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EXAMINER
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3,089,142

ARTIFICIAL DIELECTRIC POLARIZER

Filed Oct. 30, 1959

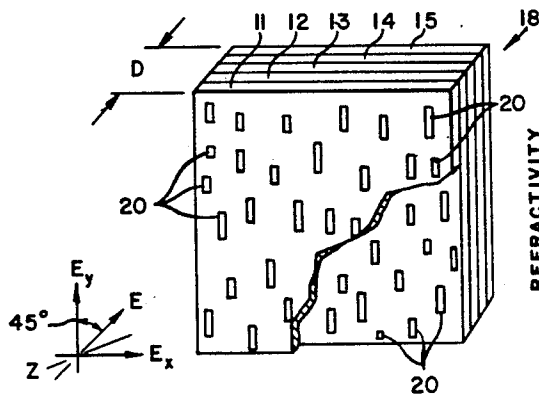


FIG-1

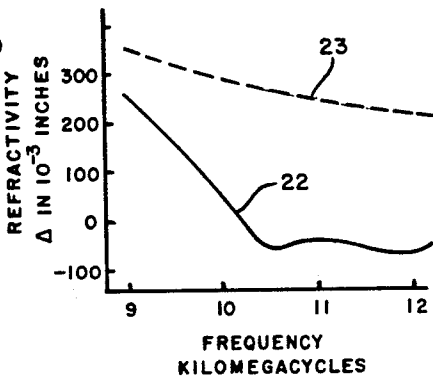


FIG-2

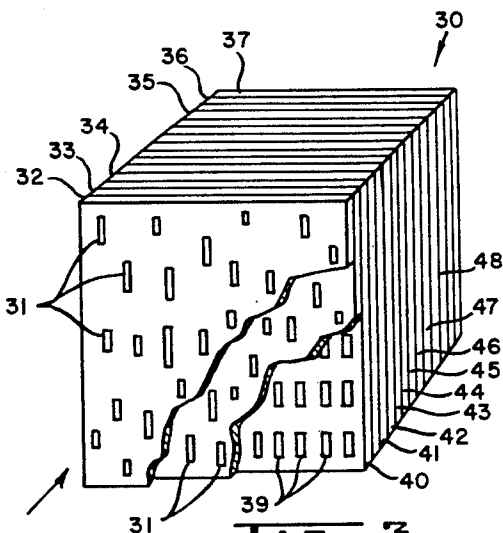


FIG-3

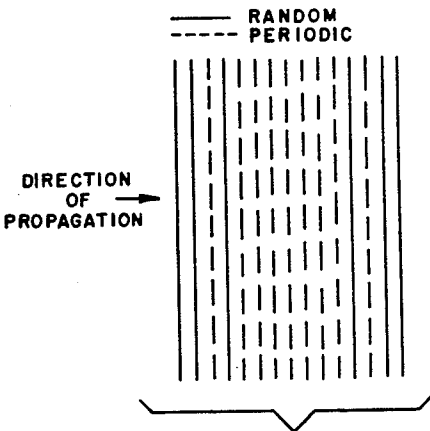


FIG-4

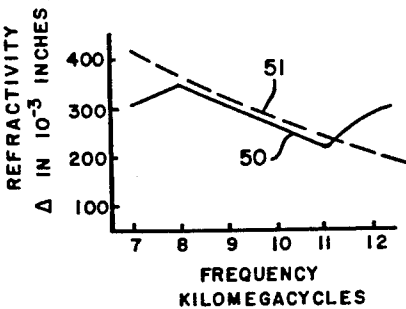


FIG-5

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ARTIFICIAL DIELECTRIC POLARIZER

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1 Claim. (Cl. 343-911)

This invention relates to artificial dielectrics and more particularly is concerned with an artificial dielectric polarizer which exhibits a substantially constant phase shift over a broad band of frequencies. A similar artificial dielectric is disclosed in my co-pending application, Serial No. 705,191, now Patent No. 2,921,312, filed December 26, 1957, entitled Artificial Dielectric Polarizer.

The term "artificial dielectric" has come to have divergent meanings in different scientific fields, but as used herein is understood to mean wave-propagating media consisting of fabricated assemblies of conducting or non-conducting members or both. Such dielectrics are used principally in microwave lens antennas where their advantages over homogeneous (natural) dielectrics include lightness, mechanical strength and stability, and a choice of any desired index of refraction over wide limits. Other devices in which artificial dielectrics find application include polarizers or matching walls.

To have utility in a quarterwave plate or polarizer, a dielectric medium must satisfy the condition

$$\Delta = \frac{\lambda}{4} \quad (1)$$

where Δ is the optical path difference between two rays traversing the medium, the first ray being polarized in a first principal plane and the second ray being polarized in a plane perpendicular to the first, and λ is the wavelength of the electromagnetic wave in free space. The index of refraction, n , of the medium is approximately related to the optical path difference Δ by the following expression:

$$n = 1 + \frac{\Delta}{D} \quad (2)$$

where D is the thickness of the dielectric medium. Inasmuch as λ decreases with increasing frequency, and n (or Δ) of natural dielectrics increase with increases in frequencies, it is clear that the condition expressed in Equation 1 can be met with natural dielectrics at only one frequency.

