A Photographic Method for Displaying Sound Wave and Microwave Space Patterns

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A photographic method using mechanical scanning for displaying the space patterns of sound and microwaves is described. A probe pick-up scans the sound or microwave field and the amplified probe output controls the brilliance of a small lamp affixed to the probe. A camera set at time exposure records the light intensity variations of the lamp as it moves across the scanned field, forming a pattern on the film of the amplitude distribution. Phase fronts can be delineated by adding a constant amplitude signal to the probe output. Photographs are included which show: sound and microwave patterns of lenses, diffraction at a straight edge and disk, refraction by a prism, diffusion of sound by a divergent lens, and radiation from loud speakers. Also, by transposition of source and receiver, directional patterns of transducers acting as microphones are obtained which (by reciprocity) appear identical with their radiation patterns. This provides a means for examining the directional characteristics of non-reversible transducers such as a carbon microphone. A calibration method is described which allows the relative value of the field intensities to be determined.

Introduction

In analyzing the performance of an acoustic or microwave radiator it is helpful to know the way in which the waves proceed as they emerge from the source. It is desirable in some cases to have a photographic record of the distribution of intensity in the field generated by the radiator. This paper describes a simple mechanical scanning method for accomplishing this result. For acoustic analysis, a probe microphone is moved back and forth through the sound field to be explored and a small lamp is affixed to the microphone. When the output of the microphone is connected to the lamp through an amplifier, the intensity of the light varies in accordance with the sound level encountered by the probe microphone. A camera set at time exposure records the variations of light intensity. In this way the desired picture is built up by scanning the sound field somewhat after the manner in which a television image is formed.[1] For analyzing microwave fields the microphone is replaced with a microwave pickup probe.

Experimental

The scanning device is shown in Fig. 1.[2] The microphone is located at the end of the rocking arm. Attached to it (at the left) is a small neon lamp

[1] A similar procedure in which the probe output, instead of lighting a lamp and bein- photographically recorded, is traced on spark paper (Teledeltos paper) has been emg ployed for microwave presentations by H. Iams, "A Phase Front Plotter for Centimeter Waves," *R.C.A. Review*, *8*, 270 (1947); also *Proc. I.R.E.*, *38*, 543 (1950).

[2] This device was designed by Mr. T. Aamodt of these Laboratories.

which is energized by the amplified output of the microphone. As the rocker arm moves through its vertical motion the entire assembly including the motor and gear reducer is caused to move slowly towards the reader by the

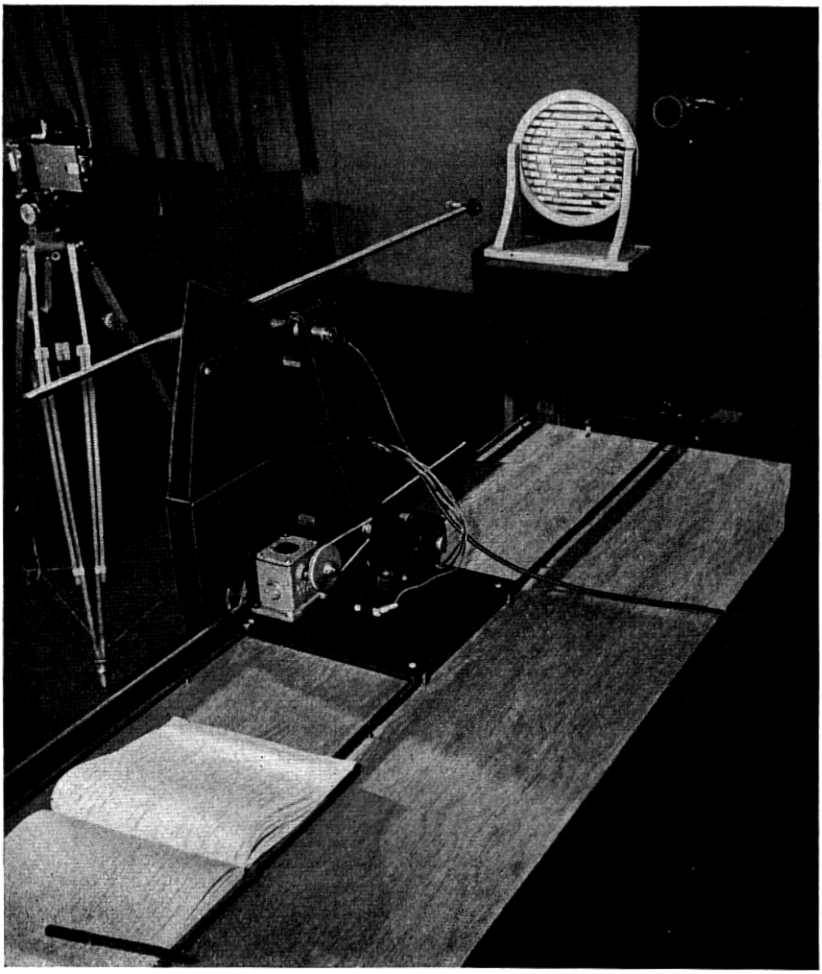

Fig. 1—The scanning mechanism set up for photographing the sound field in front of an acoustic lens.

rack and pinion shown at the left of the photograph. An acoustic lens[3] is seen in its test position between the end of the rocking arm and a tweeter

[3] W. E. Kock and F. K. Harvey, "Refracting Sound Waves," *Jour. Acous. Soc. Am.*, *21*, 471 (1949).

