SEVERAL DEMONSTRATIONS OF THE DOPPLER EFFECT AND INTERFERENCE IN THE CENTIMETER RADIO BAND

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1. The Doppler effect in the centimeter radio wave band is conveniently demonstrated with the aid of an interferometer whose general form is shown in Fig. 1. The main part of the instrument is a simple branching device, constituting a junction of three waveguide lines soldered at an angle of 120° to one another. A low-power klystron generator is connected to one end of the junction, a line segment with a detector to the second, and a pyramidal horn antenna to the third. The lines with the detector and with the klystron have short-circuiting plungers for tuning. A reflector mirror is placed ahead of the horn on a carrier, and can be moved on rails in the direction to and from the horn.

The operating principle of the radio interferometer is as follows: the radio waves propagating along the waveguide from the klystron generator are split in the junction into two beams, one of which goes to the detector and the other through the radiating horn to the reflector. Upon reflection, a second beam passes through the aforementioned horn back to the junction, and after a second splitting it interferes with the waves of the first beam. Depending on the path difference of the interfering radio waves in the first and second beams, the voltage picked off the detector is different. Thus, the reflection of the radio waves from the moving mirror mounted in one of the elements of the interferometer reveals the displacement of the interference pattern or makes it possible to register beats of radio waves with several different frequencies[1]. This frequency difference is the result of the Doppler effect for one of the radio waves, which is reflected from the moving mirror. The demonstration is related to the well-known schemes of observing and registering the so-called light beats, developed by Rigghi back in 1883.

A similar method, for example, was used in[2] to demonstrate the reflection of light from a moving mirror. The use of a radio interferometer for instructional purposes is reported also in[3,4]. However, the method used in[3] of registering interference phenomena by means of a pointer instrument, and the small travel of the moving mirror[3,4] have the shortcoming of not affording spatial visualization of the interference effect.

In our experiment, the Doppler effect was demonstrated by using simultaneously audio reception and displaying the signal on an I4-M oscilloscope with a long-persistence screen of 31 cm diameter. The reflector used in the interferometer is made up of vertical copper wires (for type TE_{01} modes) of 2 mm diameter, mounted in epoxy resin, and forming a spherical surface with curvature radius R = 3 m. The spherical reflector has many advantages. For example, when it is moved in a range 0.8–2.6 m, measured from the front cut of the horn, the obtained value of the standing-wave coefficient ($K_{SW} = E_{max}/E_{min}$) is larger by more than a factor of 2 for the spherical reflector than for a flat metallic reflector having the same dimensions 310 × 240 mm. In addition, a spherical reflector is less sensitive to inaccuracies in the setting relative to the optical axis of the horn and reflector.

This setting was effected in the following manner. The reflector with the carriage were rolled to the end of the rails closest to the horn. The horn was oriented in such a way that the center of its aperture was on a horizontal line passing through the center of the reflector, and the angles of the front edges of the horn touched the surface of the reflector. The rails were then drawn away 0.4–0.5 m away from the horn. Such an adjustment was always sufficient and optimal.

In experiments with the interferometer, the high-frequency radiation of the klystron generator was modulated with 800-Hz audio frequency at a voltage of about 40 mV, for which purpose the voltage from the UIP-1 M rectifier of the klystron reflector was fed in series with the output winding of the transformer of the audio generator GZ-3 M. The use of modulated radiation offers great conveniences, since the signal from the DK-I 2 M

