THE

Lloyd William Taylor Manual

OF

ADVANCED UNDERGRADUATE EXPERIMENTS IN PHYSICS

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the far end is now acting as the stub, and it will be noted that a standing wave still exists on it. If the oscillator has sufficient output, it is convenient to use a neon bulb as a voltage indicator for qualitative or demonstration purposes. A short wire soldered to the center terminal of the lamp may be used to make contact with one wire of the Lecher line while the glass portion is held in the hand. The effectiveness of the visual demonstration offsets any slight unbalance caused by hand capacitance.

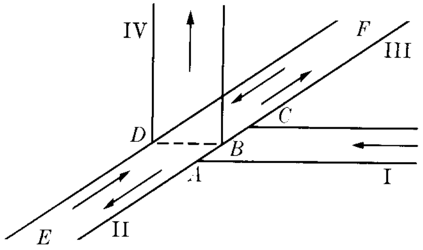

FIG. 6–21. Lecher wire impedance bridge.

(c) *Lecher wire bridge.* A transmission-line analog of the Wheatstone bridge can be made as shown in Fig. 6–21. Power is fed into arm I. The wire *ABC* shorts line I, producing a current antinode at that point. The alternating current in *ABC* sets up an alternating magnetic field in the region between *B* and *D*, and this, in turn, results in an alternating electric field between *B* and *D* of such geometry that two waves out of phase with each other travel down arms II and III. None of this energy enters arm IV. If the two waves in II and III are reflected back in such a way as to arrive at *BD* out of phase, energy will enter arm IV; if these reflected waves are in phase and of equal amplitude, no energy will enter arm IV. Hence this circuit can be used to compare an unknown impedance, placed at the end of arm III, to a known impedance in arm II.

V. Experiments in Microwave Optics

6–25 Introduction. The group of experiments which follows is based on the series of experiments developed by C. L. Andrews, and described by him in "Suggested Experiments in Microwave Optics, Using General Electric Microwave Demonstration Equipment" (General Electric Specialty Division, Syracuse, New York, 1946). The descriptions are, in part, copied from the pamphlet, by permission of the author.

The experiments consist of optical studies at microwave frequencies. The beauty of these experiments is that in them one can study optical effects at wavelengths which can be measured with a laboratory meter stick. The apparatus is simpler than the corresponding optical equipment, adjustments are less critical, and the effects are more evident.

A 10-cm transmitter and a receiver suitable for these experiments are available from Central Scientific Co. Design information is given in the aforementioned pamphlet, and in an article by Andrews (5). A simplified detector is described by Comley and Talham (10). Hull (25) discusses 3-cm equipment. The directions given in the following paragraphs sometimes refer specifically to the commercial equipment.

6–26 Qualitative studies of reflection of microwaves. For these studies the equipment should be located in a room where there are no large objects nearby to reflect the radiation. Reflections from the walls can be made less troublesome if the axis of the microwave system is parallel to none of the walls.

First, some rather general studies might be made. The transmitter and receiver are set facing along lines at right angles to each other, and at such a distance that the intensity meter indicates about one-tenth of full scale. The reflector being tested can be put at the intersection of the two lines. An ordinary silvered-glass mirror about one foot square, or larger, might be tried first, to see if the reflection law is the same as for the optical case. The mirror might also be turned over, to see if its back is a good reflector. Other reflectors to be tried might be an ordinary piece of sheet metal, window screen, and then wire meshes of increasing coarseness. From these trials, some idea can be obtained as to how "smooth" the surface must be to be a good reflector. The radius of curvature of a piece of screen or sheet metal bent into the shape of a cylinder might be varied to get a maximum intensity at the detector, and the result compared with the prediction of optical theory. Various other objects can be tested as reflectors: a man, his coat hung over a chair, window glass, blackboard, fiber board, green and dry lumber, etc. Metal objects in the walls, such as ventilator shafts, can be searched for.

If the transmitter and receiver are placed facing each other, the transmission of various objects, such as wire screens and dielectric sheets, can be tested. The sample should be very close either to the transmitter or to the receiver, and should be two or more wavelengths wide, if diffraction effects are to be small.