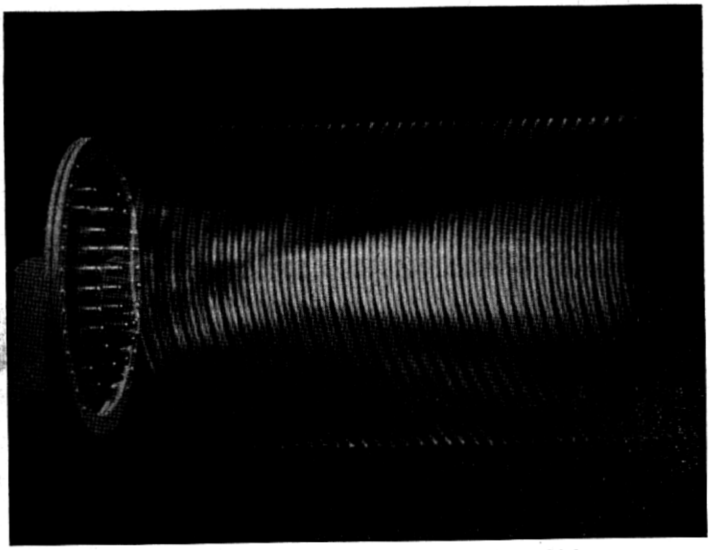

Fig. 2—An early photo of a sound field in which the scanning strokes were too coarse.

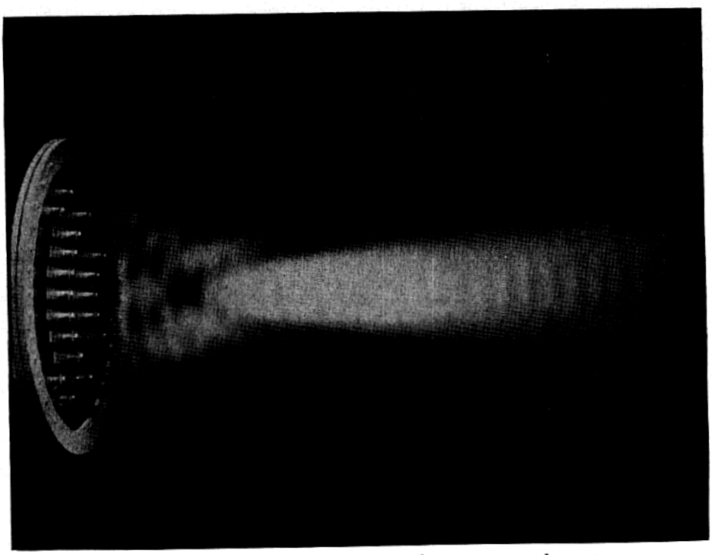

Fig. 3—Finer grained scanning produces a smooth pattern of the 10″ acoustic lens of Fig. 2. f = 9 KC (λ = 1.51″).

loud speaker which supplies a single frequency sound field. The Polaroid-Land camera in the background has been favored because its short development time of 1 minute allows the photographic record to be inspected almost immediately after the scanning run has been completed.

Amplitude Patterns

The first pictures were taken to determine the amplitude distribution in the focal region of a 10″ diam. acoustic lens. This acoustic lens is made of rigid metal strips arranged in an open construction.[2] Figure 2 shows an early photograph in which the horizontal motion of the scanning device was too rapid. The line structure of the scanner is therefore very coarse but

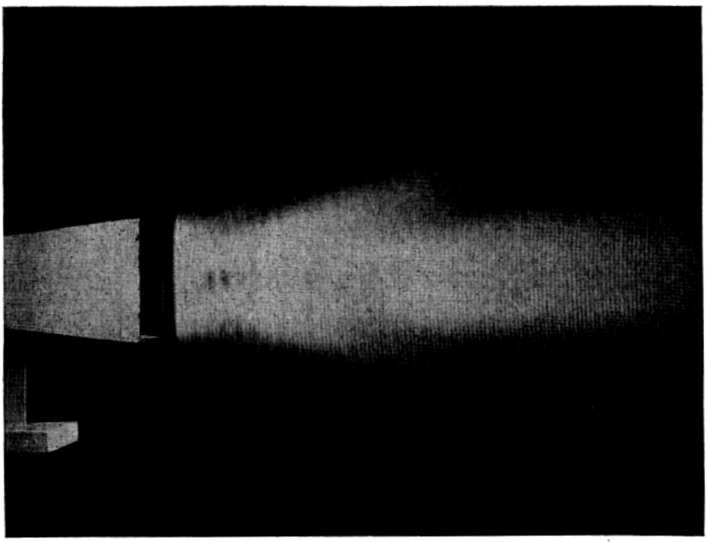

Fig. 4—Radiation pattern of a 6″ square aperture horn. f = 9 KC.

the lobe structure and focusing effect of the lens are evident. Figure 3 shows a later photograph in which a finer gradation scan with a longer stroke provides a smooth appearing pattern.

The radiation pattern of a long horn with a 6″ square aperture is shown in Fig. 4, taken at a frequency of 9 KC. As in the lens pictures, minor lobes can be seen forming at the sides of the major lobe, while several minima appear faintly in the central region near the aperture (the close-in or Fresnel field).