It is a primary object of the present invention to provide a quarterwave plate or polarizer which operates over a broad band of microwave frequencies.

Another object of the invention is to provide an artificial dielectric which has a dispersion curve which decreases with increasing frequency over a wide frequency range so as to satisfy Equation 1.

Still another object of the invention is to provide an artificial dielectric wherein the path difference between two orthogonally polarized waves is a decreasing function of frequency so as to be operative as a quarter wave plate or polarizer over a wide frequency range.

The foregoing objects are achieved by the formation of a compound artificial dielectric consisting of arrays of conducting scattering elements arranged in a supporting dielectric material. More specifically, the compound artificial dielectric comprises a plurality of stacked thin sheets of low density dielectric material, such as Polyfoam (polystyrene foam), on each of which is supported an array of thin narrow conducting strips, the longitudinal axes of the strips on each and successive supporting layers being generally parallel. The strips are rectangular conductors

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having random lengths, within prescribed limits according to the theory to be set forth, and a random distribution such that the dispersion curve for the material has a negative slope and the losses are minimized due to the distribution of resonances of the strips over a wide band of frequencies. By exercising control over the resonant lengths of the strips, the dispersion curve can be so shaped that the relationship between Δ , the optical path difference, and frequency can be made to satisfy Equation 1 over a broad band of frequencies.

The nature of the invention will be better understood from the following detailed description of an illustrative embodiment, reference being had to the accompanying drawings in which:

FIGURE 1 is a perspective view, partially cut away, of a compound artificial dielectric made in accordance with the present invention;

FIGURE 2 is a graph illustrating an ideal and actual dispersion curves for the compound dielectric of FIGURE 1;

FIGURE 3 is a perspective view, also partially cut away, of a modified form of compound artificial dielectric comprised of sheets of periodic and random arrays of conducting strips;

FIGURE 4 is a schematic representation of the compound dielectric of FIGURE 3 showing the preferred arrangement of random and periodic arrays; and

FIGURE 5 is a graph showing the ideal and actual dispersion characteristics of the compound dielectric of FIGURE 3.

Referring to the drawings, a compound artificial dielectric made according to the present invention comprises a plurality of thin layers or sheets 11, 12, 13, 14 and 15 of light-weight dielectric material, such as Polyfoam (polystyrene foam), stacked together to form a dielectric assembly 18 shown in FIGURE 1. The dielectric sheets support arrays of scattering elements 20 consisting of thin, elongated, preferably rectangular strips of conducting material, such as metallic foil or paint, the strips are arranged on each sheet with their longitudinal axes parallel.

The elements on each sheet are randomly spaced apart both longitudinally and transversely, and, additionally, the lengths of the elements are varied in a random manner with no theoretical limits on the lengths of the elements, though practically it is preferred that the lengths of the elements be prescribed according to theory by a distribution function. The distribution function relates the lengths of the elements required and the number of elements of a given length to a predetermined dispersion characteristic. The distribution function is obtained by solving an integral equation for the prescribed dispersion characteristic of the artificial dielectric and by applying the Wiener-Hopf technique in conjunction with the Fourier integral methods as generally described in Methods of Theoretical Physics, part 1, by P. Morse and H. Feshbach, at page 978 et seq. (McGraw-Hill, 1953). The function prescribes elements of lengths from a minimum to a maximum, and a certain number of elements of each length. However, the positioning of these elements is random, that is, the physical spacing of the elements is restricted only in the sense that there is a specific number of elements of a specified length. The dielectric sheets may be fabricated, for example, by silk screening strips of silver or aluminum paint on a face of each sheet and then bonding the several sheets together in a stack with the strips on adjacent sheets separated by the thickness of one sheet.

The several sheets 11, 12, 13, 14 and 15 which comprise assembly 18 are formed in substantially the same manner, that is, the lengths of the elements 20 and the

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spacing between adjacent elements on each sheet are varied in a random manner. Each element 20 is in effect an elementary dipole or resonator whose resonant frequency is dependent upon its length. The elements in the whole assembly which have the same length form a sub-group of elements which have a characteristic resonance, the effect of which is proportional to the number of elements in the sub-group. The term "effect of the characteristic resonance" as used herein means the magnitude of the total current induced in the resonant elements, or the magnitude of the electromagnetic energy scattered by the resonant elements. There are a plurality of such sub-groups which make up the entire assembly 18, and the square of the index of refraction of the assembly is proportional to the sum of the squares of the refractive indexes of the sub-groups. The refractive index of the sub-groups can be computed by means of the classical Helmholtz theory, see H. Helmholtz, Poggendorff's Annalen der Physik und Chemi, pages 154 and 582 (Johann Ambrosius Barth/Verlag/Leipzig, 1875). By varying the total number, N , of the sub-groups of elements in the assembly, the distribution of resonant frequencies, and the magnitude of resonance effects at each resonant frequency, it is possible to achieve a desired resultant index of refraction n for the assembly, that is, an index of refraction which decreases with an increase in frequency of the incident microwave energy. The variation of these parameters is subject to the limitation that the total number of elementary resonators at any one frequency should be sufficiently small to prevent substantial adsorption of energy at that frequency.