The properties of a corner reflector can be studied by means of a two-dimensional reflector formed of a sheet of metal 4 ft by 2 ft bent to make two mirrors 2 ft square. The transmitter and receiver are set side by side with their axes parallel, and pointing at the reflector. The parallelism of the incident and reflected rays, and the nondependence on the orientation of the reflector can be noted.

6–27 Interference of radiation from two secondary point sources. (See Jenkins and White, Ref. 28, Secs. 13–3, 13–4.) The study of interference from two secondary sources is considered the most fundamental experiment in the nature of electromagnetic radiation, for it was by this method that Thomas Young showed that light is wave motion. When the experiment is performed with light, the primary source is a bright carbon arc. The secondary sources are two slits less than a millimeter apart, the distance being measured with a micrometer microscope. The interference pattern is observed and measured through a microscope eyepiece, and the wavelength is computed by indirect means involving approximations in geometry.

When microwaves are used, the wavelength is measured directly on a meter stick. In addition to the transmitter and receiver, an accessory to the transmitter, to give the two secondary sources, is required, as shown in Fig. 6–22. The dipole is removed from the transmitter and the coupling loop inserted in its place. The reflectors on the secondary sources can be omitted at some sacrifice in intensity.

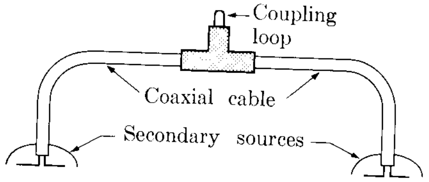

FIG. 6–22. Arrangement for producing two coherent sources of microwave radiation.

The two secondary sources are clamped on the meter stick of a wooden optical bench. The two dipoles should be oriented in a vertical position, with the grounded half of each pointing in the same direction, either up or down. Then, since the cables are of the same length, the radiation leaving the antennas will be in phase. If the plane of the T is horizontal and the coupling loop is pushed as far into the silver tube of the oscillator as it will go, radiation will be observed from the secondary sources.

For the first measurements, the secondary radiators should be set about 50 cm apart. If the experiment is performed outdoors, the two sources should be about shoulder height above the ground (the reason for this position will be seen in Article 6–28).

The interference pattern of the radiation from the two sources is three-dimensional, but it is sufficient to study the two-dimensional pattern in the horizontal plane through the sources. In this plane field, lines of constructive and destructive interference form a family of hyperbolas, as shown by Jenkins and White (28, p. 232). See also below. For a beginning, the observer can try to locate some of the hyperbolas by walking along lines of maximum or minimum intensity, holding the detector at the height of the sources. Various points of, say, minimum intensity may be located at convenient distances from the double sources, and in each

case the distances to the two sources measured. The distances from the two sources should, in each case, differ by an odd number of half-wavelengths. From these measurements the frequency of the transmitter can be calculated.

If one dipole is rotated 180°, the two waves will now leave their respective sources out of phase, and the interference pattern should be shifted correspondingly. This can be verified by test.

The antennas can be set at separations of one, two, three, etc., wavelengths, and the pattern studied in each case. It is instructive to predict, before the tests are made, how many paths of constructive and destructive interference will be present. A relationship between the number of paths of constructive or destructive interference and the separation of the dipoles in wavelengths can be worked out.

In order to visualize more clearly the interference pattern which has been measured, it can be traced on the ground with a tennis-court marker, or drawn 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. Short stakes are driven into the ground vertically below the two antennas and screw eyes put in the tops of the stakes so that a heavy cord will slip through easily. A cord is tied to a marker such as a tennis-court marker and drawn through the eyes of F and F', as shown in Fig. 6–23, where 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 also be constant.

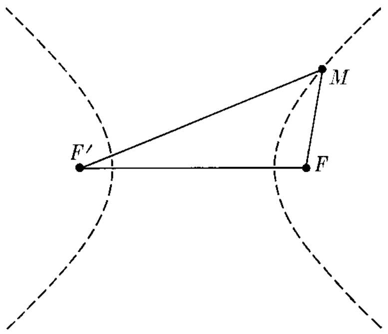

FIG. 6–23. A method for constructing a hyperbola. This method is the equivalent of one of the better known methods for constructing an ellipse.

