cenco

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CENTRAL SCIENTIFIC COMPANY

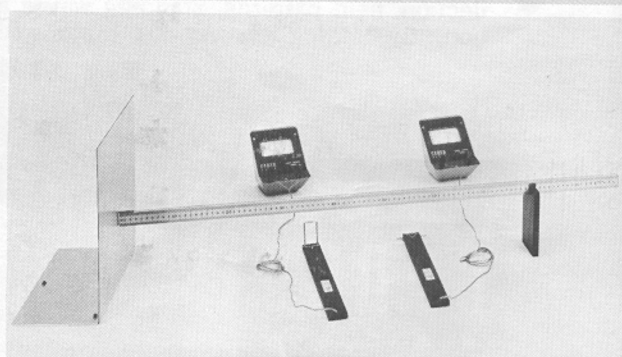
microwave optics demonstration apparatus

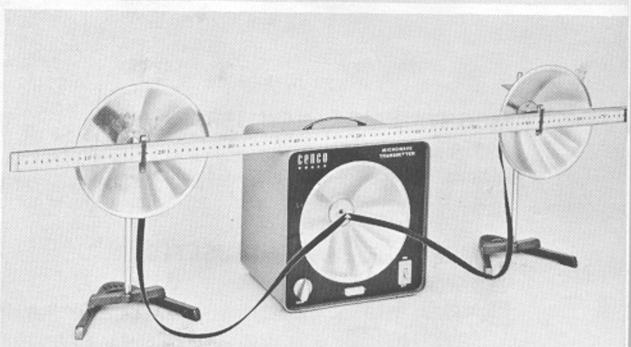
17 DETAILED EXPERIMENTS IN ELECTROMAGNETIC RADIATION

DEMONSTRATE BASIC OPTICAL LAWS IN A FULLY LIGHTED CLASSROOM

wave experiments in

POLARIZATION
REFLECTION
INTERFERENCE
DIFFRACTION
STANDING WAVES
FIELD PATTERNS





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This manual was prepared by Dr. C. L. Andrews, Professor of Physics, New York State College for Teachers.

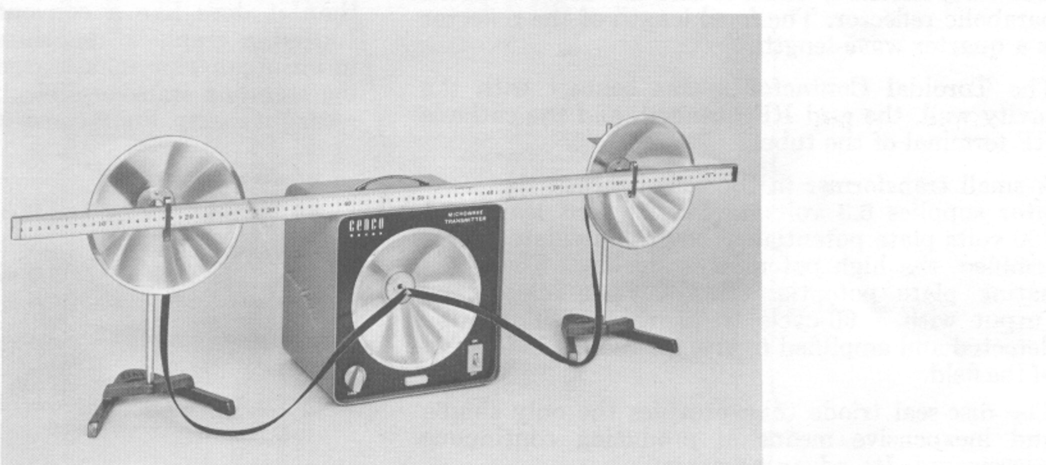


Fig. 1 Transmitter and Reflectors shown in use with Double Dipole Antenna

1 introduction

In this age of nuclear and cosmic technology, microwaves and their behavior have assumed unique importance in man's study of the electromagnetic spectrum.

Since microwaves are identical in nature to other electromagnetic radiations, the study of microwaves result in a better understanding of radio waves, x-rays, and visible light spectra.

The principal instruments needed for the study of microwaves are a transmitter for producing the radiation and a receiver for exploring the microwave field. (See Frontispiece). Cenco's Microwave Demonstration Equipment is simple and rugged in design and is adaptable to the wave experiments commonly performed in courses in physical optics, and yet the equipment is so versatile that the discriminating physicist may employ it for his own studies of microwaves in free space or in waveguides and coaxial lines.

2 description

2.1 transmitter

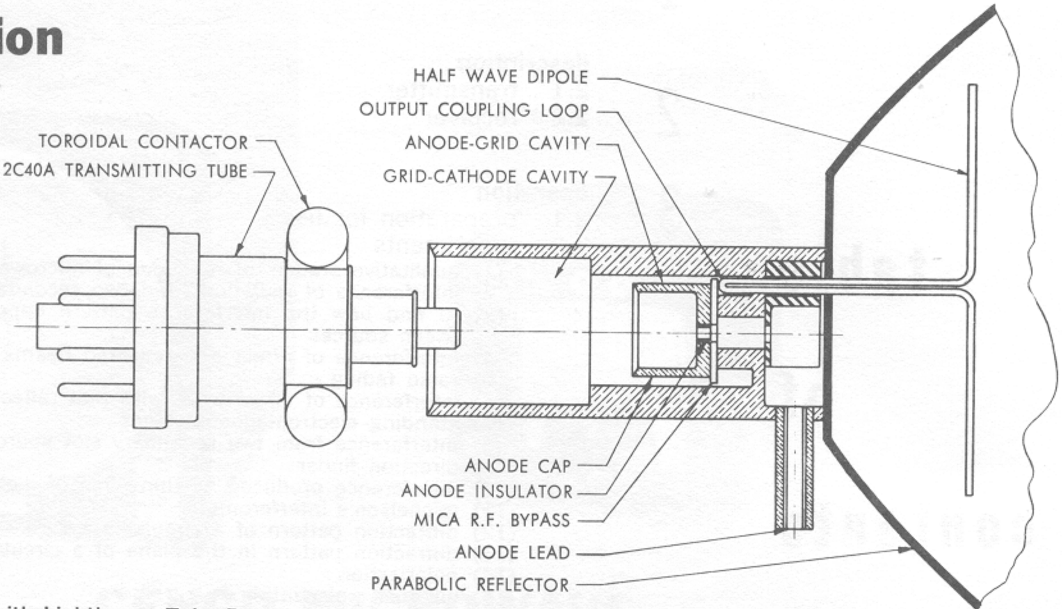


Fig. 2 Cavity Oscillator with Lighthouse Tube Removed

The one-piece transmitter is shipped completely assembled. It consists of a power supply, an oscillator, and an antenna. A cross-sectional view of the transmitter is shown in Fig. 2. The two resonant cavities are drilled concentrically to accommodate the General Electric 2C40A disc-seal triode tube, commonly known as the "lighthouse tube." A one-half turn wire loop couples the inner cavity directly to the half-wave antenna, which is held at the focus of the parabolic reflector. The focal length of the reflector is a quarter wave-length.