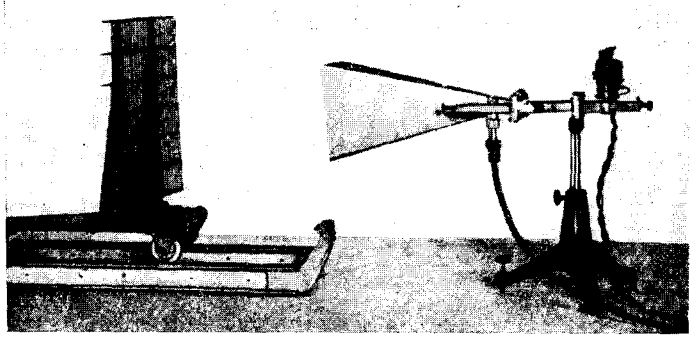

FIG. 1

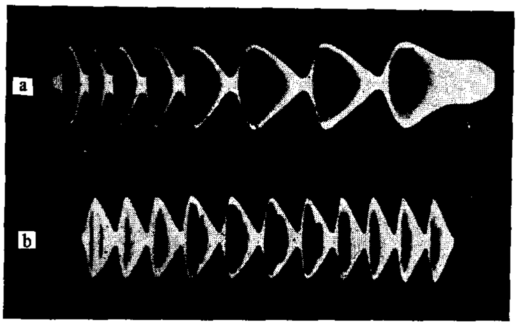

FIG. 2

detector can be amplified by means of an ordinary low-frequency amplifier. The amplified signal was heard through a loudspeaker and was simultaneously viewed on the screen of an oscilloscope operating with a slow linear sweep of the oscillogram, with a sweep time 5—10 sec.

By establishing a weak coupling between the exciting post of the klystron (type K-27, wavelength in free space 3.2 cm) and the waveguide line, the positions of the short-circuiting plungers were chosen experimentally such that when the reflecting mirror was moved, a picture of the beats was observed on the oscilloscope screen without a distortion of the envelope and with a sufficiently large SWR.

The demonstration was produced in the following manner. After completely adjusting the interferometer, the reflector was set in the central part of the tracks in a position corresponding to the minimum signal from the detector. At the instant of the start of the next sweep of the oscilloscope beam, the reflector together with the carriage were moved slowly by hand. This produced a periodic increase and decrease of the signal at the beat frequency. Obviously, this beat frequency is equal to the rate of motion of the reflector, expressed in terms of the number of half-waves traversed by the reflector in one second. Figure 2a shows an oscillogram corresponding to the motion of the reflector with a decreasing velocity (average velocity 2—3 cm/sec, beat frequency 1—2 Hz). A certain distortion of the signal—a shift of the maxima away from the central position—is due to reflection of the radio waves from the detector, owing to the strong coupling between the latter and the lines[5]. The experiment can be carried out successfully while moving the reflector in a range of distances 0.4—3.5 m between the front edge of the horn and the reflector.

2. The interference pattern of the standing waves produced in free space between the reflecting mirror and the receiving-transmitting antenna can be demonstrated by means of the foregoing radio interferometer, but with a slight modification, by registering the signal picked off the detector. This modification was undertaken in order to "visualize" the interference pattern, and consists in the following. A high-resistance rheostat, 200—300 mm long, with a sliding contact, is mounted on the rail track in special openings. One can use laboratory wire-wound rheostats, or else rheostats prepared by winding on a cylindrical form several layers of electrically-conducting paper (used in physical modeling of potential fields). The carriage with the reflector, which is located between the rheostat and the antenna, is rigidly secured, by means of a post, to the sliding contact of the rheostat, so that when the sliding contact is moved manually the carriage and the reflector on it are moved simultaneously. A dc voltage (50—60 V) is applied to the terminals of the rheostat from the rectifier UIP-1M or from a battery, and the voltage picked off the rheostat slider and one of the terminals of the rheostat is fed to the input of an oscilloscope operating with an external sweep. The horizontal gain is set in such a way that when the slider contact is moved through a definite distance (and consequently also the reflector), the beam spot on the oscilloscope screen moves through the same distance and in the same direction. This is important for subsequent measurements of the radiation wavelength. In all other respects, the setting of the interferometer proceeds in accordance with the method described in the preceding demonstration.