For each hyperbola drawn, $F'M - FM$ is to be an odd number of half-wavelengths. A simple way to satisfy this condition 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,

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

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

If one case has been checked, others may be analyzed more rapidly by making the constructions on a drawing board with a pencil for M and thumbtacks at F' and F.

6–28 Interference of direct and reflected beams; Lloyd's mirror. The Lloyd's mirror experiment is a well-known optical demonstration of interference which requires only one source of light, instead of the two required for Young's experiments. See Jenkins and White (28, p. 238). The microwave analog of this experiment requires a sheet of metal or a wire screen two feet square or larger. The transmitter and receiver are set some distance apart, facing each other. The transmitter and receiver dipoles are set vertical. The reflector is set in a vertical plane parallel to the axis of the optical system, and about 20 cm distant. The radiation reflected by the mirror appears to come from a virtual source an equal distance the other side of the mirror. The interference pattern between the radiation reaching the receiver directly and that reflected should be similar to that in Young's experiment.

If the field is explored, it will be found to be the same as in Young's experiment for the case where the antennas of the two sources were rotated 180° with respect to each other. The source and its image are, therefore, 180° out of phase, which means that the radiation has undergone a phase reversal upon reflection. The plane of the mirror is a plane of destructive interference. The metallic reflector can be replaced by a large plate of glass or other dielectric, and the field explored again to see if it is the same as before. It is instructive to compare the results with the predictions of electromagnetic theory. Also, the student should explain why the dipoles are set vertical in this part of the experiment and horizontal in what follows.

In slightly modified form, this same apparatus can be used to demonstrate radio fading, which, as is well known, results from the rise and fall of the reflecting layers of the ionosphere. An experiment simulating radio fading is of interest because it demonstrates in the laboratory how we can use radiowaves to study the ionosphere. For this experiment the reflector is held horizontally over the apparatus. The dipoles must now be set horizontal. One observer can raise and lower the sheet, while another observes the readings on the intensity meter. Since we know the wavelength (which was determined in the previous experiment or could be determined in the same way in this one), and remembering the phase reversal upon reflection, the heights of the reflector at which complete destructive interference should occur can be computed and compared with the experimental results.

The Lloyd's-mirror effect is also noticed in the operation of a radar search set which is located on a headland above the ocean, when it is being used to detect approaching aircraft. It is found that as the aircraft approaches, the signal from it will disappear when the airplane is at certain distances from the radar set. The effect can be studied by setting up the transmitter with its dipole horizontal, and about three or four wavelengths above the ground. The receiver can be used to locate lines of destructive interference in the vertical plane through the axis of the transmitting antenna. The lines can be plotted, so that their shape can be observed. A simpler experiment consists of approaching the transmitter with the receiver and noting the variations in signal strength with position. The student should note what the intensity is along the ground, and explain. It is also of interest to see what happens if the dipoles are set vertical instead of horizontal.

6–29 Standing waves. A method for determining wavelength is discussed in Article 6–27. The wavelength can be found more precisely by studying the standing wave pattern resulting from interference between the wave incident perpendicularly on a plane mirror and the reflected wave. See Jenkins and White (28, Secs. 12–3 and 28–11).

To observe the standing wave pattern, the transmitter is set facing a reflector consisting of a metal sheet or screen at least two feet square. The reflector is set at right angles to the transmitter beam, and about three meters in front of the transmitter. The dipole of the transmitter is set in a vertical position. A wooden optical bench (*not a metal bench*) is placed in front of the mirror, along the axis of the beam. The optical bench consists of a meter stick mounted in two slotted wooden blocks. The observer should hold the intensity meter facing the mirror with its dipole vertical, and move the antenna of the intensity meter slowly along the meter stick, keeping his body well back from the optical bench. The positions of the nodes and antinodes should be noted. The position of the nodes can be located more sharply than those of the antinodes. If the intensity meter is moved very slowly, nodes can be located within a millimeter.

If the intensity at the node is not zero, it may be decreased somewhat by moving the mirror by steps of a few millimeters toward or away from the source until the node intensity is a minimum. This adjustment is of little value when such a small portion of the reflected radiation is fed back to the source, but if the widths of the mirror and the parabolic reflector are large compared with the distance between them, or if the wave is confined to a hollow waveguide, this adjustment is necessary.

