Interference of 3-cm radio waves in a plane-parallel dielectric layer

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If an electromagnetic linearly-polarized monochromatic plane wave is incident from air on a plane-parallel layer of a homogeneous absorbing dielectric with dielectric constant $\epsilon > 1$, then the intensities $I^{(t)}$ and $I^{(r)}$ of the waves transmitted and reflected from this layer respectively, are expressed in terms of the well known Airy formulas[1], which were derived with account taken of an infinite number of reflections from both boundaries of the layer:

$$I^{(t)}=\frac{I_0T^2}{(1-R^2)+4R\sin^2(\delta/2)}=I_0Q^2, \tag{1}$$

$$I^{(r)}=\frac{I_0 4R\sin^2\delta/2}{(1-R)^2+4R\sin^2(\delta/2)}=I_0P^2. \tag{2}$$

In these formulas, R and T are respectively the coefficients of reflection and transmission of the layer boundary and are connected by the relation $R + T = 1$, $\delta = (2\pi h/\lambda_0)\cos\theta$, where h is the thickness of the dielectric layer, λ_0 is the wavelength of the radiation in air, θ is the angle of refraction of the radiation at the layer boundary, and P and Q are the reflection and transmission coefficients of the layer as a whole. We confine ourselves henceforth to cases in which $\theta = 0$.

The value of $I^{(r)}$ is maximal when the layer of thickness h satisfies the conditions

$$h=\frac{1}{4}\frac{\lambda_0}{\sqrt{\varepsilon}},\ \frac{3}{4}\frac{\lambda_0}{\sqrt{\varepsilon}},\ \frac{5}{4}\frac{\lambda_0}{\sqrt{\varepsilon}}\ \text{etc.} \tag{3}$$

$I^{(r)}$ vanishes when

$$h=\frac{1}{2}\frac{\lambda_0}{\sqrt{\varepsilon}},\ \frac{2}{2}\frac{\lambda_0}{\sqrt{\varepsilon}},\ \frac{3}{2}\frac{\lambda_0}{\sqrt{\varepsilon}}\ \text{etc.} \tag{4}$$

As seen from (1), and also from the condition $I^{(t)} + I^{(r)} = 1$, $I^{(t)}$ is maximal if the conditions (4) are satisfied and minimal if conditions (3) are satisfied.

The wave incident on the layer interferes with the less intense wave reflected from the layer, as a result of which a system of standing waves superimposed on the traveling wave is produced in front of the layer. This spatial distribution of the intensity is characterized by the standing wave ratio (SWR), defined as the ratio of the maximum field amplitude A_{max} to the minimum

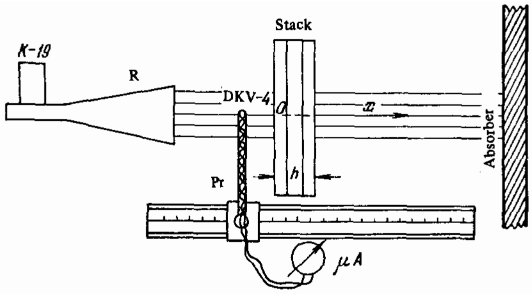

FIG. 1

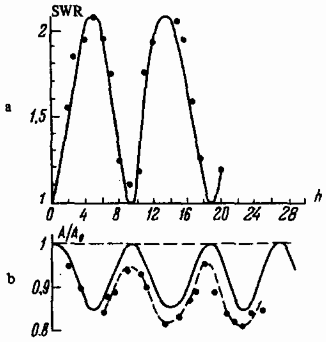

FIG. 2

amplitude A_{min}. By investigating the distribution of the intensity on both sides of the layer and by measuring the SWR it is possible to obtain a complete idea concerning the regularities described above and to obtain the value of ϵ of the layer. This is conveniently done in the three-cm radio band for a layer having $h < \lambda_0$.

A diagram of the installation used for this purpose is shown in Fig. 1. Here R is a horn radiator excited by a K-19 klystron oscillator, Pr is a receiving probe whose antennas are metallic detector clamps of the DKV-4 type. The detector is mounted on a foamed-plastic holder, which in turn is fastened on a slide. The latter is displaced along two horizontal guides with a micrometric screw.