Demonstration. By moving manually the sliding contact back and forth and the reflector connected with it, with the klystron supply disconnected and with the horizontal oscilloscope sweep circuit connected, one demonstrates the synchronism of the displacement of the reflector and the spot of the electron beam on the screen. The klystron supply is then turned on, the reflector is moved slowly, and the picture of the standing electromagnetic waves is displayed visually and acoustically (Fig. 2b). Owing to long persistence of the screen, it is possible to demonstrate the interference not only qualitatively, but to measure the wavelength in free space. To this end it is necessary to measure first the distance l between two fixed points on the screen, for example between two edges of a mask placed over the screen, and to count the number of half-waves N contained between these points; then, in accordance with the special sweep regime established in the oscilloscope, the wavelength λ is determined from the condition, $\lambda = 2l/N$.

3. Interference of wave beams coming from two slits (Young's scheme). This basic experiment illustrates the wave nature of electromagnetic radiation and can be performed with the setup shown in Fig. 3. The electromagnetic waves excited by the klystron generator are fed through the waveguides to the junction (described above) and are split into two beams, each of which is radiated from one of the two so-called E-planes of sector horns[6] forming a double antenna. The horn types are chosen such as to obtain a broad directivity pattern in the horizontal plane and a narrow one in the vertical plane. The edges of the horns are soldered to the edges of the radiating openings of a metallic screen mounted on a vertical post. The entire radiating system as a whole can be rotated manually around the axis of the post in a range ± 90°, in a bearing mounted in the base. The base holds also a type SP potentiometer, and the axis of the current-conducting contact of the potentiometer is rigidly connected to this post. A dc voltage 50—60 V is connected to the terminals of the potentiometer, and the signal from the moving contact is fed to the input of the oscilloscope, which is connected with the receiving device (see below) in such a way, that when the entire radiating system is rotated manually to the right or to the left away from the central position, the dc voltage fed to the input of the oscilloscope is

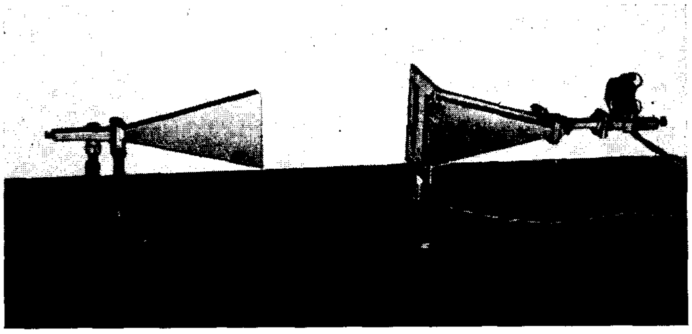

FIG. 3

increased or decreased in proportion. The radial waves from the radiator slits are received by a single E-plane sector horn mounted at a distance 1—2 m from the radiators. The amplification and the observation of the signal are effected by the already described method.

Demonstration. When the radiating system is rotated to the right or to the left from the central position and the klystron supply is disconnected but the horizontal sweep is turned on, the spot on the oscilloscope screen moves in synchronism.

When the klystron is turned on and the radiating system is slowly rotated, one observes visually (and by ear) the signal from the detector of the receiving antenna; the amplitude of the signal depends on the phase difference between the interfering waves from the two slits. An oscillogram of the phenomenon is shown in Fig. 4. The slight asymmetry of the outermost maxima is due to the nonlinear dependence of the voltage picked off the potentiometer on the angle rotation of the radiating system.

In conclusion we note that the experiment can be performed also in a different variant (which would be difficult to realize in the optical band), in which the radiator is a single horn, and the radio waves are received by a double antenna. To this end it is sufficient to interchange the waveguide segments containing the klystron generator and the detector. By rotating the receiving double antenna, it is possible to observe a similar interference pattern as in the first variant.