The Toroidal Contactor makes contact with the cavity wall, the grid RF terminal, and the cathode RF terminal of the tube.

A small transformer in the case beneath the oscillator supplies 6.3 volts to the filament leads and 350 volts plate potential. When the oscillator is assembled, the high potential is shielded. The alternating plate potential effectively modulates the output with a 60-cycle frequency which may be detected and amplified to give an audible indication of the field.

The disc-seal triode tube provides the only simple and inexpensive means of producing continuous microwaves. Its advantages are:

1. Cylindrical or disc leads from the tube elements fit into the coaxial cavities, thus making the tube an integral part of the cavities. The cavities in turn prevent the tube from radiating into space.
2. The leads from the three elements conduct heat away more rapidly than the conventional wire leads, permitting operation at higher power.
3. There is less interelectrode capacitance than between the conventional wire leads through the base; also, the disc lead has less inductance than the conventional wire leads.
4. With the disc-seal and taut grid, it is possible to reduce the distances between the cathode and grid and between the grid and plate so that the transit time of the electrons is less than a half period of the high-frequency oscillation produced.

A cavity spacer ring and clamp holds the tube firmly in place during shipment.

The microwave oscillator looks more like a whistle than it does like a conventional radio oscillator. Indeed, a graphical description of a standing wave in an organ pipe makes a good analogy for studying standing transverse electromagnetic waves in a resonant cavity. Fig. 3 consists of pictures and graphs

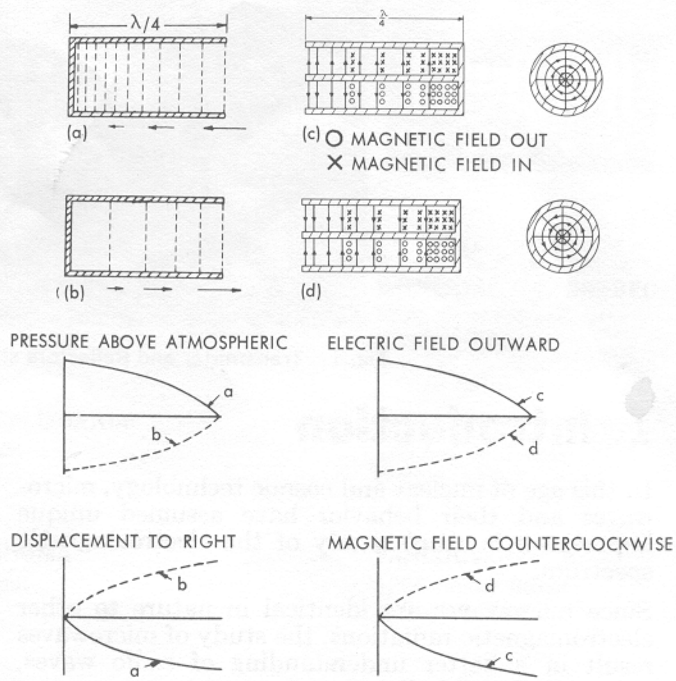


Fig. 3 Standing Wave Analogy

to describe the oscillations in resonant cavities. Fig. 3a shows a quarter-wave sound resonator when the displacement to the left is a maximum. Fig. 3b shows the same resonator, or tube, a half-period later, when displacements are a maximum to the right. Fig. 3c represents a coaxial resonator closed at one end, shown at a time when the radially outward electrical field is a maximum. Fig. 3d represents the same tube shown a half period later, when the radially inward electrical field is a maximum.

The closed end of the coaxial electrical resonator is analogous to the open end of the sound resonator. A node of pressure and an antinode of displacement are present at the open end of the sound resonator. In the microwave resonator, a node of electric field and an antinode of magnetic field appear at the shorted end.

2.2 receiver

The Receiver is completely assembled and ready for use with the Transmitter. The case is constructed of material especially selected to eliminate internal reflection of microwaves. Two banana jacks are located on the Receiver front panel for audible detection of the field. Headphones may be used directly or the 60 cycle signal may be amplified and heard over a speaker.

The receiver, shown diagrammatically in Fig. 4, is a crystal detector with a half-wave dipole antenna, a short coaxial line, a crystal and a layer of cellulose Scotch tape wrapped around the crystal holder as a by-pass for the radio frequency. The quarter-wave stub acts as a by-pass for the rectified current without reflecting the radio frequency at that point. The load is a G-E Model *DO-90* microammeter. A switch is provided for shunting the meter from 20 to 100 microamperes. The detector is a microwave crystal diode *1N23B*. Since the current through the crystal is very nearly proportional to the square of the potential across it, the meter reading is proportional to the intensity of radiation. The metal disc, a quarter wavelength behind the antenna, acts as a reflector. Since the electric field undergoes a change in phase of 180° upon reflection, the reflected wave arrives at the antenna in phase with the incident wave.