The investigated plane-parallel layer of the dielectric is a stack of tightly compressed sheets of organic glass. The thickness h of the stack can be varied from 2 to 31 mm. The absorber for the radiation passing through the stack is a multilayer set of felt plates dusted with graphite powder. The probe with the detector is placed in the investigated wave field. An emf induced by the high-frequency field of the radiator is produced in its antenna. The signal is detected and the dc component is measured by an LM pointer-type galvanometer. The characteristic of the DKV-4 detector is quadratic for weak signals. Therefore the dc component of the rectified current is proportional to the radiation intensity.

The measurements begin with a determination of the wavelength λ_0 of the employed radiation. To this end, a flat metallic mirror is placed in front of the horn of the radiator. The approximate distance between the mirror and the horn is 1 m. By moving the detecting antenna from the mirror towards the horn, one measures the distribution of the intensity I along the x axis in the standing-wave system produced in this case. The position of the antenna is measured on a scale secured to the guides of the slide. The value of 0 is determined from the plot of the distribution of I vs. x with accuracy to several tenths of a millimeter.

To observe interference effects and to calculate ϵ of the dielectric layer, the measurements (using the reflected wave) are performed in the following manner: the metallic mirror is removed and is replaced by a stack of organic-glass plates with different thicknesses h. In order for the radio horn not to influence the distribution of the intensity in the standing-wave system, it is also placed far enough from the stack.

The probe is first placed in front of the stack, as close to it as permitted by the thickness of the probe. Then, moving the probe towards the horn, the maximum and minimum readings of the galvanometer $i_{max} \sim A^2_{max}$ and $i_{min} \sim A^2_{min}$ are recorded in an interval $(8-10)\lambda_0$. Such measurements are performed for a number of thicknesses h of the dielectric-plate stacks.

The measurement results are reduced in the following manner. The value of $SWR = A_{max}/A_{min}$ is determined and its mean value is found for each measurement run made at each value of h. A plot of SWR against h is constructed (Fig. 2a). The reflection coefficient P of the layer in formula (2) is expressed in terms of the SWR as follows:

$$P=\frac{SWR-1}{SWR+1} \tag{5}$$

and accordingly

$$SWR=\frac{1+P}{1-P}. \tag{6}$$

It follows therefore that the extremal values of the SWR correspond to extremal values of P. Consequently, using the plot and the conditions (3) and (4), and knowing beforehand the measured value of λ_0, it is possible to obtain the value of ϵ of organic glass at 10^{10} Hz. It turns out to equal 3.2 ± 0.1, which agrees with the data given in the handbook[2]. Then, using (2) and (6), one can calculate the theoretical values of SWR at the obtained value of ϵ. In our case, the plot of these values practically coincides with the curve drawn through the experimental data (see Fig. 2a), with the exception of the points at which the indicated values of SWR are equal to unity.

The next cycle of measurements is carried out for a wave passing through the stack, and therefore the probe is placed between the stack in the absorber. Since the latter is not ideal, a system of standing waves is produced also behind the stack. It is easy to see that the sought traveling-wave amplitude $A \sim Q\sqrt{I_0}$, which depends on the thickness h of the stack, can be obtained if the field of the standing waves between the stack and the absorber is measured by moving the probe. In fact

$$A=\frac{A_{max}+A_{min}}{2}\sim\frac{\sqrt{i_{max}}+\sqrt{i_{min}}}{2}.$$

When the thickness h of the stack satisfies the conditions (4), the amplitude of the traveling wave assumes the maximum value A_0. The dashed curve in Fig. 2b shows the experimentally obtained plot of A/A_0 against h. The solid line in the same figure shows a plot of the theoretical dependence of A/A_0 on h at the previously obtained value of ϵ. The maximum value of P from (1) is assumed to be unity.

Thus, the entire aggregate of the experiments and their reduction illustrate clearly the interference effects in a plane-parallel dielectric layer, something difficult to demonstrate in the optical band of the electromagnetic spectrum.

[1] M. Born and E. Wolf, Principles of Optics, Pergamon, 1970.

[2] G. W. Kaye and T. H. Laby, Tables of Physical and Chemical Constants, Wiley, 1966.