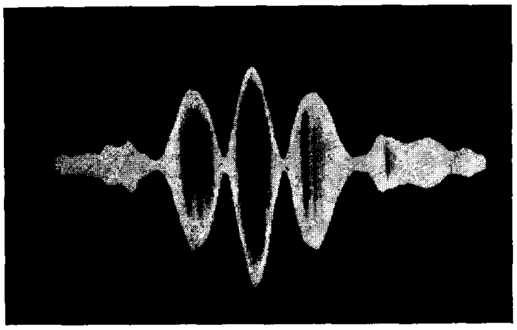

FIG. 4

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LECTURE DEMONSTRATIONS OF ACOUSTIC PHASE ZONE PLATES

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A zone plate, which blocks the sound-wave-front path sections corresponding to even or odd Fresnel zones, was proposed already by Rayleigh[1]. A description of its construction and use can be found, for example, in[2]. The construction of the zone plate that rotates the phase of the oscillations of half the zones is a much more complicated matter. The reason lies in the fact that the acoustic resistance ρ_c of any substance is so much larger than the corresponding value for air, that the sound waves are reflected from solids practically completely. A phase zone plate was constructed in the Physics Department of the Tomsk University. The method proposed by W. Kock[3,4] for the preparation of waveguide lenses was used. In this method the waves are made to move between inclined plates. In this case the path traversed by the sound in the waveguide was $1/\cos\theta$ times longer than its direct propagation in the medium, corresponding to an effective refraction index $n = 1/\cos\theta$ in the waveguide section of the path.

This principle was used to prepare at first plates introducing path differences $\lambda/2$ and λ between the sections of a wave front propagating through a plate and in free space. To this end, inclined strips of cardboard or tin plate were mounted in wooden frames at an angle of 45° to the surface of the frame. The width l of the strips was determined from the usual relation $d(n - 1) = \lambda/2$ (or λ), which in our case, at $n = 1/\cos\theta$ and a strip width $l = d/\cos\theta$ takes the simple form $l - d = \begin{cases}\lambda/2 \\ \lambda\end{cases}$ (Fig. 1). For a half-wave plate and a wavelength $\lambda = 3/2$ cm, the width of the strip is 5.4 cm; for a full-wave plate the width is 10.8 cm (Fig. 2). The intervals between the plates are 2 cm and 4 cm* measured along the frame. The source of the sound is a dynamic speaker 2GD-21 fed from an audio generator. The generator frequency is chosen close to 10 kHz, so as to make the wavelength 3.2 cm. The frequency of the sound is adjusted after the plate is finished. To this end, it is desirable to have a sufficiently continuous control of the audio-generator frequency. The experiment is performed as follows: The dynamic speaker is placed at the focus of a spherical mirror so as to obtain a plane acoustic wave. The reception is with a 1-MD-35 microphone located in the focus of another spherical mirror. The voltage from the microphone is fed to a low-frequency amplifier 28IM (U2-1A), and then to an oscilloscope S1-1 (EO-7)† with the time sweep disconnected.

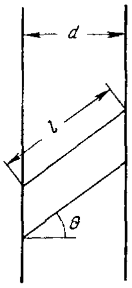

FIG. 1. Side view of plate.

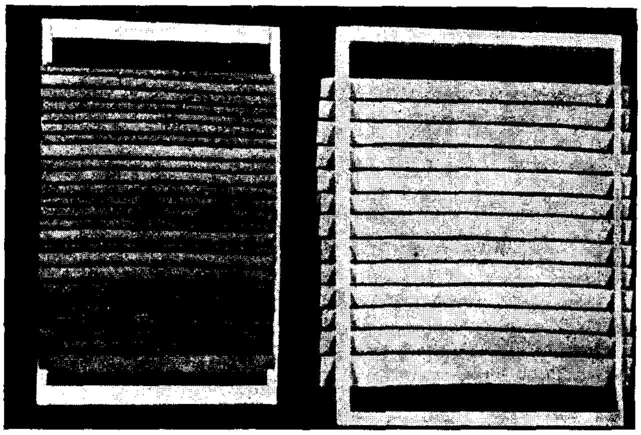

FIG. 2

1. The plate introducing a path difference $\lambda/2$ is placed between the section of the wave front passing through the plate and another section propagating in free space, in such a way as to lengthen the path of half the wave front traveling to the microphone; it is observed that the reception amplitude decreases practically to zero (at the proper frequency). Covering the entire wave front by this plate demonstrates that the intense reception of the sound wave is resumed.