About fifteen nodes can be located along the meter stick, and the average internodal distance can then be calculated. Since the distance between the nodes is a half-wavelength, the wavelength can be determined. A student accustomed to precision methods will subtract the position of the first node from the last, the second from the next to the last, and so on, and employ the method of the weighted mean.

6–30 Interference from two secondary slot sources.

The preceding experiments involve interference of waves from two secondary point sources. Sometimes one of the point sources is a virtual image behind a mirror. See Jenkins and White (28, pp. 226 ff). If the intensity is studied in a plane perpendicular to the antenna, the antenna may be considered to be a true point source with a cross section much smaller than one 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 one 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 essentially the interference pattern of two point sources.

A suitable screen for this experiment has two slots of width about $\lambda/2$, and spaced about 2λ, center-to-center. The transmitter should be placed about 12 cm behind the screen, and then moved toward or away from it until the intensity on the other side at a point on the centerline is a maximum. The wavelength and frequency can be determined by the method of Article 6–27. A study of the intensity in a plane parallel to the screen and distant several wavelengths can be made. It may be of interest also to study the patterns produced by screens with two slots spaced different amounts, or with multiple slots.

6–31 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 oxide on heated metal, insect 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. See Jenkins and White (28, pp. 254–260). When microwaves are employed, the thickness of "thin" films may be measured directly on a meter stick.

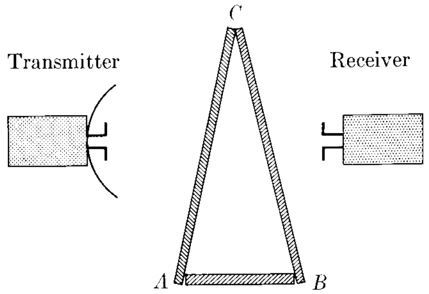

FIG. 6–24. Arrangement for studying the interference of microwaves in the wedge of air between dielectric slabs.

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 is reversed. The thicknesses of film may be measured and the wavelength calculated. If the film is of dielectric, the dielectric constant can 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 which are not necessary for light should be taken:

(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 are a quarter-wave thick, 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 shown in Fig. 6–24, 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 the measurement of wavelength will be 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 a Lloyd's mirror and produce an additional interference pattern, as was shown in Article 6–28.

(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. 6–24, only the interference pattern will be observed.

An arrangement is shown in Fig. 6–25 for a quantitative study of interference by a thin film of dielectric. A metal shield with an aperture one wavelength or less in diameter prevents effects of diffraction around small pieces of dielectric. Ideally, each piece should be many wavelengths wide. The shield makes it possible to deal with small quantities of dielectric.

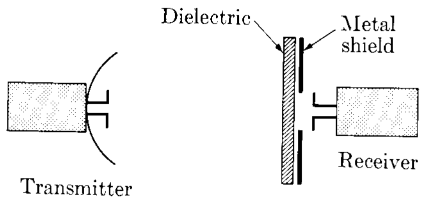

Fig. 6–25. Arrangement for studying the interference of microwaves in a thin film of dielectric.

The arrangement of Fig. 6–25 can also be used for a study of transmission through a dielectric as a function of thickness. About 12 sheets of $\frac{1}{4}$-in. plywood, about 6 in. square will be needed. The pieces of wood are placed, one at a time, in front of the receiver, and the intensity of the transmitted wave measured. The wavelength of the radiation in the wood can be determined from a plot of intensity *versus* thickness. Since we also know the free-space wavelength, the index of refraction of the wood at microwave frequencies can be calculated. Glass and transite, both of which have higher dielectric constants, can also be investigated. With either of these materials the contrast in intensities of the transmitted beam will be greater as the thickness is varied. Transite has about the same index of refraction as glass, but a higher absorption coefficient.

Interference in thin films with parallel surfaces can be studied by means of two sheets of glass, each a quarter-wave thick, arranged as in Fig. 6–25. The two plates are placed next to the metal shield. The outer plate is then moved toward the transmitter, and the transmitted intensity is measured for various separations. The wavelength can be determined from a plot of the results.