The refracting property of a prism made of rigid strips is illustrated by the amplitude pattern in Fig. 5. In combination with the strip lens of Fig. 3, it bends the sound beam downward away from the axis. The lens itself is an example of a refractor, of course, but the prism is usually chosen to demon-

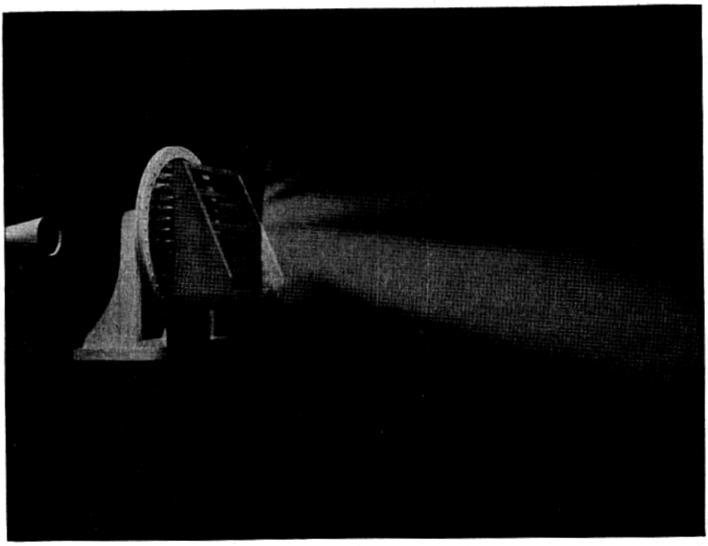

Fig. 5—A strip prism placed before the lens of Fig. 3 tilts the focussed beam downward. f = 9 KC.

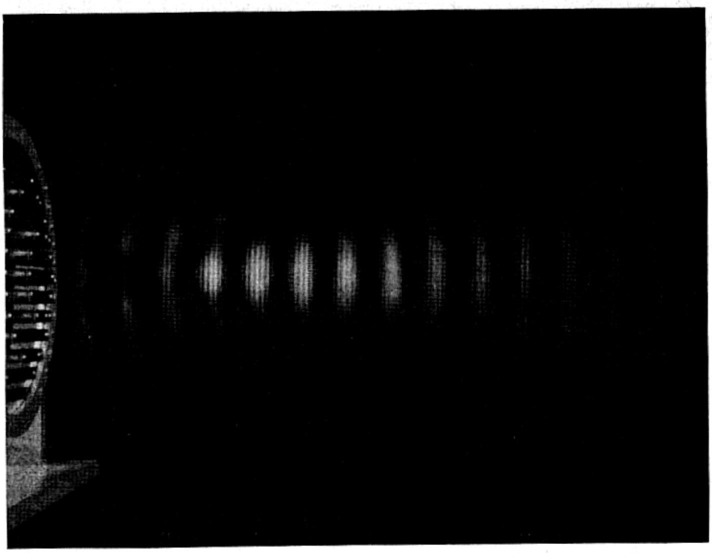

Fig. 6—Adding a signal of constant phase to the signal picked up by the scanning microphone delineates the position of the wave crests as they progress outward toward the right. (These are not standing waves.) f = 9 KC.

strate refraction in its simplest form. One sees, along with the downward beam tilt, a dissymmetry of the minor lobe structure, the upper lobe being quite pronounced.

Addition of Phase

From this point on, the portrayal of phase will be added to most of the photographs. This is accomplished by combining, with the signal picked up by the probe microphone, a constant-phase constant-amplitude signal from the oscillator feeding the source loud speaker. As the probe moves away

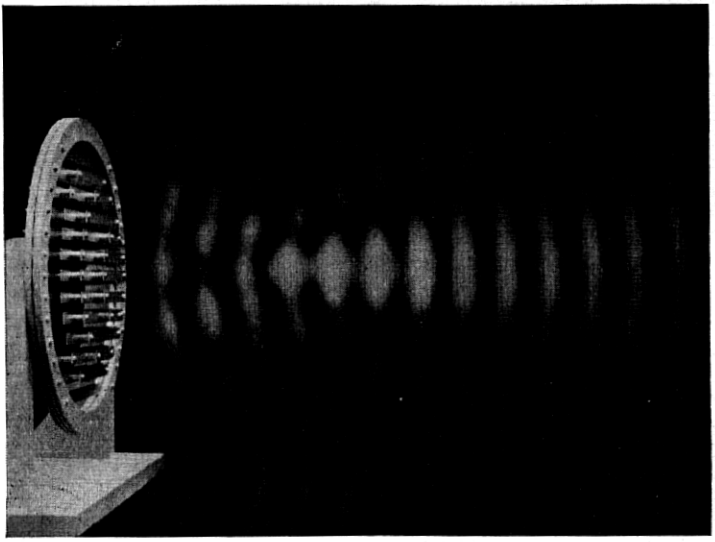

Fig. 7—Increasing the sound intensity in Fig. 6 brings out the details of the minor lobes. $f = 9$ KC.

from the loud speaker and lens combination, the phase of the microphone signal varies with respect to the constant signal from the oscillator. Constructive and destructive interference results and pictures such as shown in Fig. 6 are obtained. This is a pattern for a progressive sound wave (not a standing wave) emerging from the strip lens; it is, in fact, the same pattern as that of Fig. 3 except that phase has been added and the signal intensity reduced somewhat. The curved wave fronts converging towards the brighter focal spot are evident and as the sound energy progresses through the focal point the wave fronts become concave outward. Figure 7 shows a similar pattern but with the intensity of the signal increased. This procedure brings up the intensity of the weaker field and shows more clearly the minor lobe

