METHODOLOGICAL NOTES

Demonstration microscope with field emission

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The effectiveness of lectures devoted to the study of the crystalline structure of bodies, field emission, or lensless microscopes can be greatly enhanced by using a demonstration microscope with field emission (an electronic projector).

We constructed a demonstration microscope with an electron field emission using a television kinescope with screen diameter 18 cm (18LK, LK-726). In the kinescope, the electron gun is replaced by an arch of tungsten wire of 0.2 mm diameter (Fig. 1). A tungsten needle made of wire 0.1 mm diameter is welded to the center of the arch. The needle is sharpened by automatic electrochemical etching. To produce the required vacuum in the tube of the instrument (10^{-8}–10^{-9} mm Hg), a getter is used in the form of a tungsten wire (0.2 mm diameter) on which titanium beads are placed (see Fig. 1).

The bulb is evacuated with a vacuum installation consisting of a VN-461 forevacuum pump, an MM-40 diffusion pump, and a nitrogen trap.

After evacuating the bulb with the vacuum installation, any further increase of the vacuum is produced by the getter, through one of the filaments of which a current of 2.7–2.8 A was made to flow for several hours.

The demonstration is made with the assembly illustrated in Fig. 2. The assembly includes, besides the electron projector, also an adjustable dc voltage source (up to 4 kV) and a microammeter (with scale 0–10 μA). The anode of the projector is connected to the power supply through a limiting resistor rated 30–50 Meg.

Before performing the experiments, a current of 5 A is made to flow through the cathode of the projector for several dozen seconds. This heats the needle, so that its point becomes single-crystal and becomes rounded in shape.

Next, the high-voltage source is turned on, the voltage on the anode is adjusted smoothly to ensure that the current through the instrument does not exceed 5–7 μA. The screen then shows a magnified emission image of the surface of the cathode. reflecting the symmetry of the crystal structure of the needle point (Fig. 3). The obtained magnification is on the order of 800 000 ×.

Experiments performed for over a year with the described electron projector have shown it to be highly reliable. We noted no deterioration of the vacuum in the bulb during this time.

1. ANALOG OF "COATED OPTICS" AT CENTIMETER WAVELENGTHS

As is well known, to decrease the reflection of light from surfaces of optical glasses, the latter are coated with a dielectric layer; the thickness of the coating is made equal to an odd number of quarter wavelengths of light in the dielectric, and the relative dielectric constant of the latter is (see[1]) $\epsilon_1 = \sqrt{\epsilon}$, where ϵ is the relative dielectric constant of glass surrounded by air ($\epsilon_2 = 1$).

In the region of long visible wavelengths, it is difficult to demonstrate the influence of the dielectric layer thickness on the extent to which the reflection is reduced by the coating; at centimeter wavelengths the experiment can be performed without difficulty.

The horn antennas of the generator (G) and receiver (R) for centimeter wavelengths are mounted vertically at a distance 2–3 m from each other (Fig. 1a).

A glass plate (Gl) is placed over the horn antenna of the receiver and covers the entire aperture of the horn; the thickness of the glass is several centimeters ($\epsilon \approx 6$). A quarter-wave reflection-illuminating layer is produced with the aid of a liquid, in our case benzene ($\epsilon_1 = 2.28$), which is poured into a thin-wall glass cell mounted on the plate. Before the experiment, a record is made (with the cell empty), the intensity of the signal passing through the cell. The cell is then slowly filled with benzene. The transmission coefficient of the system then changes and goes through a maximum when the thickness of the benzene layer becomes equal to an odd number of quarter wavelengths of the light in benzene:

$$h = (2k+1)\frac{\lambda}{4}, \quad k = 0, 1, \ldots$$

Figure 2 shows the dependence of the intensity I of

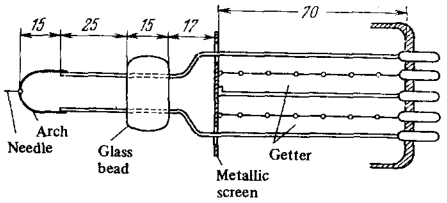

FIG. 1

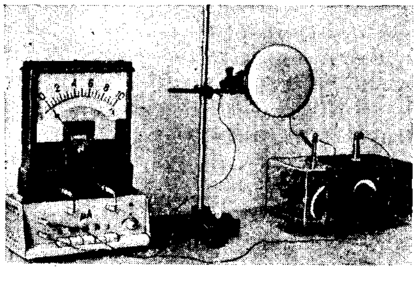

FIG. 2

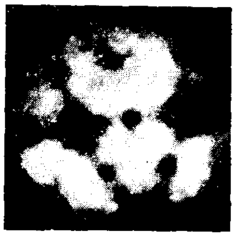

FIG. 3

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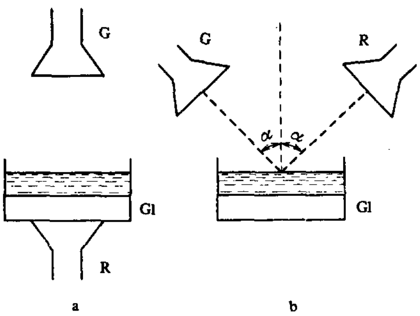