In optics, when two plates of glass are in sufficiently close contact to transmit about 99% of the radiation, the glass plates are said to be in optical contact. For microwaves, two plates of dielectric are in fair optical contact if they are one millimeter apart. The student should calculate the spacing for an equally good optical contact when the waves are from sodium light.

6–32 Michelson's interferometer. Michelson's interferometer is used to measure small displacements of a surface in terms of known wavelengths of light. See Jenkins and White (28, Sec. 13–10). A microwave version of Michelson's interferometer may be set up on the laboratory or lecture table as shown in Fig. 6–26. The half-reflecting screen may be of chicken wire or square mesh wire with meshes about $\frac{1}{5}$ wavelength across. The screen is held by a wooden clamp in a vertical plane at 45° to the direction of the incident beam. The half-reflecting screen, as well as mirrors A and B, should not be smaller than one foot square. Mirrors A and B may be of sheet metal or window screen, carefully set in vertical planes at right angles to each other. Mirror A is fixed and mirror B can be moved between two guides, one of which may be a meter stick. The intensity meter should be set in the position shown in Fig. 6–26, where motion of mirror B will produce the greatest variation in the received intensity. The output of the transmitter and the position of the intensity meter are adjusted until motion of mirror B causes the reading of the meter to vary over half the scale.

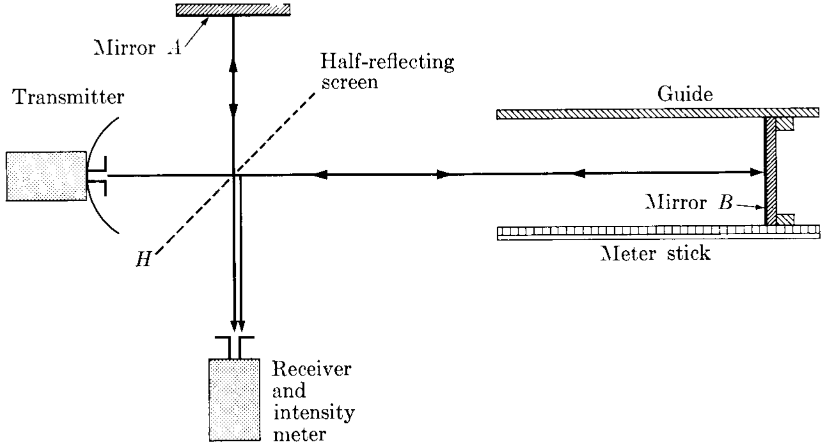

Fig. 6–26. A microwave version of Michelson's interferometer.

It is suggested that the interferometer be used to measure the wavelength of the microwave radiation and the index of refraction of some material, for example, glass. The former measurement is made by finding positions of mirror B where the detector reads a minimum. For the latter measurement one or more sheets of the test material are needed. The sheets are inserted, one at a time, into the beam to mirror B, and the change in the optical path is found by readjusting B for a minimum reading of the detector. The thickness of each sheet should be less than $\lambda/(n - 1)$ if ambiguity in the results is to be avoided. It may be advisable to tilt the sheets away from the vertical so that the radiation reflected from the faces does not reach the detector.

6–33 Diffraction pattern of a circular aperture. When Fresnel diffraction is observed with light, the source is a well-shielded carbon arc with a small aperture. The apertures or obstacles which are to produce the diffraction pattern are placed in the beam a few feet from the arc and the diffraction pattern is observed at the far end of the room on a ground glass

but is not experimental evidence of the plane in which the light is polarized. See Jenkins and White (28, Chap. 24).

If the study of microwaves precedes the study of light waves, the student need have only an experimental picture of the electrostatic field around a dipole to determine the plane of polarization of the microwaves. When the potential between the dipoles is alternating at microwave frequencies, the electric lines of force are "snapped off" in loops which travel outward as waves. When oscillating currents are present in the dipoles, oscillating magnetic fields which travel out as a part of the electromagnetic wave are also produced. See Harnwell (22, p. 604).