2. When a plate introducing a path difference λ between the section of the wave front passing through it and the section of the front moving in free space is employed, the reception is weakened very little if either the entire front or half the front is covered by the plate. When the plates are installed, it is important to prevent occurrence of intense standing waves between the dynamic speaker and the zone plate.

3. To prepare a zone plate with reversal of the oscillation phase, a cross piece is used, on which three rings of brass tubing are mounted; the ends of the tube are secured by means of a rod soldered in them. A tube of suitable length is first bent on a cylindrical surface. Strips of tin plate, producing an additional phase shift of 180° for waves passing on the inclined path between the strips, are soldered to the rings at an angle of 60°. Spherical acoustic waves are used (the mirror forming the plane wave is removed in this case). The dimension of the rings is calculated for spherical waves with $\lambda = 3/2$ cm, and for distances of 1 m each from the zone plate to the sound source and to the receiver. The radii of the central and succeeding Fresnel zones are in

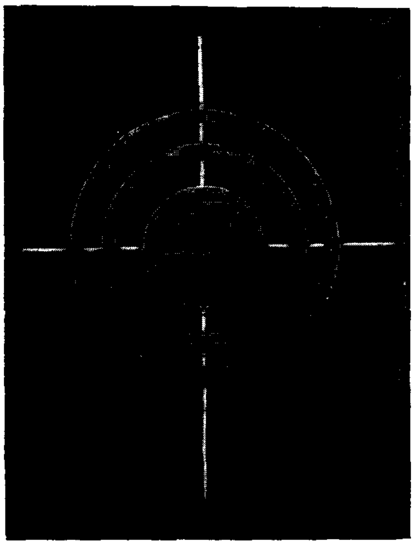

FIG. 3

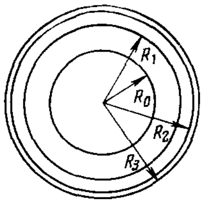

FIG. 4

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*An interval of 4 cm was taken for a wave plate in order to weaken the reflection of the acoustic waves from the broad inclined plates.

†It is possible to modulate the 10 kHz carrier frequency by a lower audio frequency, and then, after amplification and detection, the low-frequency signal can be fed to the dynamic speaker.

this case $R_0 = 12.67$, $R_1 = 17.95$, $R_2 = 22.03$, $R_3 = 25.48$, $R_4 = 28.54$, $R_5 = 31.80$, and $R_6 = 32.70$ cm.

In our setup, the phase shift was produced on the area of the central, second, and fourth Fresnel zones (Figs. 3 and 4).

By placing the phase zone plate in the path of spherical waves, half-way between the microphone and the dynamic speaker, it is demonstrated that the zone plate increases greatly the received amplitude to more than double the value obtained when the even zones are covered by rings of plywood or tin plate and no waves pass through them at all, i.e., in the case of an amplitude zone plate[2].

4. For the fourth experiment, the following instrument was prepared: a sheet of plywood was mounted on a stand and an opening of radius $R_3 = 25.40$ cm was cut in it; four Fresnel zones fit inside this hole. On a cross piece left when sawing out the hole, it was possible to mount with the aid of posts an aluminum disk and rings with radii R_0, R_1, R_2, and R_3 as indicated above. The stand was placed half-way between the microphone and the dynamic speaker, the distance between which was 2 m, just as in experiment 3. By removing the disc covering the central Fresnel zone, it is demonstrated that the amplitude of the received sound wave has doubled compared with the case when the wave front is completely exposed. By removing the next ring, it is verified that reception drops to zero. When the second Fresnel zone is uncovered, the reception is restored, but it is greatly weakened when the third zone is uncovered.

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