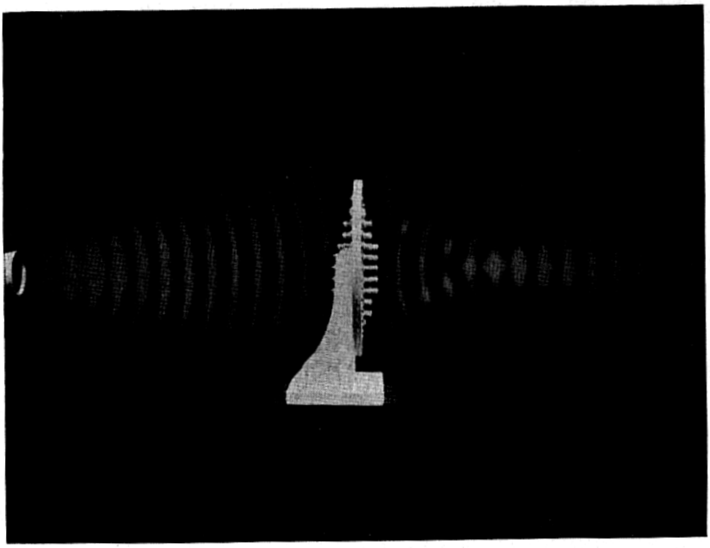

Fig. 8—A composite pattern of horn and lens which shows that the lens delays the wave fronts by approximately one wavelength. f = 9 KC.

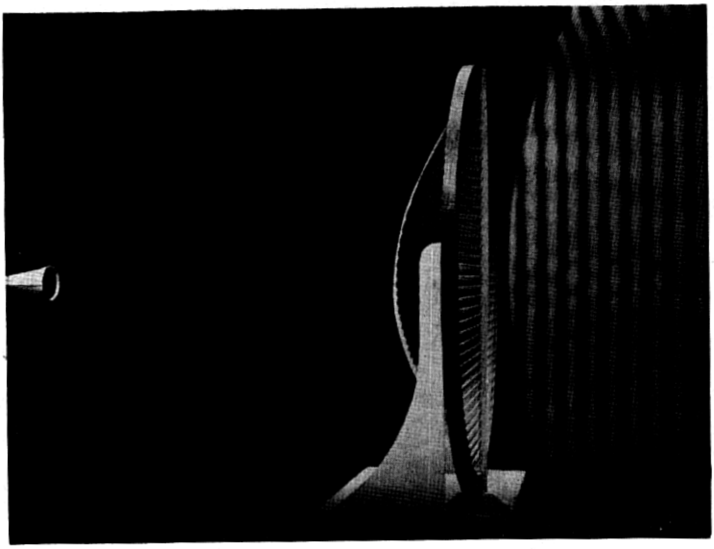

Fig. 9—Flat phase fronts are obtained with a 30″ diameter slant plate lens "illuminated" by the 3″ aperture feed horn of Fig. 8 placed at the focus. f = 9 KC.

structure of the lens. The phase reversal at each successive minor lobe is readily seen from the fact that the bright areas in the minor lobes line up with the dark areas of the adjacent lobes.

The addition of phase makes it possible to obtain motion pictures of progressive wave motion. By taking successive movie "stills", in which the phase front pattern is advanced one-eighth of a wavelength, a complete cycle is obtained. This series of eight pictures is then repeated until a reasonable length or loop of film is obtained.

An example of the retarding effect caused by a delay lens is shown in Fig. 8. This wave pattern is a composite (two exposure) picture and was obtained in the following way: the left side of the photo was scanned with only the feed horn active (lens removed). The lens was then put in place and the probe continued to scan the area to the right. At the top of the photo, the circular wave fronts are seen to be continuous from the horn out, but in the shadow region behind the lens the wave fronts are retarded. One sees that the insertion of the lens has caused a delay equal to about one wavelength along the axis. This results in a curved wave front emerging from the lens and a consequent focusing action.

An acoustic (or microwave) lens in which the delay elements are slanted guides similar in construction to a venetian blind[3, 4] is shown in Fig. 9. The feed horn is the same as that in Fig. 8 and is set at the focus of this lens so as to produce flat rather than converging phase fronts in the emerging wave. As the directional pattern of the feed horn would indicate (Fig. 8), the center portion of this lens is rather strongly "illuminated," but the resulting energy concentration, in passing through the lens, is shifted upwards by the guiding action of the slanted plates. The resulting dissymmetry of the vertical amplitude distribution at the aperture of this lens (indicated by the increased thickness of the phase lines in the upper section of the photograph) is in a large part responsible for the unsymmetrical minor lobe structure as reported.[4] The straightness of the phase lines, however, indicates that the lens has converted the circular wave fronts from the horn into the desired plane wave fronts.

The undesirable concentration of energy at the center portion of the lens can be materially reduced by substituting, for the small feed horn of Fig. 8, a full conical horn shield having its throat at the focal point of the lens. The energy distribution entering the lens is then fairly uniform and the slant plates cause only a slight dissymmetry in the amplitude distribution of the emerging wave as shown in Fig. 10. The distribution of such a "shielded" lens in the horizontal plane, however, is even more uniform since it is not skewed by the slant plates in this plane (Fig. 11).