(a) *Linear polarization.* For this study, the transmitter and receiver are set facing each other. The intensity meter should be mounted so as to allow its rotation about the axis of the system, and it should have a protractor to allow measurement of the amount of rotation. The intensity meter is rotated about the axis by 5-degree steps through 180°. A plot of intensity of radiation *versus* angle should be made on polar coordinate paper. The intensity of radiation received should be proportional to the square of the cosine of the angle between the direction of the electric field and the line of the antenna of the receiver. The observer can compare his results with theoretical predictions.

For the next set of observations the transmitter and receiver dipoles are set vertical. Between them is interposed a polarizing screen consisting of a set of parallel wires about $\frac{1}{8}$ wavelength apart. If the polarizing screen is close to the transmitter or receiver, Fresnel diffraction around the screen will be slight. To avoid diffraction effects, the metal sheet with the circular aperture (described in Article 6–33) may be placed close to the receiver as a shield, with the first zone aperture in place, and the polarizing screen placed over it. A number of interesting observations can be made:

(i) The screen is rotated about the axis of the system, and the variation of intensity of the received signal with angle is noted. This variation should be compared with that found when the receiver dipole was rotated. Also, the positions of extinction and of best transmission should be noted.

(ii) The dipole of the receiver is now rotated through 90°, so that with the polarizer removed no signal is received. The polarizer is inserted in the beam and rotated as in (i). The variation of received intensity with angle is again noted.

(iii) In part (i) the question arises as to what happens to the energy when the transmission of the polarizer is zero; is it absorbed or reflected? This can be tested by setting the transmitter and receiver side by side with dipoles set vertical, and setting the polarizer to reflect the radiation from the transmitter back to the receiver. The polarizer is rotated about an axis bisecting the incident and reflected beams, and the variation of received intensity with angle is noted. The intensity when the polarizer is set for extinction of the transmitted beam is of particular interest.

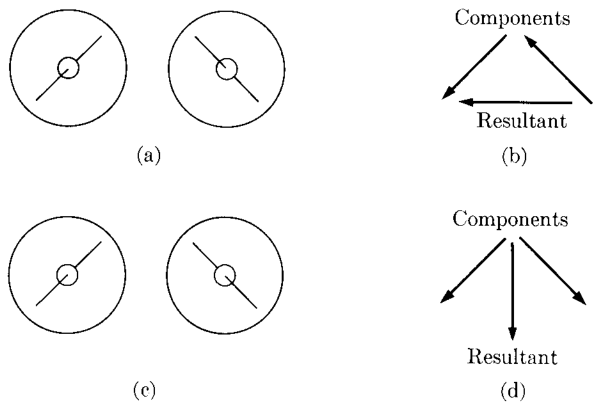

FIG. 6–27. Arrangement for producing elliptically polarized microwaves.

(b) *Elliptical polarization.* If the two secondary sources of Article 6–27 are arranged with their dipoles at right angles, as shown in Fig. 6–27(a), and the faces of the two paraboloids are in the same plane, the resulting plane of polarization is found to be horizontal, as indicated in Fig. 6–27(b). The arrows, which indicate relative phase of the two sources, have been drawn in the direction from the grounded half to the elevated half of the dipole antenna. If one of the two antennas is rotated through 180°, as in Fig. 6–27(c), the resulting plane of polarization is vertical, as shown in Fig. 6–27(d).

The two secondary sources can be set up as in Article 6–27, and the predictions just made can be checked. If the two coaxial lines are not of precisely the same length, it may be necessary to move one of the sources backward or forward a few millimeters before the resultant beam is linearly polarized. One of the sources is now moved $\frac{1}{8}$ wavelength nearer the intensity meter. The resulting wave should be elliptically polarized. The intensity as a function of angle can be determined by rotating the intensity meter through 360° by steps of 10° and plotting the results on polar paper. As a check with predictions, the square root of the intensity, or amplitude, should be plotted against angle. In like manner, one source can be moved $\frac{1}{4}$ wavelength ahead of the other and the measurements repeated. The results might be predicted and checked when the difference in distance from the sources to the intensity meter is increased in steps of $\frac{1}{4}$ wavelength. The conditions under which polarization is circular can thus be found.

