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Methodological Notes

TWO DEMONSTRATION EXPERIMENTS WITH THREE-CENTIMETER ELECTROMAGNETIC WAVES

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1. PROPAGATION OF ELECTROMAGNETIC WAVES IN AN ANISOTROPIC MEDIUM

In the present communication we describe illustrative experiments on birefringence of centimeter waves in artificial dielectrics[1,2]. Such media have a number of advantages over natural anisotropic media[3] for waves in this band.

Figure 1 shows a rectangular birefringent prism with a vertex angle 45°. It constitutes a "bundle" made of 49 tinplate waveguides soldered together, each with dimensions $a_x = 27$ mm and $a_y = 23$ mm. The x axis is directed vertically. The experiment with the described prism consists of demonstrating that waves having one linear polarization, say vertical, are refracted in it in a different manner than waves having another (horizontal) polarization.

The prism is irradiated (Fig. 2) with a vertically polarized wave $E_0 = E_x$. The wave propagating inside the waveguides of the prism (guided H_{01} or TE_{01} wave) has a wavelength $\lambda_{01} = \lambda/[1 - (\lambda/2a_y)^2]^{1/2} = 4.5$ cm, which depends on the dimension a_y of the waveguides. $\lambda = 3.2$ cm is the wavelength in free space. The equivalent refractive index for a vertically polarized wave turns out to be $n_{01} = \lambda/\lambda_{01} = [1 - (\lambda/2a_y)^2]^{1/2} = 0.71$. By moving a receiving horn antenna connected with an S1-1 oscilloscope along a circle with center on the inclined surface of the prism, one notes that the maximum reception takes place when the axis of the horn of the receiving antenna is inclined at an angle 19° to the horizontal. In the demonstration it is necessary to call attention to the fact that the waveguide prism deflects the radiation from its base, since for this prism $n < 1$. By irradiating the prism with a horizontal polarized wave $E_0 = E_y$ and moving the receiving antenna as before, it is shown that the maximum reception occurs at an angle 15° to the horizontal. The equivalent refractive index for the horizontally polarized wave is $n_{10} = [1 - (\lambda/2a_x)^2]^{1/2} = 0.80$. The different refraction of waves of different polarization, as can be readily seen, is due to the anisotropy of the properties of the artificial dielectric: $a_x \neq a_y$. If the prism is made of waveguides of square cross section, then there is no birefringence.

Figure 3 shows a "plate" of an anisotropic medium, made of 56 rectangular waveguides of identical length having the same cross section 23 × 27 mm as before. A linearly-polarized wave with electric vector **E** making an angle 45° to the walls of the "bundle" of waveguides, when incident normally on such a "plate," breaks up into two (ordinary H_{01} and extraordinary H_{10}) waves of equal amplitude and orthogonal planes of polarization. Because of the difference of the refractive indices for these waves, $n_{10} \neq n_{01}$, these waves will be propagated in the "plate" with different phase velocities. After passing through a "plate" of thickness d, the extraordinary and ordinary waves acquire a phase difference φ, which determines the polarization of the transmitted wave.

Figure 4 shows the experimentally obtained change of the polarization diagram of a wave passing through the "plate" as a function of its thickness d. The polar-