FIG. 1

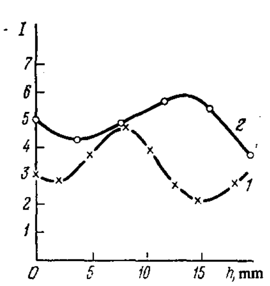

FIG. 2

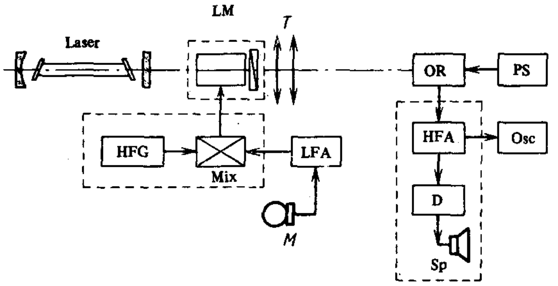

FIG. 3

the transmitted signal on the thickness h of the benzene layer (curve II).

The reflection coefficient is simultaneously altered (it has a minimum at the thicknesses indicated above); this can be verified by placing the receiving horn antenna near the transmitting antenna and slightly inclining the axes of both horns relative to the vertical (Fig. 1b, where the inclination angles α are exaggerated).

The experiment can be successfully performed also if the benzene is replaced with sheets of cardboard placed one on top of the other.

Curve 2 (Fig. 2) determines the dependence of the reflected signal on the total thickness of the cardboard layer. Since the absorption in cardboard is larger than in benzene, the influence of h is less clearly pronounced; in addition, in such an experiment the thickness of the dielectric must, of course, be varied jumpwise, which also makes for worse demonstration conditions.

2. DEMONSTRATION OF AN OPTICAL COMMUNICATION CHANNEL

The proposed demonstration of a communication channel using an optical beam, illustrates, in addition to the principle of optical communication, also the operation of a laser as a carrier-wave generator in the optical band, the action of a modern low-inertia light modulator, and operation of a light receiver of the photomultiplier type[2-4].

A diagram of the demonstration is shown in Fig. 3. The light source is an OKG-11 gas laser. The light is intensity modulated, in accordance with the transmitted communication, by a light modulator LM (type OLMSh-100), the operating principle of which is based on the Pockels effect. The carrier-frequency voltage is set by a high-frequency generator (HFG) (type GZ-12). The subcarrier amplitude is modulated in accordance with the transmitted communication through the external-modulation channel in the mixer (Mix). This communication in our experiment is human speech acting on the mixer through a microphone M and a low-frequency amplifier LFA.

The modulated laser beam was focused with the aid of a telescopic system T on the entrance diaphragm of an optical receiver OR. The optical detector was an FEU-28 photomultiplier fed from a power supply PS. Being a light-intensity detector, as are all optical receivers, the photomultiplier can register changes in the intensity of the light flux.

The signal at the subcarrier frequency flows from the output of the optical receiver to the input of the high-frequency amplifier HFA (a selective voltmeter of type V6-1). A cathode ray oscilloscope (Osc) at the amplifier output makes it possible to observe visually the variation of the subcarrier amplitude in accordance with the modulation law, and the low-frequency detector D with the loudspeaker Sp of the V6-1 instrument reproduces the transmitted speech.

The transmitting and receiving parts of the demonstration setup are ~10 m apart during the experiment.

The installation described above makes it possible to demonstrate the high degree of directivity of the laser signal, the interference immunity of the communication channel (the demonstration is carried out in daylight), and the possibility of communication at different values of the subcarrier frequency. If two (or several) subcarrier generators are used simultaneously, it is possible to demonstrate also multiple-channel optical communication.

3. FOURIER EXPANSION OF DAMPED OSCILLATIONS

Spectrum analyzers of the type ASChKh-1 or SCh-8 can be used in lecture demonstrations of Fourier expansion.