[4] W. E. Kock, "Path Length Microwave Lenses," *Proc. I.R.E.*, *37*, 852 (1949).

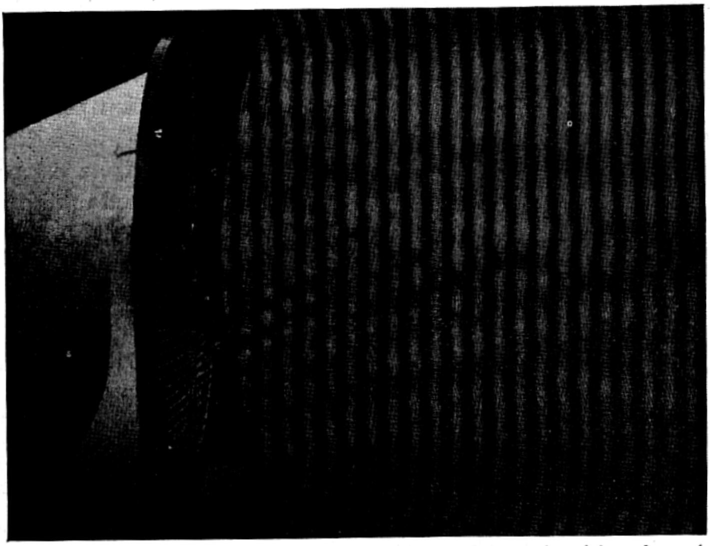

Fig. 10—The pattern of the slant plate lens of Fig. 9 when enclosed in a horn (vertical plane). f = 9 KC.

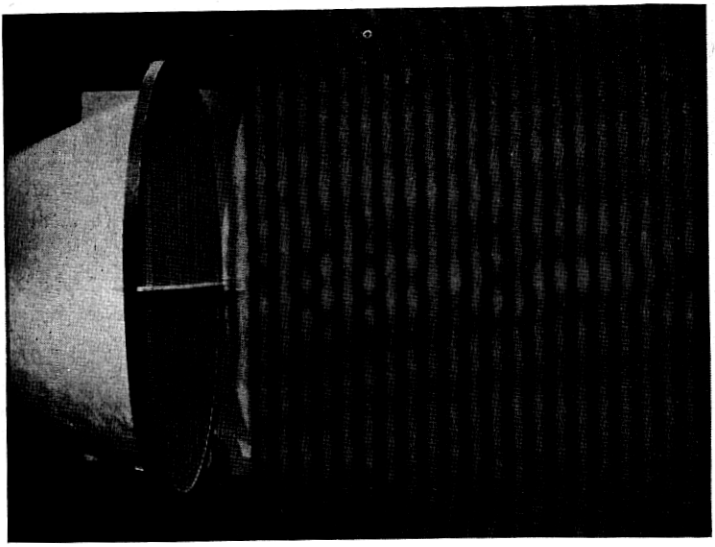

Fig. 11—The horizontal plane pattern of the horn and lens of Fig. 10. f = 9 KC.

In some acoustic investigations it is desirable to have a source of plane waves of extended area. Figures 10 and 11 show that a shielded acoustic lens provides a simple way of achieving this result. The broad band nature of the slant plate lens ensures that plane wave fronts will be produced from 14 KC down to the lowest frequency contemplated for use, and almost any size can be employed since microwave lenses of 10 and 20 foot apertures[5] have been built and found quite satisfactory.

In the three preceding photographs, variations in the intensity of the emerging waves (variations in the thickness of the phase lines) can be observed. To show this effect more clearly and to indicate the symmetry of these amplitude variations, Fig. 11 was retaken with the phasing signal

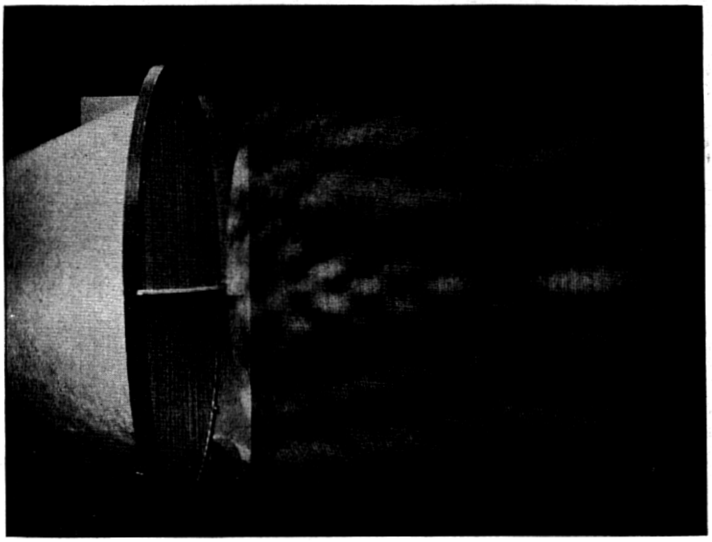

Fig. 12—Removal of the phase signal in Fig. 11 shows more clearly the amplitude variations present in this horn-lens pattern. $f = 9$ KC.

removed so as to obtain a pure amplitude pattern (Fig. 12). As mentioned in connection with Fig. 4, these patterns simply show the intensity variations which are always present in the close-in or Fresnel field of any plane wave source having a finite cross-sectional extent. For a given wavelength and cross-sectional dimension, these variations can be calculated from diffraction theory and evaluated with the aid of Cornu's spiral. It is interesting to compare Fig. 12 with Fig. 13 which is a Schlieren photo of the sound field in front of an ultrasonic quartz radiator of 14 wavelengths aperture dimension.[6] Although the aperture dimensions in wavelengths in the two cases are different and the actual wavelengths are quite different, there is a

[5] W. E. Kock, "Metal Lens Antennas," *Proc. I.R.E.*, *34*, 828 (1946).
[6] K. Osterhammel, "Optische Untersuchung des Schallfeldes Kolbenförmig schwingender Quarze," *Akustische Zeits.* *6*, 82. (1941).