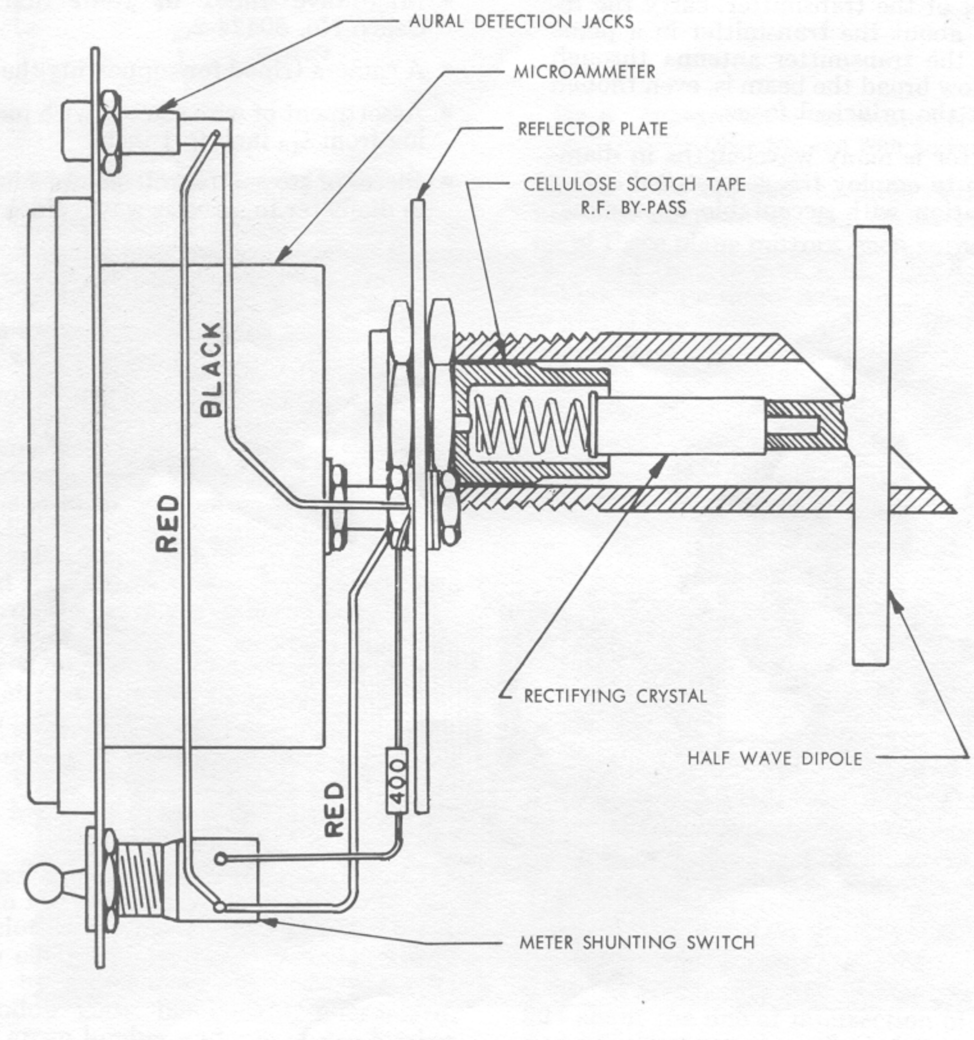


Fig. 4 Receiver Intensity Meter, Diagrammatically Represented

3 operation

3.1 preparation for use

Plug the transmitter into a 115-volt, 60-cycle line and allow two minutes for the cathode to become hot. Turn the knob on the front of the transmitter control all the way to the right. Hold the receiver about ten feet in front of the transmitter with the antenna parallel to that of the transmitter. At that distance, the receiver should indicate about one-quarter of full scale with the switch set at 100 microamps.

Another factor which may be critical is the distance that the coupling loop to the antenna extends into the cavity. If the loop is too far out, the radiated power will be very low; if pushed too far in, the loading of the oscillator may be too great and oscillation will be prevented or unstable. Note that the radiation is polarized with the electric field parallel to the antenna. Observe the changes in received intensity as the receiver and its antenna are rotated about an axis through the coaxial line.

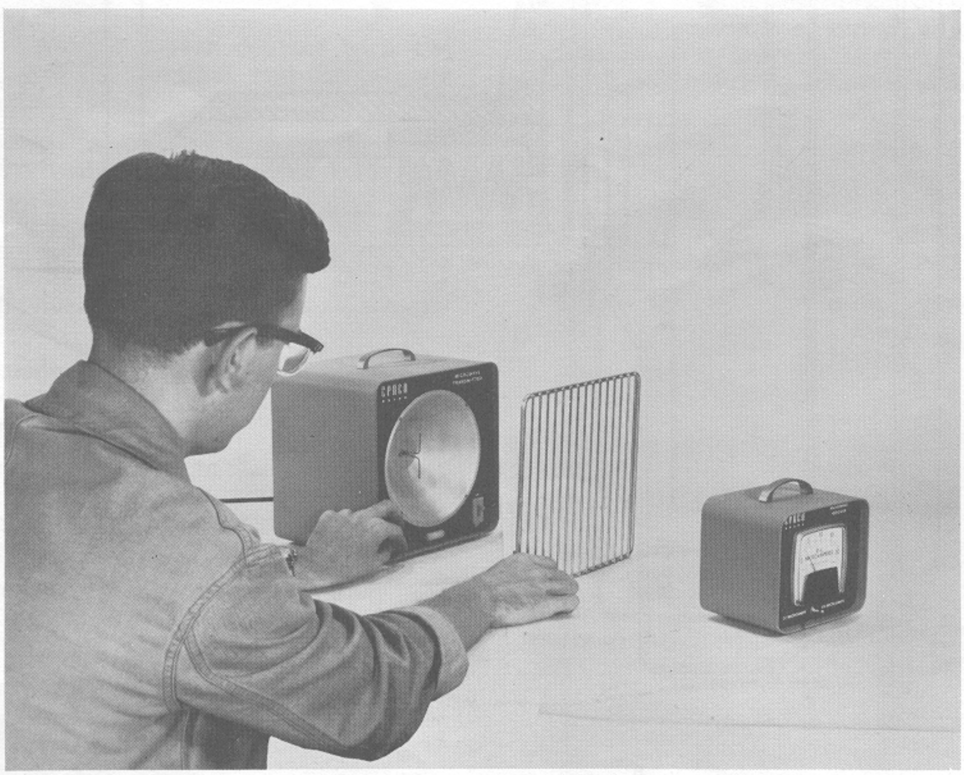
To observe the field pattern of the antenna and parabolic reflector of the transmitter, carry the receiver in a circle about the transmitter in a plane perpendicular to the transmitter antenna through its center. Note how broad the beam is, even though the antenna is at the principal focus.

Only if the reflector is many wavelengths in diameter can we begin to employ the geometrical optics of linear propagation with acceptable approximation. It will be noted that some radiation escapes from the oscillator by way of the tube and the anode line. For the studies which are to be made, that radiation may be neglected when compared with radiation from the antenna. For high precision, oscillators may be built with filter and shields to prevent the direct radiation from the oscillator.