(c) *Elliptical polarization by relative retardation.* A linearly polarized wave may be divided into two components polarized at right angles to each other, with one component retarded in phase relative to the other, by two methods: (1) by causing the two components to travel paths of different lengths before uniting, and (2) by passing the two components through a doubly refracting medium in which two components travel at different speeds. The latter method is employed in the science of crystallography, the engineering study of mechanical strain in models of complex structures, and in electro-optical shutters. The first method will be employed in this experiment because of its simplicity.

Figure 6–28 is an arrangement for the production of elliptical polarization with one of the components retarded in phase by traveling an extra distance. The metal disk is the first zone disk of Article 6–33. With the parallel-wire screen removed, the intensity meter is set at the diffraction maximum by moving it a few millimeters in the wooden frame. The parallel-wire screen from part (a) may be supported by a wooden tripod and clamp in front of the disk with its plane parallel to that of the disk, and with the wires at an angle of 45° with the plane of polarization. When the incident wave reaches the wire screen, it will be divided into two components of nearly equal amplitude, one parallel to the wires, or reflected, and one perpendicular to the wires, or transmitted. The component perpendicular to the wires will be reflected by the disk and will again pass through the parallel-wire screen to join the other component. Since both waves undergo 180° phase change upon reflection, the phase difference will be determined solely by the path difference in wavelengths. If d is the distance between the parallel-wire screen and the disk, the path difference in wavelengths is $2d/\lambda$. The phase retardation of one component relative to the other is $4\pi d/\lambda$.

FIG. 6–28. Arrangement for producing elliptical polarization of reflected microwaves.

With the parallel-wire screen $\frac{1}{16}$ wavelength in front of the disk, the intensity meter can be rotated through 360° by steps of 15°, and the amplitudes plotted on polar coordinate paper. In order that the operator's body will not interfere, the intensity meter should be read from behind the transmitter. A second set of readings should be taken with the wire screen $\frac{1}{8}$ wavelength from the plate.

Let the antenna of the intensity meter be set in a vertical orientation and the screen and disk be further separated until the meter indicates zero. The resulting wave is polarized horizontally, or at right angles to the incident wave. What must the distance between the screen and disk be? What is the phase retardation of one component relative to the other?

With the antenna of the intensity meter horizontally oriented, the screen and disk are separated still further, until the intensity is zero. The wave is again polarized vertically. The distance between the screen and disk in wavelengths, and the phase retardation should now be calculated.

An alternative method of producing relative retardation in phase is to use the parallel-wire polarizing screen in the Michelson's interferometer experiment of Article 6–32. The wire must be at 45° with the vertical, so that half the wave is reflected to one mirror and half transmitted to the other. The waves reflected from the two mirrors will be polarized at right angles to each other. When used in this way, the apparatus is not really an interferometer, since the two components do not interfere but combine to form an elliptically polarized beam. If the antenna of the intensity meter is kept vertical, the intensity will go through the same maxima and minima when mirror B of Fig. 6–26 is moved toward the source as it did in Article 6–32, when interference was involved. When this method is used, the intensity meter may be rotated to follow the major axis of the ellipse. Thus the meter will be rotated once for every wavelength that the screen is moved, effectively adding a circular micrometer scale to Michelson's interferometer. This method has never been employed with light, but is theoretically possible.

6–36 Field patterns of parabolic reflectors. Since the reflector used in the microwave transmitter is only about two wavelengths in diameter, the beam from the reflector will be far from an ideal parallel beam. Instead, the radiation will be spread out in a broad diffraction pattern which will have the same geometry as the Fraunhofer diffraction pattern of a circular aperture of the same diameter as the reflector. If one should explore in a plane perpendicular to the axis of the reflector, he would obtain an intensity pattern which is the same as that found in optical experiments. See Jenkins and White (28, Chap. 15). If, on the other hand, the exploration is made along a circular arc whose center is at the reflector and the intensities are plotted on polar coordinate paper, the familiar antenna pattern is obtained, in which the lobes are equivalent to the maxima in the conventional optical plot.

A parabolic reflector two or three wavelengths in diameter is suitable. If one is not available, a cylindrical parabolic reflector can be made by making end pieces of wood, and bending sheet metal around them. The transmitter should be outdoors, facing away from any nearby building, and at least 4 ft above level ground. There should be no trees or large reflecting objects within about 50 ft. By driving stakes at intervals of 5° and using a string 20 ft or more in length, a 180° protractor can be constructed on the ground.