Demonstrations of Fourier expansion have already been described in the methodological literature[5,6]. It is of interest, however, to demonstrate with the aid of the indicated spectral instrument the spectral expansion, into a Fourier integral, of a function that describes damped oscillations:

$$f(t) = e^{-\alpha t} \sin \omega_1 t.$$

For a one-shot process, the distribution function $S(\omega)$ is shown in Fig. 4, and the maximum of the function[7] is obtained at $\omega = \omega_0$, where ω_0 is the frequency of the free oscillations of a tank circuit with damping coefficient α:

$$\omega_0^2 = \omega_1^2 - \alpha^2.$$

It is impossible, however, to register single processes with spectrum analyzers of the types indicated above. But if a process of this kind is repeated periodically, then the expansion represents a line spectrum inscribed in the $S(\omega)$ curve. The intervals between the spectral components are determined by the pulse repetition frequency $\Omega = 2\pi/T$.

An experimental confirmation of the Fourier theorem can be obtained by surge excitation of the tank circuit. In the demonstration, a diagram of which is shown in Fig. 5, the surge excitation of the LCR circuit is produced by a sawtooth voltage taken from the X-plates of an S1-4 oscilloscope (I). Damped electromagnetic oscillations are produced in the LCR circuit (Fig. 6). The voltage U is applied to the input of the vertical amplifier of the S1-4 cathode-ray oscilloscope (II) and an

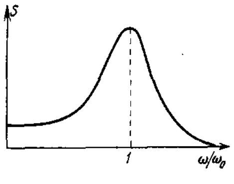

FIG. 4

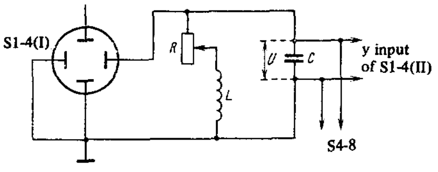

FIG. 5

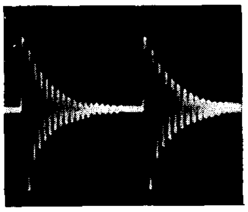

FIG. 6

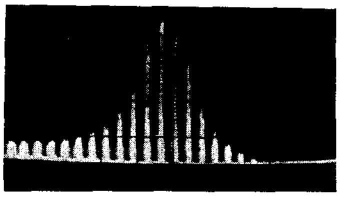

FIG. 7

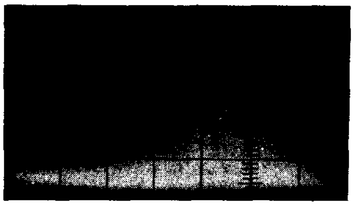

FIG. 8

S4-8 high-frequency spectrum analyzer. The resolving power of a spectral analyzer of this type is 8 kHz. The natural frequency of the task circuit is about 500 kHz. If the repetition frequency of the pulses is high enough (20 kHz), the spectrum has a line-like character (Fig. 7), and the envelope of the line spectrum coincides with the envelope of the continuous spectrum. It can be shown here also that the maximum of the expansion is determined by the natural frequency of the tank circuit, and the width of the spectrum is determined by the damping in the tank circuit—the larger the damping in the circuit, the broader the spectrum.

At a low pulse repetition frequency (150 Hz), the spectrum analyzer screen shows practically a continuous spectrum (Fig. 8), inasmuch as it is impossible to resolve the neighboring harmonics. The envelope of the spectrum corresponds to the curve shown in Fig. 4.

Thus, it is clearly demonstrated that the resolving power of the instrument determines the character of the obtained spectrum: if the individual spectral components cannot be resolved, then the observer sees a continuous spectrum.

On the other hand, the agreement between the real envelope and the theoretical curve of Fig. 4 allows us to conclude that on going to less frequent processes (down to a single process), the expansion should coincide with the theoretical one.

4. OPEN TUNABLE RESONATOR WITH SEMITRANSPARENT WALLS FOR CENTIMETER ELECTROMAGNETIC WAVES (λ = 3.2 cm)

The resonator comprises a system in which a wave is multiply reflected between parallel semitransparent metallic films coated on a dielectric base stretched on a ring of 20 cm diameter.

The energy reflection coefficients R, the transmission coefficients T, and the absorption coefficients A, which are connected by the relation $R + T + A = 1$, were measured and amounted to $R = 0.58$, $T = 0.07$, and $A = 0.35$. The films were mounted parallel on a vernier device, which made it possible to move one "mirror" S relative to the other (Fig. 9). By the same token it was possible to measure the path difference between the interfering beams.

The maximum intensity of the transmitted wave occurs when the condition

$$2l\cos\varphi = m\lambda, \quad \text{where } m = 0, 1, 2, \ldots$$

is satisfied φ being the angle between the beam and the normal to the film. The minimum intensity occurs at

$$m = \frac{1}{2};\ \frac{3}{2}.$$

The highest order of the interference for our interferometer, at normal incidence of the beams ($\cos\varphi = 1$) is

$$m = 2\frac{l}{\lambda} = 7.$$

The wave source is a standard klystron generator feeding a rectangular radiating horn antenna. A similar receiving horn is connected through a detector to an amplifier and a cathode-ray oscilloscope, on which an oscillogram of the modulating voltage is observed.