3.2 experiments

Several accessories are required for the performance of all the experiments described in this booklet:

- Microwave mirror 2 ft. by 2 ft. made of metallic window screening.
- Secondary sources for Young's experiment. These sources consist of Cenco Nos. 80429-3 Double Dipole Antenna and 80429-4 Reflectors.
- A Fresnel zone plate and meter support, available under Cenco No. 80424-1.
- A polarizing screen, Cenco No. 80434.
- Probes, Cenco No. 80423, for measuring E and H components of microwave fields.
- Microwave Index of Refraction Apparatus, Cenco No. 80424-2.
- A camera tripod for supporting the transmitter.
- Assortment of wire screens with mesh size ranging from 1/16 inch to 1 inch.
- Pieces of stove pipe and elbows 3 inches or more in diameter to serve as waveguides.



Experimental set-up using No. 80434 Polarization Grid

2 interference of radiation from two secondary point sources

The study of interference from two secondary sources is considered the most fundamental experiment in wave motion of electromagnetic waves, for it was by this method that Thomas Young showed that light was wave motion. As the experiment is performed with light, the primary source is a bright carbon arc. The two secondary sources are two slits less than a millimeter apart, that distance being measured with a micrometer microscope. The interference pattern is observed and measured through a microscope eyepiece and wavelength is computed by indirect means involving approximations in geometry.

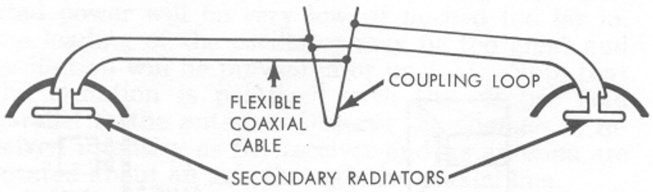


Fig. 8 Secondary Sources for Young's Experiment

When microwaves are used, the wavelength is measured directly on a meter stick. The equipment consists of the transmitter, receiver, and the transmitter accessories Cenco Nos. 80429-3 and 80429-4. The setup is shown pictorially in Fig. 1 and schematically in Fig. 8. Following is a step-by-step procedure for setting up the apparatus.

(1) Mount the parabolic reflectors on their support rods.
(2) Bend the wire of the No. 80429-3 Dipole Antenna against the side of the flat metal dipole.
(3) Push the antenna through the hole at the rear of the reflector.
(4) Repeat the procedure with the other antenna and reflector.
(5) Remove the dipole antenna from the transmitter by squeezing the wires together and pulling outward.
(6) Insert the coupling loop of the double dipole antenna into the transmitter by squeezing the loop and sliding it into the transmitter fitting as far as it will go.
(7) Position the reflectors high enough so that after the meter stick has been slid through the antennas, it rests on the top of the transmitter as shown in Fig. 1.
(8) Adjust the dipoles so that the red dotted portion of each points in the same direction, either up or down.

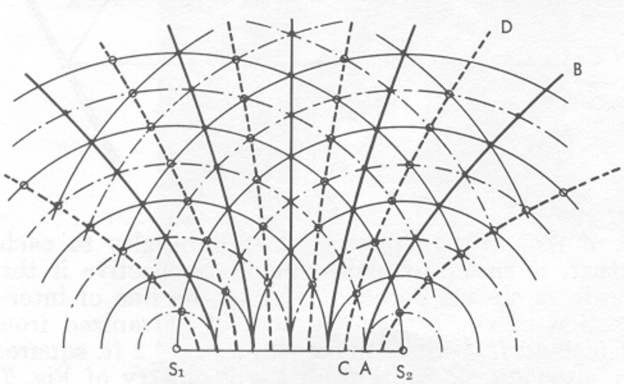


Fig. 9 Interference pattern produced by two sources S_1 and S_2. Maxima or constructive interference along the solid lines, AB etc., while the minima or destructive interference is along the dashed lines, CD etc.

Since the flexible twin lead cables are of the same length to each dipole, the radiation leaving the antennas will be in phase when the red dotted portion of each dipole points in the same direction.

For the first measurements, set the secondary radiators about 50 cm apart. If the experiment is performed out of doors, place the two sources about shoulder-height above the ground. The reason for this position will be seen in Experiment 7.

A horizontal section of the wave pattern from two similar sources S_1 and S_2 is shown for some particular instant in Fig. 9. In this figure the sources are set apart a distance of 3λ, and the full circles represent the crests while the dot-dash circles represent the troughs at the instant considered. Constructive interferences between the two waves occurs at the intersection of two full or two dot-dash wave patterns as shown by the line AB in Fig. 9. The intersection of a full and a dot-dash circle represents a crest from one source and a trough from the other source arriving together. This would correspond to destructive interference as shown by the line CD. As the waves from the sources move out the points of interference move out along hyperbolic paths.

Using the receiver, walk toward the source along paths of maximum intensity and paths of minimum intensity. You can come close to the source without the meter reading being full scale by following paths of minimum intensity. If audible detection is required, use No. 80575 audio amplifier and speaker. For visible demonstration use Cenco No. 71557 or 71558 oscilloscope. Indicate a point of minimum in-

No. 80575 Audio Amplifier and Speaker

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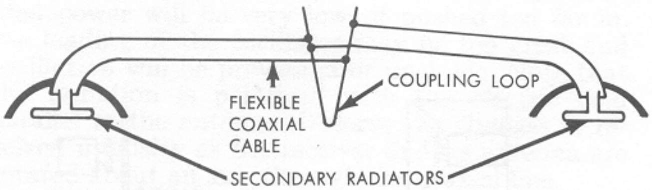

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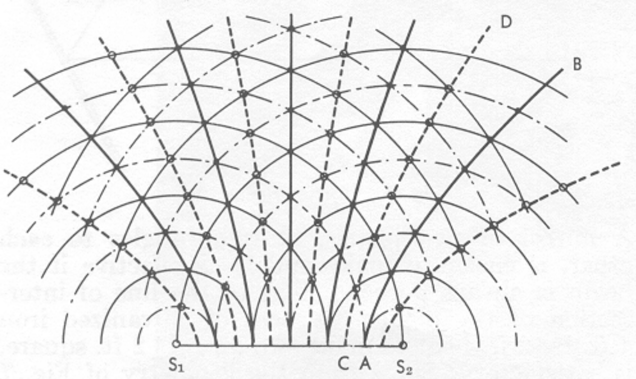