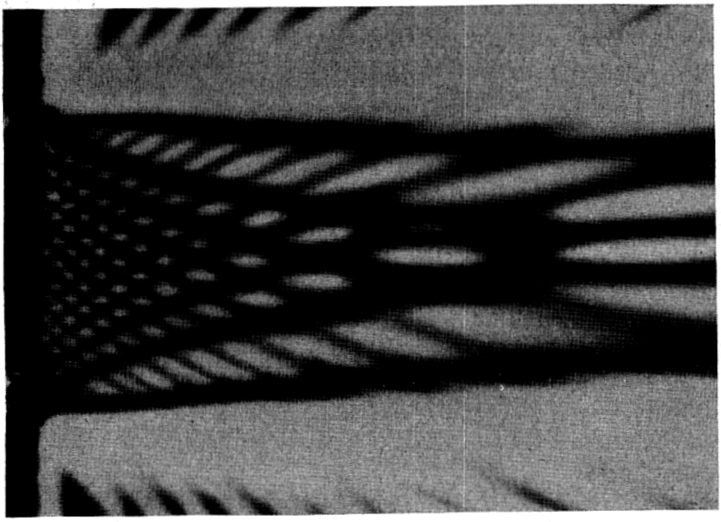

Fig. 13—A Schlieren photograph of an ultrasonic quartz radiator shows the presence of amplitude variations similar to those of Fig. 12. (After Osterhammel.)

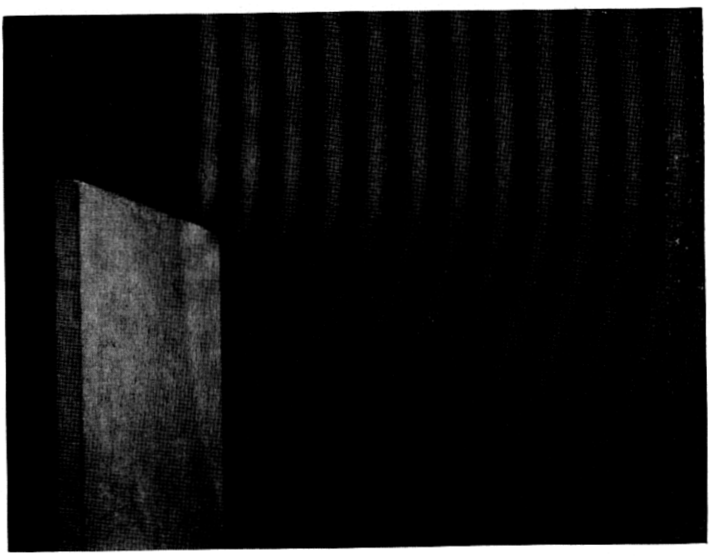

Fig. 14—Plane waves diffracted by a knife edge become cylindrical in the shadow region. $f = 9$ KC.

remarkable similarity in the general appearance of the patterns. Immediately along the axis of the radiators, one observes quite large amplitude fluctuations which become more rapid as the radiating source is approached; similar fluctuations are observed in front of large-area microwave antennas.

Diffracted Waves

Figure 14 shows the diffraction of waves over a straight edge. The sound waves in the upper half of the pattern are seen to progress with flat phase fronts, but in the shadow region of the $\frac{3}{4}''$ wooden board circular wave fronts are evident, indicating that the edge is acting as a new Huyghens source. Figure 15 is a similar pattern showing diffraction around a wooden disk.

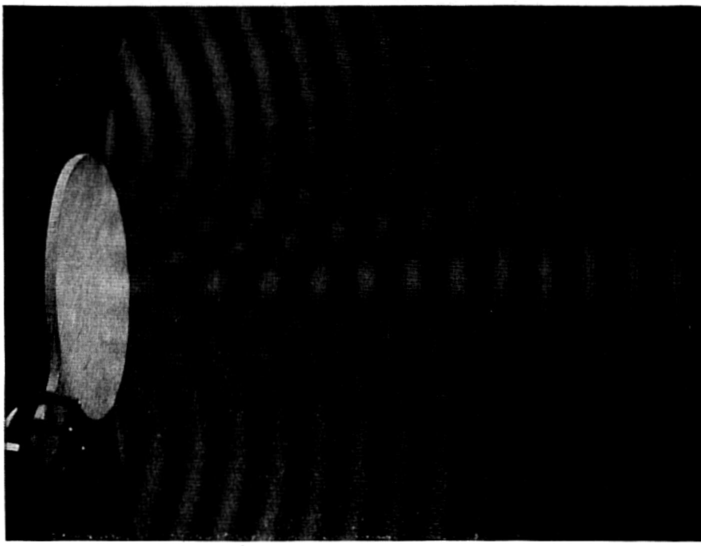

Fig. 15—The circular wave fronts in the shadow of a 10″ diameter "opaque" disk combine to produce a lobe structure.

