure for controlling the plane of polarization of a radio wave, comprising two dielectric mediums each having two axes perpendicular to each other, each of said axes presenting an effectively different dielectric constant to an electrical field parallel thereto and having a dimension along the direction of propagation of a radio wave propagated successively through said mediums to cause a substantially 90° shift in phase between two electrical vectors of said wave at right angles to each other, the axes of maximum dielectric constants of said mediums being at an angle to each other.

8. A radio wave polarization structure for controlling the polarization of a radio wave propagated therethrough, said structure having two axes perpendicular to each other, each of said axes presenting an effectively different dielectric constant to an electrical field parallel thereto, the length of said structure along the line of propagation of the radio wave being substantially equal to

$$\frac{b}{4\left(\sqrt{\frac{E_z}{E_y}} - 1\right)^{\lambda_y}}$$

9

where b is an odd integer, E_x is the dielectric constant along one of said axes, E_y is the dielectric constant along the other of said axes and λ_y is the wave length in the structure of that component of the propagated radio wave having its electrical vector lying along the last-named axis.

9. A radio wave polarization structure for controlling the plane of polarization of the radio wave, comprising the dielectric members, each having two axes in planes parallel to each other, each of said axes presenting an effectively different dielectric constant to an electrical field parallel thereto, and each member having a dimension along the direction of propagation of a radio wave propagating successively through said members substantially equal to

$$\frac{b}{4\left(\sqrt{\frac{E_x}{E_y}} - 1\right)}\lambda_y$$

where b is an odd integer, E_x is the dielectric constant along one of said axes, E_y is the dielectric constant along the other of said axes and λ_y is the wave length in the structure of that component of the propagated radio wave having its electrical vector lying along the last-named axis, the axes of maximum dielectric constants of each of said members being at an angle to each other.

10

10. A structure for controlling the plane of polarization of a radio wave, comprising two dielectric mediums, each having two axes perpendicular to each other, each of said axes presenting an effectively different dielectric constant to an electric field parallel thereto and having a dimension along the direction of a radio wave propagated successively through said mediums to cause a relative shift in phase between two electrical vectors of said wave at right angles to each other, the axes of maximum dielectric constants of said mediums being at an angle to each other.

CHARLES G. SMITH.

REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

Number	Name	Date
1,931,458	Lang	Oct. 17, 1933
2,051,537	Wolff et al.	Aug. 18, 1936
2,064,582	Wolff	Dec. 15, 1936
2,085,406	Zworykin	June 29, 1937
2,129,669	Bowen	Sept. 13, 1938
2,130,389	Gothel	Sept. 20, 1938
2,142,648	Linder	Jan. 3, 1939
2,223,950	Brown	Dec. 3, 1940

Certificate of Correction

Patent No. 2,464,269.

March 15, 1949.

CHARLES G. SMITH

It is hereby certified that errors appear in the printed specification of the above numbered patent requiring correction as follows:

Column 1, line 41, after the numeral "1" strike out the comma; column 2, line 40, strike out the word "an" second occurrence; column 4, line 39, for "it" read *It*; column 5, line 5, for "methacrylote" read *methacrylate*; column 6, line 29, for "B- $\alpha\lambda$ " read *B- $\alpha\lambda$* ; column 8, line 53, claim 7, after "mediums" insert a comma; column 9, line 9, claim 9, for "the" before "dielectric" read *two*;

and that the said Letters Patent should be read with these corrections therein that the same may conform to the record of the case in the Patent Office.

Signed and sealed this 30th day of August, A. D. 1949.

[SEAL]

THOMAS F. MURPHY,
Assistant Commissioner of Patents.

Certificate of Correction

Patent No. 2,464,269.

March 15, 1949.

CHARLES G. SMITH

It is hereby certified that errors appear in the printed specification of the above numbered patent requiring correction as follows:

Column 1, line 41, after the numeral "1" strike out the comma; column 2, line 40, strike out the word "an" second occurrence; column 4, line 39, for "it" read *It*; column 5, line 5, for "methacrylote" read *methacrylate*; column 6, line 29, for "B- $\alpha\lambda_v$ " read *B- $\alpha\lambda_v$* ; column 8, line 53, claim 7, after "mediums" insert a comma; column 9, line 9, claim 9, for "the" before "dielectric" read *two*;

and that the said Letters Patent should be read with these corrections therein that the same may conform to the record of the case in the Patent Office.

Signed and sealed this 30th day of August, A. D. 1949.

[SEAL]

THOMAS F. MURPHY,
Assistant Commissioner of Patents.