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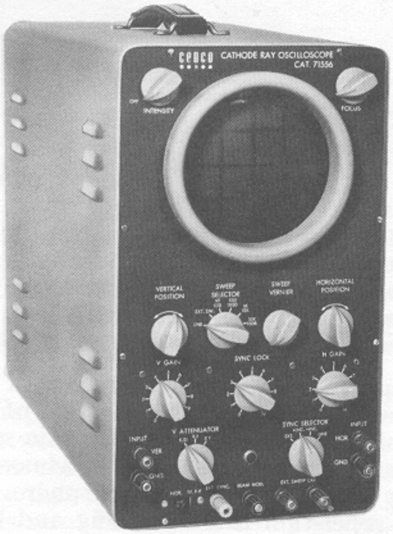
No. 80575 Audio Amplifier and Speaker



No. 71557 Five-inch Oscilloscope

tensity within the length of your meter stick from the source. Measure the distances to each of the two antennas and subtract. Determine the wavelength when the difference is one-half wavelength. Check when the difference is 3 and 5 half-wavelengths. Knowing that the velocity of the wave is 3×10^{10} cm/sec., compute its frequency in cycles per second. Express it in megacycles per second.

Rotate the antenna of one of the secondary sources 180° about its center line so that the red dotted section of one dipole points upward and the other points downward. The waves from the two sources will thus leave their antennas exactly out of phase. Note that the paths of constructive and destructive interference will be interchanged. Check the wavelength in this case.

REFERENCES:
Howe, *Introduction to Physics* (McGraw-Hill, 1942) pp. 530-532.
Hausmann and Slack, *Physics* (VanNostrand, ed. 2, 1939) pp. 679-682.
Wood, *Physical Optics* (Macmillan, ed. 3, 1934) pp. 162-163.
Valasek, *Elements of Optics* (McGraw-Hill, 1932) pp. 27-33.
Jenkins and White, *Fundamentals of Physical Optics* (McGraw-Hill, 1937) pp. 51-61.
Houstoun, *A Treatise on Light* (Longmans, 1927) pp. 131-134.

3 to find how the interference pattern depends on the distance between sources

Making use of the wavelength determined in Experiment 2, set the antennas one wavelength apart. Before making observations, predict by a scaled construction similar to Fig. 10 how many paths of constructive and destructive interference will be present. Check your predictions. Repeat the predictions and checks when the antennas are two, three, four, etc. wavelengths apart. What is the relation between the number of paths of destructive interference and the distance between the antennas in wavelengths; between the number of paths of constructive interference and the distance between antennas in wavelengths?

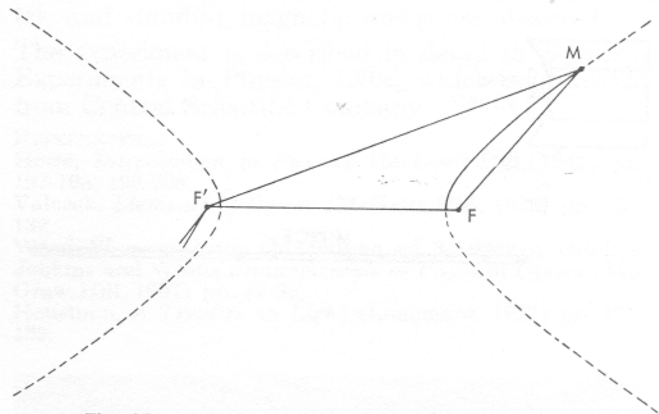


Fig. 10 Method of Constructing a Hyperbola

In order to visualize the interference pattern more clearly, trace it on the ground with a tennis-court marker, or draw it on the laboratory floor. The pattern will not be the actual pattern on the ground, but a projection of the pattern in the horizontal plane through the two sources.

A satisfying procedure for at least one separation of the sources is to predict and mark off paths of destructive interference before the oscillator is turned on and then to check the intensity along those paths. Drive short stakes into the ground vertically below the two antennas and put screw eyes in the tops of the stakes so a heavy cord will slip through easily. Tie a cord to a marker such as a tennis-court marker and draw it through the eyes of F and F'.

In Fig. 10, M is the marker and F and F' are the secondary sources. If the ends are drawn in or let out together, M will describe a hyperbola since $(F'F + FM) - F'M$ remains constant. Since $F'F$ is constant, $F'M - FM$ must be constant.

For each hyperbola drawn, $F'M - FM$ is to be an odd number of half-wavelengths. A simple way to do this is to find all the points on line $F'F$ where the hyperbolic paths of destructive interference cross the line. These are points for which the difference between $F'M$ and FM is an odd number of half-wavelengths. Algebraically:

$$F'M - FM = \frac{2n+1}{2}$$

where n is any integer, positive, negative or zero for which P will lie between F′ and F.

If one case has been checked, other cases may be analyzed more rapidly by making the constructions on a drawing board with a pencil for M and thumb tacks at F′ and F.

What will the field be like if two secondary sources are (1) one wavelength apart and in phase; (2) out of phase; (3) a half-wavelength apart and in phase; (4) out of phase? For cases (3) and (4), it is necessary to remove the reflectors and replace them by flat discs a half-wavelength in diameter.

4 interference of direct and reflected beams

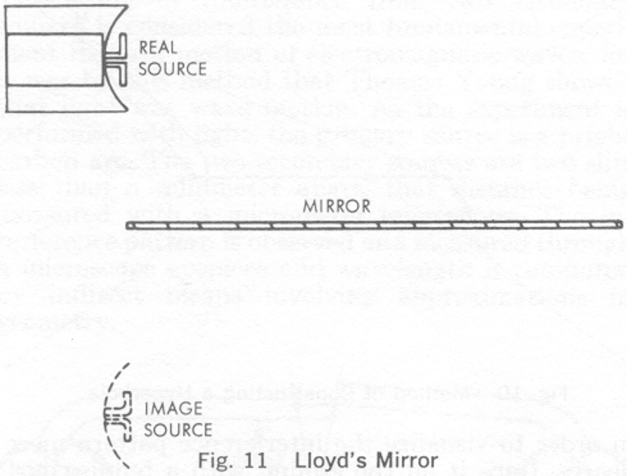


Fig. 11 Lloyd's Mirror

Put the antenna into the transmitter with the small parabolic reflector behind it. Set a sheet of metal or window screen 2 ft. square or larger in a vertical plane (see Fig. 11) at a distance of about 20 cm from the antenna. If we think of the reflected radiation as coming from an image of the source the same distance behind the mirror (the screen or metal sheet) as the real antenna is in front, the problem becomes similar to that of Experiment 2, except that the pattern will be on only one side of the mirror.