Figure 10 shows the dependence of the intensity of the transmitted wave on the distance between the plates: the sharp peaks of the maximum give way to broad minima.

This feature, which is typical in particular of the Fabry-Perot interferometer[8], makes it possible to use this demonstration when interferometers are studied in a course of general physics, in addition to the previously described Michelson interferometer[9].

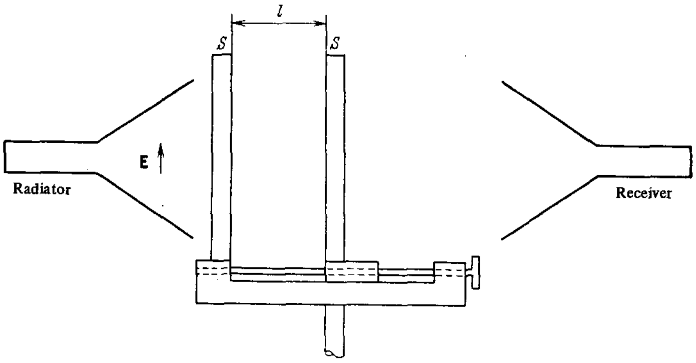

FIG. 9

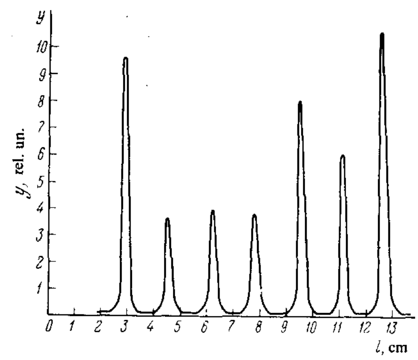

FIG. 10

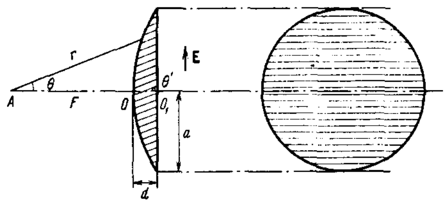

FIG. 11

Note. The difference in the amplitudes of the peaks in Fig. 10 is due to slight nonparellelism of the mirrors when they are displaced.

5. METAL-PLATE KOCK LENS FOR ACOUSTIC AND ELECTROMAGNETIC WAVES

The lens proposed by Kock makes it possible to focus a wave by means of the wave delay produced by the central part of the lens. The lens is a system of metallic thin plates which are inclined at an angle θ' to the optical axis of the lens. Side and plan views of the lens are shown in Fig. 11.

The profile of the system of inclined plates is described by the hyperbola equation

$$r=\frac{(n-1)E}{n\cos\theta^{-1}},\ \text{where}\ \ n=\frac{1}{\cos\theta'}.$$

In our case the lens has the following parameters: $\theta' = 45°$, F = 30 cm is the focal distance, d = 7 cm is the largest thickness of the lens, and a = 15 cm is the radius of the lens. The distance between plates should be less than half the employed wavelength (this is important for the case of electromagnetic waves).

Using this lens, we can perform a number of experiments with acoustic and electromagnetic waves (~3 cm).

a) A sound-wave generator ZG-10 is excited at a frequency f = 10^4 Hz; the sound waves are radiated by a dynamic loudspeaker GD-05 placed on one straight line with a microphone MD-45, with the distance between them ~120 cm. From the amplitudes of the oscillograms of the amplified receiving signal (S1-1 oscilloscope) it is possible to estimate the signal amplitude. By placing the lens between the microphone and the speaker and by moving it along the ray, it is possible to choose a lens position such that the amplitude of the received signal is increased by 3—5 times.

Moving the microphone along the ray and perpendicular to it, it is possible to show that the "focal spot" of the lens extends in both directions to approximately one-quarter wavelength. By rotating the lens about the optical axis, we note that rotation has practically no effect on the intensity of the received signal, since the sound waves are longitudinal.

b) Generator and receiver horn antennas for 3-cm electromagnetic waves replace the microphone and the dynamic speaker. The reception intensity in the absence of the lens is recorded. The lens is then introduced, and the disposition of its plates and the orientation of the electric vector E of the incident wave correspond to Fig. 11. The amplitude of the received signal can be increased by 3—6 times. If half of the lens surface is covered by a half-wave plate, reception stops; if the half-wave plate covers the entire surface of the lens, reception is resumed.

Finally, by rotating the lens about the optical axis through 90° it is possible to observe complete vanishing of the received signal, this being due to the linear polarization of the wave and to the opacity of the lens channels to definite polarization.

Thus, the Kock lens not only makes it possible to demonstrate the general features of diverse processes, but also to reveal the differences between these processes.

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