The antenna is set for vertical polarization, and the intensity is measured in a horizontal plane at the height of the antenna at the points above the stakes. Since this plane contains the magnetic lines of the electromagnetic field, the pattern in the H-plane is thus obtained. By setting the antenna for horizontal polarization and repeating the survey, the E-plane pattern can be found.

The results are best plotted on polar coordinate paper. In order to emphasize the side lobes, the engineer often plots the logarithm of the intensity, rather than the intensity. In most applications the side lobes are undesirable. For instance, if an antenna with strong side lobes is part of a radar system with which one is attempting to locate an aircraft, when a reflected signal is received it is not known whether the aircraft is on the main beam, or on one of the side lobes.

We can define the resolving power of the antenna as the reciprocal of the angular width of the main lobe at half intensity, and determine it from measurements of the graph. If measurements have been made on two or more parabolic reflectors of different diameters, their resolving powers in the E- and H-planes can be compared. Which would yield the most precise location of a reflecting object?

VI. DIELECTRICS AND ELECTRIC FIELDS; CONDUCTIVITY

6–37 Dielectric susceptibility of a liquid. In Article 6–38 methods for measuring the dielectric constant of a liquid at audio- and radiofrequencies will be described; these methods are based on the proportionality between capacitance and dielectric constant, and involve measurements of capacitance. In this experiment, however, the dielectric susceptibility of a liquid will be determined by measuring the decrease in hydrostatic pressure in a liquid in an electrostatic field, as described by Gray (17, p. 760) and by Harnwell (22, Sec. 2-6), and calculating the susceptibility from known relationships, which are derived below.

The liquid to be tested (iso-amyl alcohol has been recommended) is contained in the cell shown schematically in Fig. 6–29. The broad faces of the cell are conducting plates, forming a parallel-plate capacitor. Connected to the cell is a small-bore tube of cross section A'. If a potential difference V is applied between the plates of the capacitor, the energy U stored in the capacitor will be

$$U = \frac{1}{2}CV^2 = \frac{k\epsilon_0 A V^2}{2d}.$$

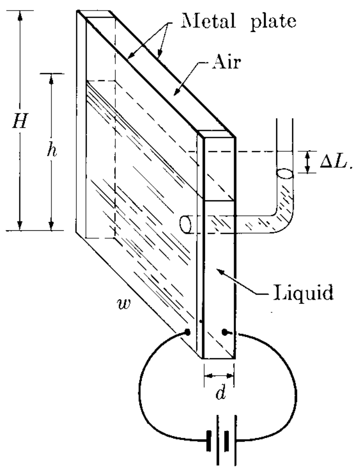

FIG. 6–29. Cell for measuring the dielectric susceptibility of a liquid. Suggested dimensions: length w and height H, 10 cm; width d, 2 mm. The narrow walls may be of lucite. The wide faces are metal plates, which may be cemented to the lucite walls.

If the cell is filled to a height h, then

$$U = \frac{\epsilon_0 V^2}{2d}\,(A_{\text{air}} + kA_{\text{liq}}) = \frac{\epsilon_0 V^2}{2d}\,w(H - h + kh),$$

where A_{air} and A_{liq} are the areas of the plates covered by the air and liquid dielectrics, respectively. The dielectric will experience an upward force F given by

$$F = \frac{\partial U}{\partial h} = \frac{\epsilon_0 V^2}{2d}\,w(k - 1). \qquad (6\text{–}15)$$

As a result of this force, the pressure P at any point in the liquid in the cell will be reduced by the amount

$$\Delta P = \frac{F}{wd} = \frac{\epsilon_0 V^2}{2d^2}\,(k - 1). \qquad (6\text{–}16)$$

The force given by Eq. (6–15) will tend to draw the liquid upward. The reservoir of liquid is the small-bore tube outside the capacitor; as the liquid level in the cell rises, therefore, the level will fall in the tube, until the difference in the two levels, ΔL, is such as to satisfy the relation

$$\Delta P = \frac{g\rho A'(\Delta L)}{A'} = g\rho(\Delta L). \qquad (6\text{–}17)$$