It will be noted that the pattern is that observed in Young's experiment, when one antenna was rotated through 180°. Thus the image source is 180° out of phase with the real source; that is, the reflected wave has undergone a change in phase of 180° upon reflection. The plane of the mirror is a plane of destructive interference.

Use this pattern to determine the wavelength of the radiation. What is the relation between the distance from the antenna to the mirror and the number of paths of destructive interference?

Replace the metal mirror with a plain plate of glass or other dielectric. Is destructive interference present in the plane of the reflecting surface in this case?

Lloyd showed by this historic experiment that a 180° phase change occurs when the radiation is reflected at the air-to-glass surface. By electromagnetic theory, it was later shown that the electric field would undergo a 180° phase change upon reflection when the wave was incident from air (a vacuum) to dielectric. We will show in Experiment 10 that no phase change occurs in the electric field upon reflection when the wave is incident from dielectric to air.

References:
Wood, *Physical Optics* (Macmillan, ed. 3, 1934) p. 165.
Valasek, *Elements of Optics* (McGraw-Hill, 1932) p. 123.
Jenkins and White, *Fundamentals of Physical Optics* (McGraw-Hill, 1937) pp. 66-68.
Houstoun, *A Treatise on Light* (Longmans, 1927) p. 138.

5 radio fading

In the days before automatic volume control on radios, it was observed that the signal often faded and rose at a regular rate, the effect being most pronounced just after sunset or before sunrise. The effect is explained on the basis of interference between two waves. One wave goes from transmitter to receiver along the ground and another wave is reflected by the ionosphere, an ionized layer in the upper atmosphere which is ionized when it absorbs certain frequencies of ultra-violet from the sun.

The ionosphere over any given region of the earth moves upward at sunset as the angle of incidence of the sun's rays increases. Thus radio waves provide a means of studying the upper atmosphere and measuring the heights of the ionosphere. By measuring the repetition rate of fading and rising, the rate of rise and fall of the ionosphere can be determined.

This experiment can be performed in the laboratory, using microwaves. Set the antenna of the transmitter in a horizontal position, either by turning the transmitter on its side or by inserting an antenna with its double line to the coupling loop twisted through 90° so that the coupling loop links with the oscillating magnetic field in the transmitter. (See Fig. 12.)

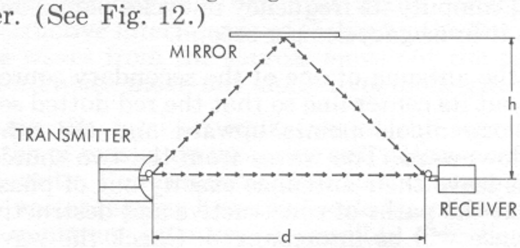


Fig. 12 Arrangement for Study of Radio Fading

Place the receiver so it faces the transmitter and at such a distance that it indicates half of full scale. Using the metal screen of Experiment 4 to simulate the ionosphere, one student may raise and lower the horizontal mirror while another observes the received intensity. Remembering that the electric field undergoes a change in phase of 180° upon reflection, it can be seen that the interference will be destructive; that is, the intensity will be a minimum when the difference in the two paths is an integral number n of wavelengths including zero.

Show from the geometry that a minimum of intensity will be received when

$$h = \sqrt{\frac{dn\,\lambda}{2} + \frac{n^2\,\lambda^2}{4}}$$

where n is a positive integer, λ is the wavelength, d is the distance between antennas and h is the height of the mirror above the line between antennas. From the wavelength determined in Experiment 2, compute the heights of mirror for which you would expect a minima of intensity at the receiver.

6 interference of direct wave with that reflected from the ground

The ground also acts as a mirror. Keeping the antenna in a horizontal plane, place the transmitter about 3 or 4 wavelengths above the level ground of a lawn or dirt tennis court.

Study the interference pattern in a vertical plane that bisects a horizontal antenna dipole. Set up a wooden stake at distances of 1, 2, 3, 4, and 5 meters from the transmitter. Measure the distances above ground of the intensity minima at each of these stakes.

Plot on graph paper the lines of destructive interference between the direct wave and the wave reflected from the ground. What is the shape of these lines? Note that along the surface of the ground the intensity is zero. From your study in Experiment 4, why is this so?

7 standing electromagnetic waves

In the experiment Standing Electromagnetic Waves, accessories for Measuring E and H Components of Microwave Fields, Cenco No. 80423, are used to measure the wavelengths of the interdependent electric and magnetic waves that make up a standing electromagnetic wave. A beam of Microwaves is directed upon a plane mirror and reflected to yield superposed standing electric and standing magnetic waves. The positions of the nodes in each standing wave are measured on a meter-stick optical bench and the wavelength is calculated. The relative positions of the nodes in the standing electric and standing magnetic waves are observed.

The experiment is described in detail in Selective Experiments in Physics, L70c, which is available from Central Scientific Company.

REFERENCES:

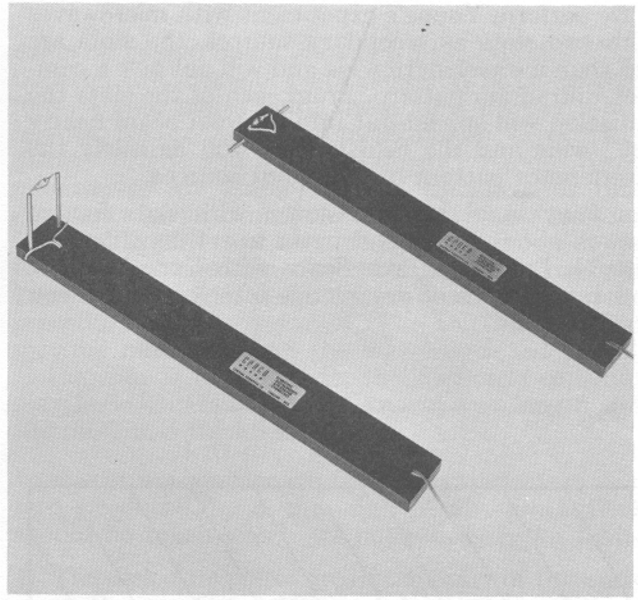
Howe, *Introduction to Physics* (McGraw-Hill, 1942) pp. 197-198, 199-208.

Valasek, *Elements of Optics* (McGraw-Hill, 1932) pp. 131-132.