The density of elements 20 on each dielectric sheet and the number of such sheets which comprise an assembly are selected to provide optimum matching between the medium from which the incident energy emerges and the artificial dielectric structure. In order to optimize this match the number of arrays or layers in an assembly may be increased and the areal density of the elements on each layer correspondingly decreased without otherwise affecting the performance of the structure.

In order that the composite dielectric structure 18 function as a quarterwave plate, it is oriented so that the incident microwave energy propagates through the structure normal to the planes of the several sheets. This radiating energy should be a linearly polarized wave having an E-vector at an angle of 45° relative to the axes of the elements 20 comprising the arrays, see FIGURE 1, so that the E_y and E_x components are either parallel to or perpendicular to the axes of these elements. As the E_x component of the wave passes through the arrays on the several sheets, there is negligible effect because of the perpendicular relationship and the E_x component is essentially unchanged. The E_y component, however, is parallel to the axes of elements 20 and therefore is responsive to these elements. The phase velocities of the two wave components E_x and E_y passing through the medium can thus be controlled so that the optical path difference Δ of the two components in the composite structure of thickness D is a decreasing function of frequency over a wide band of operating frequencies and the phase shift caused by the artificial dielectric is substantially constant.

In the practice of the invention, dielectric sheets 11, 12, 13, 14 and 15 were fabricated by depositing conducting silver paint (by silk-screen process) onto sheets of high impact styrene, each approximately 10 mils thick. The sheets were 20 inches square and were separated by $\frac{1}{8}$ -inch layers of polystyrene foam. The average areal density of the elements 20 on each sheet was one element per square inch, and these elements varied uniformly in length from 0.365 cm. to 1.460 cm. in 200 incremental steps. However, the physical positions of the elements were determined randomly, that is, position coordinates of the elements were determined from

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a table of random digits, see "Statistical Tables and Formulas" by A. Hald (John Wiley & Sons, Inc., 1952). The measured dispersion curve (plot of index of refraction against frequency) of this dielectric is shown at 22 in FIGURE 2. For comparison purposes the dispersion curve of a "perfect" quarterwave plate is shown in broken lines at 23. It will be noted that the negative slope of curve 22 is steeper than desired though it tends to follow the general contour of the ideal curve.

In order more closely to approximate the desired dispersion of a "perfect" quarterwave plate, a composite dielectric structure 30, see FIGURE 3, was constructed with a combination of sheets of dielectric having scattering elements of equal length and evenly or periodically (as distinguished from randomly) spaced apart, called "periodic sheets," together with sheets having elements of different lengths and random distribution as described above, called "random sheets." A quarterwave plate was constructed utilizing six sheets of random-type scattering elements 31, these sheets being indicated at 32-37, inclusive, in FIGURE 3, and nine sheets of periodically arranged elements 39, the latter sheets being designated by reference characters 40-48, inclusive. The particular arrangement of the random and periodic sheets in the composite structure is more clearly indicated schematically in FIGURE 4 with the solid lines representing the random-type sheets and the broken lines the periodic sheets. The direction of propagation of the incident wave is indicated by the arrows in FIGURES 3 and 4.

The dispersion curve 50, see FIGURE 5, for the artificial dielectric structure 30 is seen to substantially duplicate the corresponding curve 51 for a "perfect" quarterwave plate over approximately a 38% frequency band. The random sheets comprising the structure 30 were constructed substantially the same as the sheets for the structure 18 of FIGURE 1. Each of the periodic arrays 40-48, inclusive, comprised a 20-inch square of high impact styrene; the areal density of elements thereon was four elements per square inch with a lateral spacing between elements of 1.25 cm., each element being of conducting silver paint 0.75 cm. long and 0.20 cm. wide.

From the foregoing description it has been shown that an artificial dielectric capable of approximating the performance of a "perfect" quarterwave plate can be constructed. This dielectric structure is readily made from light-weight mechanically strong material which may be economically produced.

While preferred embodiments of the invention have been described herein in detail, it will be understood that those skilled in the art can make various changes in or modifications of the described arrangements and configurations without departing from the principle of the invention. For example, while I have specifically described a dielectric medium in which the scattering elements are of different lengths and are randomly spaced, the elements may also have the same dimension in a random distribution, or may have random lengths in a periodic or equally-spaced arrangement. Furthermore, the conducting elements may be shaped other than as rectangles as shown and described. Therefore, the scope of the invention is defined in the appended claim.

I claim:

A broadband artificial dielectric having an index of refraction which decreases with an increase in the frequency of incident electromagnetic wave energy comprising a plurality of stacked planar dielectric arrays, each of said arrays having a plurality of elongated resonant conducting strips supported in spaced relation in a common plane and being oriented with their long axes parallel to each other and to the axes of strips in the other arrays, the position coordinates of said resonant strips in each array being varied in a random manner derived from a table of random digits, the lengths of said resonant strips in each array being varied whereby the strips are resonant at different frequencies of the electromagnetic

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wave energy, said arrays being stacked along an axis with adjacent arrays axially spaced apart.

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