The circular wave fronts emanating from the top and bottom edges are evident. Similar wave fronts are re-radiated from all around the circular edge of the disk and these combine to produce a concentration of energy along the axis corresponding to the "bright spot" of optics in the shadow of an opaque disk. Figure 16 is a repeat of 15 with the phase signal removed; this amplitude pattern shows the bright spot more clearly.

Another diffraction effect of optics, the pattern produced by two small slits, can be duplicated by two non-directional sound sources separated several wavelengths and having equal amplitudes and phase. This produces the multi-lobed pattern of Fig. 17. Destructive intereference occurs in those directions for which the two sources are out of phase, and constructive inter-

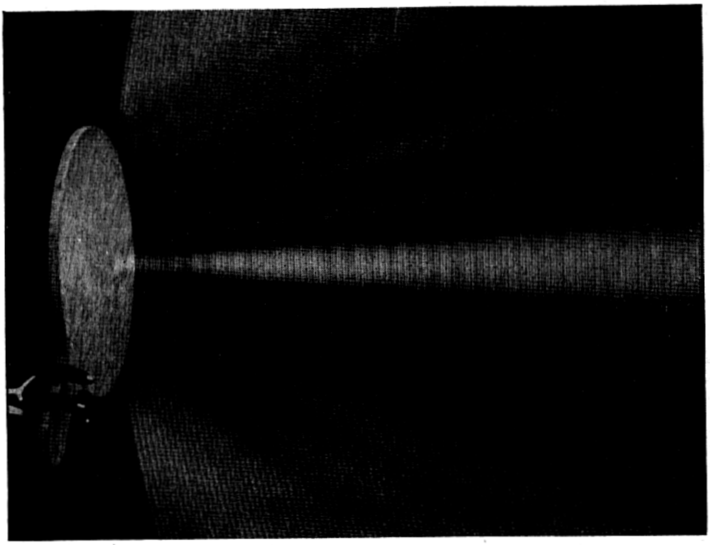

Fig. 16—Removal of the phase signal of Fig. 15 shows more clearly the major lobe of radiation in the shadow of a disc, the "bright spot" of optics. $f = 9$ KC.

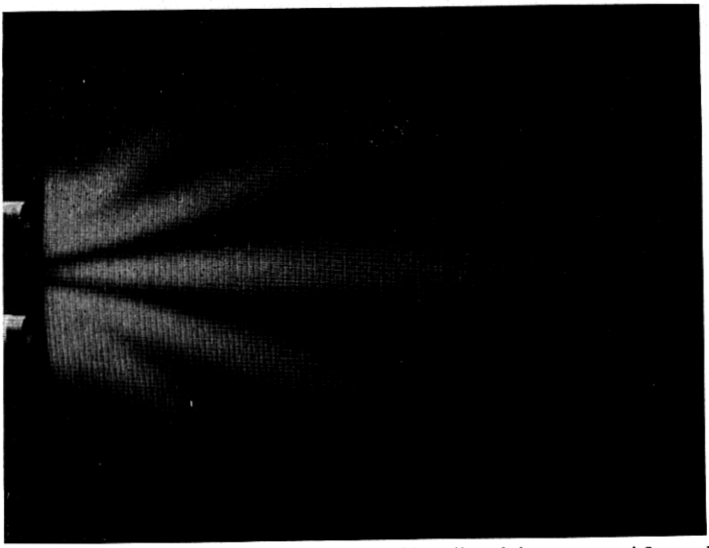

Fig. 17—Radiation pattern of two equal sources of low directivity separated 3 wavelengths center to center. $f = 9$ KC.

ference in whose directions for which the sources are in phase (such as straight ahead). The interference minima become filled in near the radiators because the amplitudes of the two signals are unequal when their distances to the point of interference are unequal. Perfect cancellation can then not occur. It is interesting to compare this photograph with the contour curves for this case as calculated from diffraction theory[7] and shown in Fig. 18. Al-

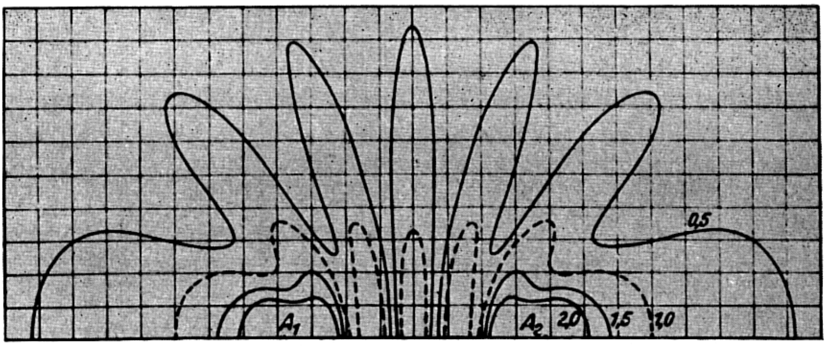

Fig. 18—Calculated radiation pattern for two non-directional sources separated 3 wavelengths. (After Stenzel.)