Wood, *Physical Optics* (Macmillan, ed. 3, 1934) pp. 210-212.

Jenkins and White, *Fundamentals of Physical Optics* (McGraw-Hill, 1937) pp. 32-35.

Houstoun, *A Treatise on Light* (Longmans, 1927) pp. 151-152.



No. 80423 Probes

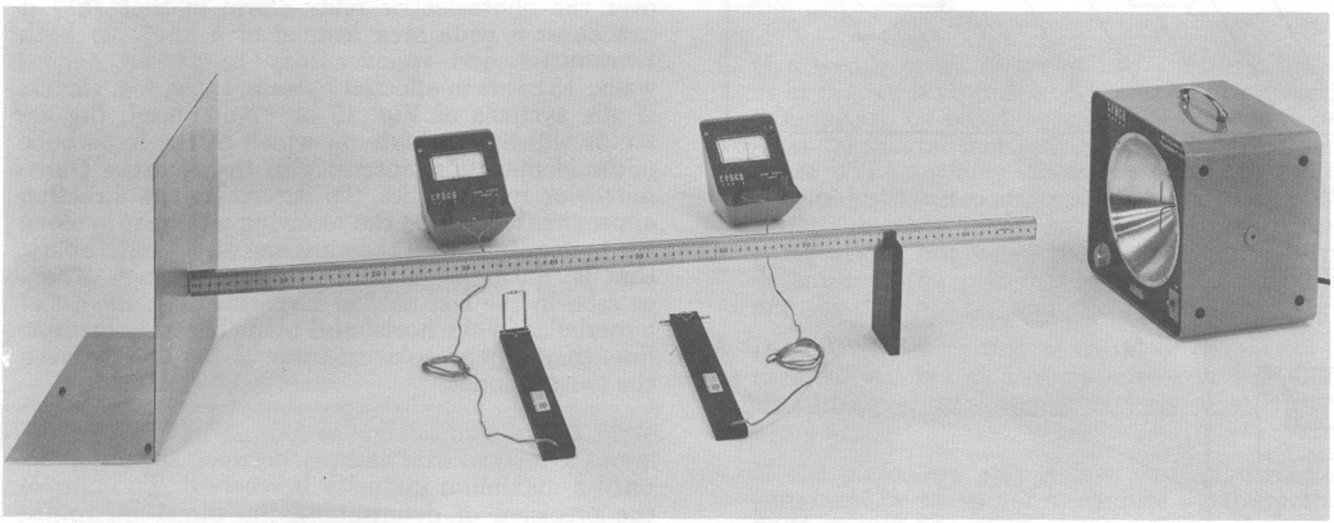


Fig. 13 Microwave Analysis

8 interference from two secondary slot sources

Experiments 2 through 7 involve interference of waves from two secondary point sources. Sometimes one of the point sources is a virtual image behind a mirror. If the intensity is studied in a plane perpendicular to the antenna, the antenna may be considered a true point source with a cross section much smaller than a wavelength.

When Young's experiment is performed with light, the two secondary sources are many wavelengths wide and the diffraction pattern of each slit is superimposed upon the interference pattern of two sources.

If we perform Young's experiment with microwaves with two slots as secondary sources, the slots are less than a wavelength wide and will not give a complex diffraction pattern. From each of the slots the radiation will spread out into a broad beam nearly 180° wide and the field pattern will be solely the interference pattern of two point sources.

You may build a metal screen with slots having centers about two wavelengths apart, as shown in Fig. 14. From your experience with Experiment 3, how many paths of destructive interference do you expect to find?

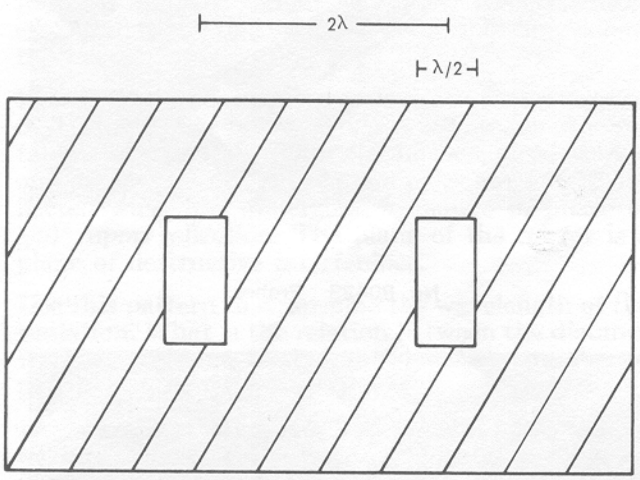


Fig. 14 Screen with Two Slots as Secondary Sources

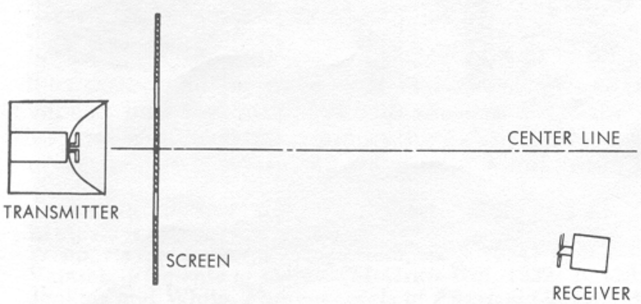


Fig. 15 Arrangement for Young's Experiment with Two Slot Sources

Place the transmitter antenna about five inches behind the screen as in Fig. 15. Move the transmitter toward or away from the screen slowly until the intensity at a point on the center line is a maximum.

Determine the wavelength and frequency as in Experiment 2. You may wish to build other screens with slots of other widths and other separations. The most desirable slot widths can be determined after a study of diffraction in later experiments.

9 direction finder

Young's experiment may be used in designing a direction finder. The two secondary sources of Experiment 2 may be used as receiving antennas.

Any antenna or system of antennas which acts as a transmitter has the same field pattern when used as a receiver. For the special case of the two point receivers, it can be seen that if both antennas are vertical, with the red-dotted sections both pointing in the same direction, and if the differences in the distances from the transmitter to each of the antennas is an integral number of wavelengths, a maximum signal will be received. The transmitter and secondary receivers are shown in Fig. 16. The receivers are prepared by modifying a Cenco No. 80429-3 Double Dipole Antenna. To modify this antenna, unsolder the coupling loop from both sections of the two-conductor ribbon, being careful to pair the conductors as they were paired when attached to the coupling loop. Solder a crystal diode (a 1N82A or a diode from an 80423 Probe) to one pair of antenna leads and a connecting wire to the other pair, as shown in Fig. 16. In Fig. 17, the transmitter is behind the receivers and radiation is received from a reflecting or scattering object.