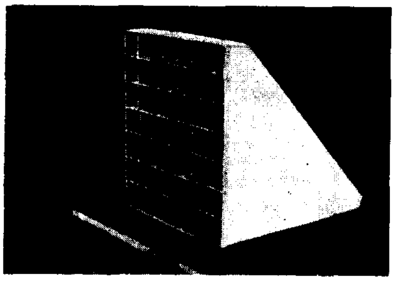

FIG. 1

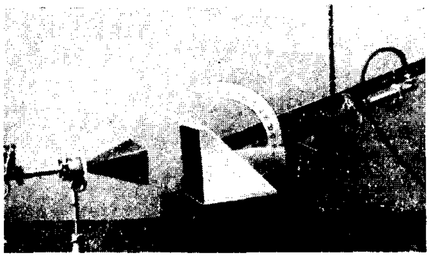

FIG. 2

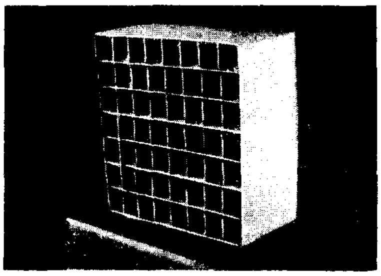

FIG. 3

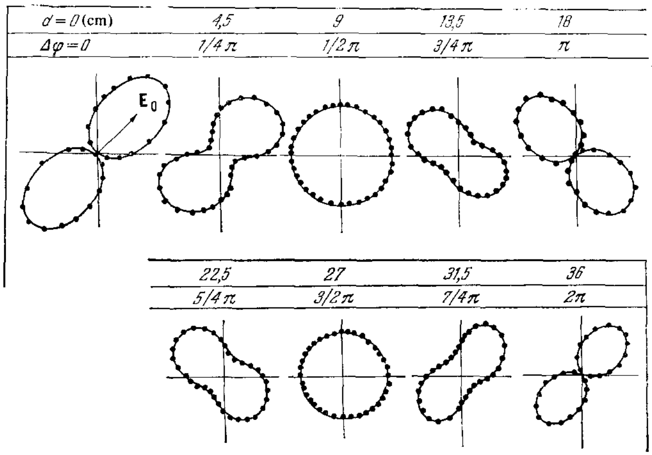

FIG. 4

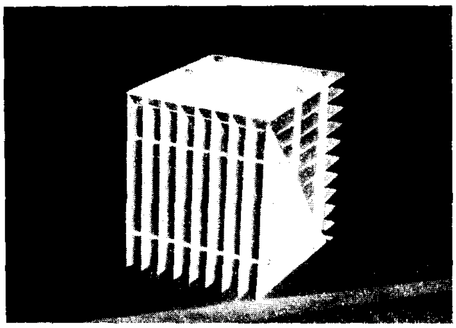

FIG. 5

ization diagrams were obtained by rotating the receiving horn antenna around the longitudinal axis. In view of the small absorption of the three-centimeter waves in the artificial dielectrics, the receiving antenna was connected directly to the oscilloscope. Analyzing the polarization diagrams, one can easily see that the "plate" made of waveguides of length d = 9 cm performs the role of a "quarter-wave plate". The use of other types of artificial dielectrics to obtain circular polarization is described in[4,5]. A "plate" of thickness d = 18 cm is accordingly a "half-wave plate."

By irradiating "plates" of different thicknesses with a wave whose electric vector makes an arbitrary angle with the walls of the "bundle" waveguides, it is demonstrated by rotating the receiving antenna about the longitudinal axis that the wave passing through the "plate" is elliptically polarized. With increasing thickness of the "plate," the major semiaxis of the ellipse changes its orientation relative to the plane of polarization of the incident wave.[6]

The plotting of the polarization diagrams is best carried out as part of a laboratory assignment, and the type of polarization should be discussed in the lecture demonstrations only qualitatively.

To obtain an arbitrary phase difference between the ordinary and extraordinary waves, we have constructed a Babinet compensator consisting of two rectangular waveguide prisms with vertex angle 25°. The planes of the section of the waveguides in the prisms are rotated relative to each other through 90°. Each prism has 84 waveguides.

In experiments on birefringence it is possible to use not only waveguides but also metallic-plate structures. Figure 5 shows a polarization Wollaston prism. By irradiating the prism with a wave whose electric vector makes an angle 45° with the metal plates, the wave is broken up into two orthogonal components. The vertical component is refracted by the first prism at its base, since for it $n'_x = [1 - (\lambda/2a)^2]^{1/2} < 1$, and is not refracted by the second, since $n''_x = 1$. The horizontal component is not refracted by the first prism, since $n'_y = 1$, and is refracted by the second from its base, since $n''_y = [1 - (\lambda/2a)^2]^{1/2} = 0.60$, where a = 20 mm is the distance between the metallic plates of the prisms. When they emerge from the Wollaston prism, the ordinary and extraordinary rays are separated by an angle of 38°.

2. ILLUSTRATION OF THE PHENOMENON OF POLARIZATION OF LIGHT SCATTERED IN TURBID MEDIA

The setup for illustrating the state of polarization of scattered radiation consists (Fig. 6) of a three-centimeter-wave radiator (1) and two receiving horn antennas (2, 3), all placed in mutually perpendicular directions. The role of the "turbid medium" is played by a piece of foamed plastic (4) measuring 200 × 200 × 200 mm, in which 300 copper dipoles are randomly oriented in space. The dipoles are made of wire and are 3.2 cm long.

The illustration of the scattering of "natural light" is performed in the following sequence: the receiving antennas, which are connected with oscilloscopes, are mounted in such a way that the wide sides of their waveguides are perpendicular to the scattering plane. The model of the turbid medium is irradiated with a wave having circular polarization (using a quarter-wave plate for this purpose). This excites all the dipoles lying in the scattering plane, which is equivalent to the use of "natural light." The oscilloscope screens reveal the identical intensities of the scattering. On rotating the receiving antennas about their longitudinal axes through 90°, it is verified that there is no scattered radiation. It is concluded from this experiment that the scattered radiation of "natural light" in this model is equally intense in all the directions in the scattering plane and is linearly polarized in this plane.

To illustrate the scattering of linearly polarized "light," the receiving antennas are set, just as in the

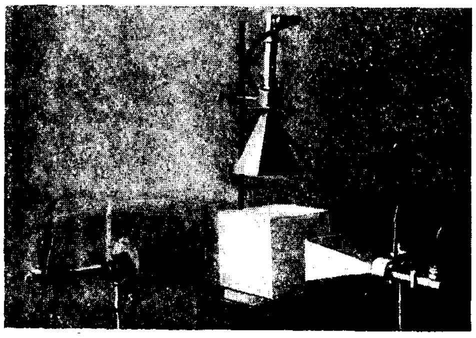

FIG. 6

first case, before the start of the experiment (see Fig. 6). The model is irradiated with a vertically-polarized wave. The existence of scattered radiation is noted only in the direction of antenna 2. By rotating the radiator 1 around the longitudinal axis through an angle of 90° one notices now that scattering exists only in the direction of the receiving antenna 3. By uniformly rotating the radiator one observes on the oscilloscope screens the change of the intensity of the scattering in the directions of the antennas. The receiving antennas are rotated through 90° about the longitudinal axis. On rotating the radiator as before, it is seen that there is no scattered radiation. It is concluded from the experiment that linearly polarized "light" is not uniformly scattered in different directions. The scattered radiation is polarized in the scattering plane again in this case.

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Translated by J. G. Adashko