As an incidental study, the arrangement of Fig. 17 may be used to detect an intruder over a wide area such as a lawn. This arrangement has advantages over the photoelectric relay alarm in that: (1) it can cover a wide area instead of a line; (2) both transmitter and receiver may be placed behind walls; (3) it is unaffected by rain, snow, fog, smoke. If the systems of Fig. 16 or 17 are used, the detector will not indicate on which of the hyperbolic paths of maximum intensity in the field the transmitter or reflector lies. To determine the direction approximately, bring the receiving antennas in along the meter stick until they are one wavelength apart; that is, until the parabolic reflectors touch. Then, as seen in the last part of Experiment 4, the set of hyperbolas in the horizontal plane becomes just one line, the perpendicular bisector of the line between the two antennas.

With the transmitter in the field, turn the receivers about a vertical axis midway between the antennas until a maximum intensity is received. To improve the precision of determining the direction, rotate one of the receiver antennas through 180° as in the last part of Experiment 3 and again rotate the receiver combination about the vertical axis until zero or minimum intensity is received.

The null method will be more exact, especially when earphones are used in the receiver. If the receiver antennas are now separated by the length of the meter stick while the stick is held rigidly in place, the angular position of the null can be determined with greater precision. The direction indicator is a rod with sights rigidly attached at right angles to the meter stick at its midpoint.

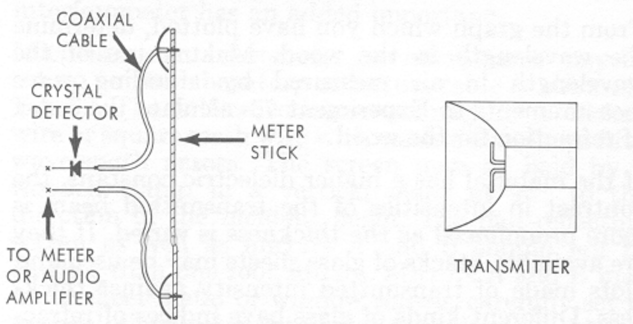


Fig. 16 Arrangement for Finding Direction to a Transmitter

To measure the angular separation of two points relative to the receiver, mount a protractor on the tripod and use the rod as an indicator.

Thus far the direction finder has been used only to find direction in a horizontal plane or to measure azimuth angle. If angular elevation is to be measured, Fig. 16 or 17 is a vertical plane. However, if the receiving antennas are near the ground and the angle of elevation to be measured is small, reflections from the ground complicate the interference pattern as seen from Experiment 6.

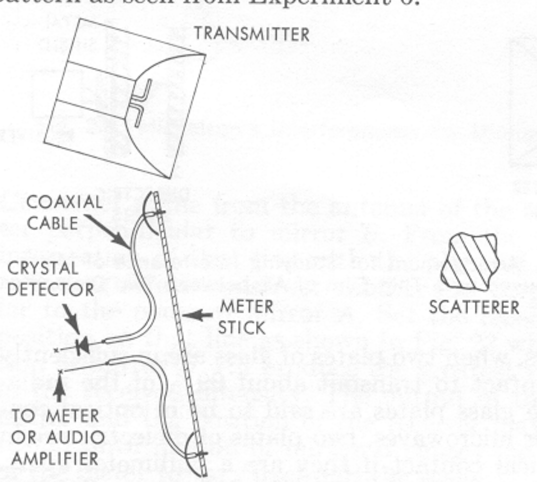


Fig. 17 Arrangement for Finding Direction to a Scatterer

10 interference produced by thin films of dielectric

The word "thin" in this study means of the order of a wavelength or a few wavelengths. When interference of light is being studied, soap bubbles, monomolecular films of oil on water, coatings of

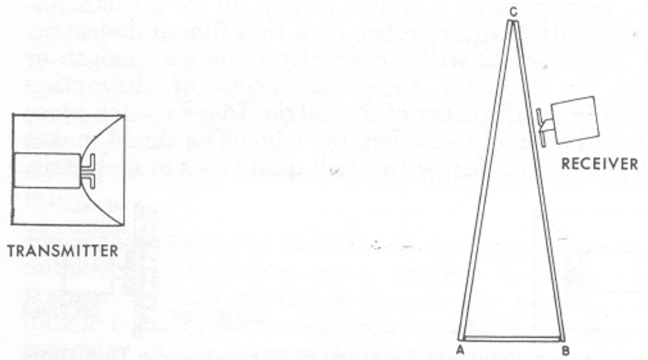


Fig. 18 Arrangement for Studying the Interference Pattern of a Wedge of Air between Two Slabs of Dielectric

oxide on heated metal, insects wings and films of air between two sheets of plate glass may be called thin films. Under white light, these films display interference colors; under monochromatic light, they display bright and dark interference bands. When microwaves are employed, the thickness of thin films may be measured directly on a meter stick. If the thin film is of air and light is employed, the thickness of the film may be computed from the known wavelength of the light. For microwaves, the procedure may be reversed. The thickness of film may be measured and the wavelength calculated. If the film is of dielectric, the dielectric constant may be calculated from the known wavelength and the measured thickness.

In measuring wavelength from the interference pattern produced by a thin film of air, precautions should be taken which are not necessary for light:

1. The dielectric plates are of the order of thickness of the air film instead of thousands of wavelengths thick. Thus the bounding plates are also thin films. If the plates have a thickness of a quarter-wave in the medium, the contrast in the interference pattern for varying thickness of air film will be greatest.

2. If a wedge of air between two dielectric plates as in Fig. 18 is studied and if several interference minima are to be observed, plates *AC* and *BC* must be several feet long or the angles of incidence will be widely different at the two plates and make the measurement of wavelength difficult. The wedge may be used for preliminary observations but when the wavelength is being determined the plates should be kept parallel and the distance between them varied.

3. If support *AB* (either of metal or dielectric) is used, it will act as Lloyd's mirror and produce an additional interference pattern. (See Experiment 4).

4. If the plates are only a few wavelengths wide, care must be taken not to confuse the diffraction pattern with the interference pattern. If the antenna of the receiver is kept close to the wedge as in Fig. 18, only the interference pattern will be observed.