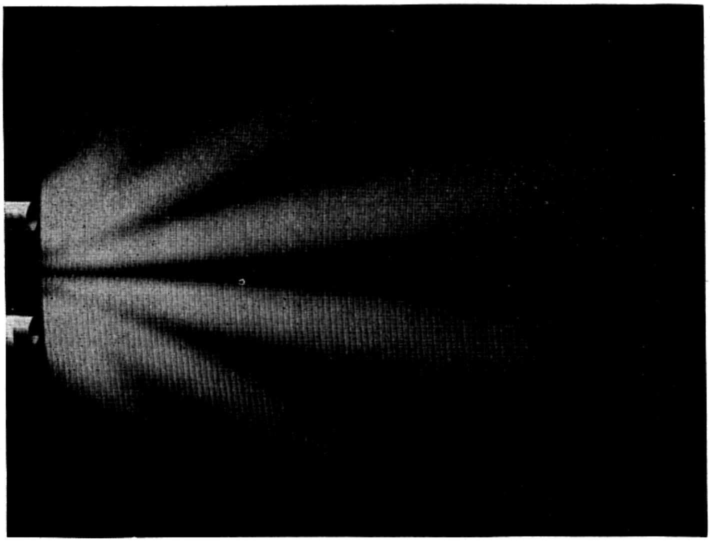

Fig. 19—The pattern of Fig. 17 except that the sound sources have opposite phase.

though the contour plot gives more quantitative information, the photograph allows one to grasp the qualitative effects more quickly. Figure 19 is similar

[7] Heinrich Stenzel, "Leitfaden zur Berechnung von Schallvorgängen," (Julius Springer, Berlin, 1939), p. 59.

to Fig. 17 except that the connections to one of the sound sources were reversed. With the two sources out of phase, cancellation now occurs straight ahead.

The diffraction pattern of one wide slit would be similar to that of the 4 wavelength radiator of Fig. 4.

To show the diffraction rings produced at the focal point of a lens, the sound field of a strip lens was scanned in a plane perpendicular to that of the previous photos. Figure 20 shows such a scan made in a plane passing through the focal point and perpendicular to the lens axis. The usual optical formulae

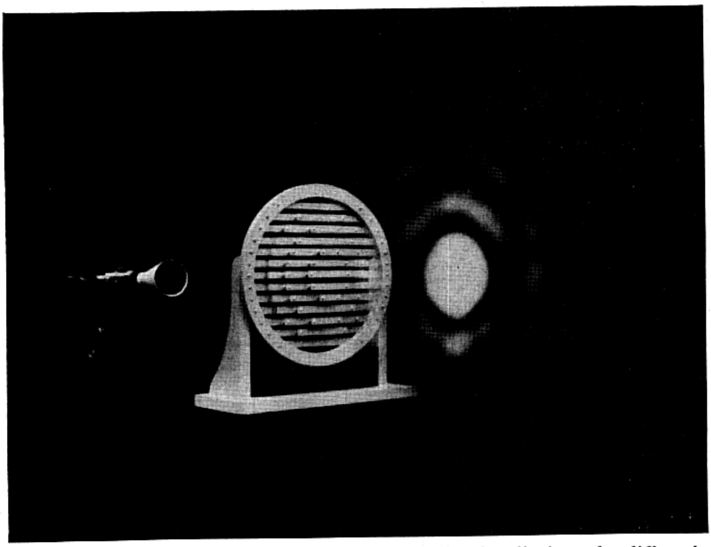

Fig. 20—By scanning a plane perpendicular to the axis of radiation, the diffraction rings around the focal spot of the lens of Fig. 3 are portrayed. $f = 9$ KC.

determine the size of the focal spot and the position of the surrounding diffraction rings. They are functions of the focal distance, the aperture, and the wavelength. In the previous lens patterns of Figs. 3 and 7, these diffraction rings show up as minor lobes. For a perfectly symmetrical lens construction, the rings would be more perfect, and the minor "lobes" would in reality be cones of energy surrounding the major lobe.

Diffusion of Sound

The previous lenses have been of the convergent type for focusing or beaming energy. In the next pair of pictures is shown the effect of a divergent lens diffusing energy. The phase pattern of a 6″ square aperture horn

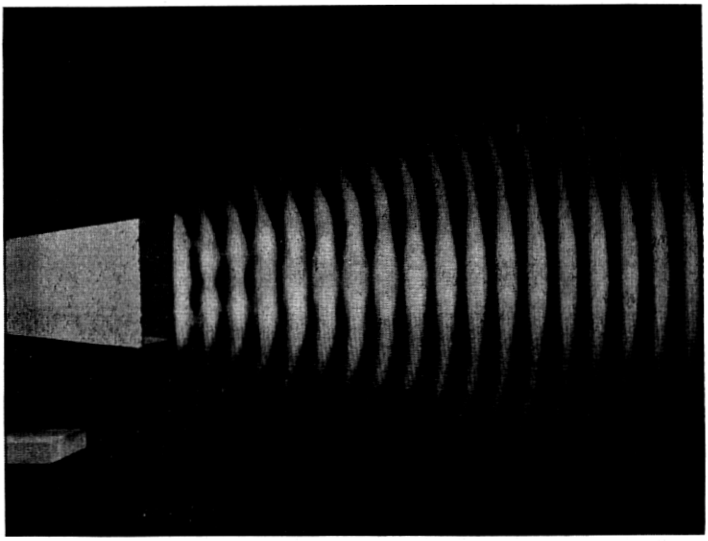

Fig. 21—The beam from the 6″ aperture horn loud speaker of Fig. 4 has fairly flat wave fronts and a narrow angular coverage. f = 9 KC.

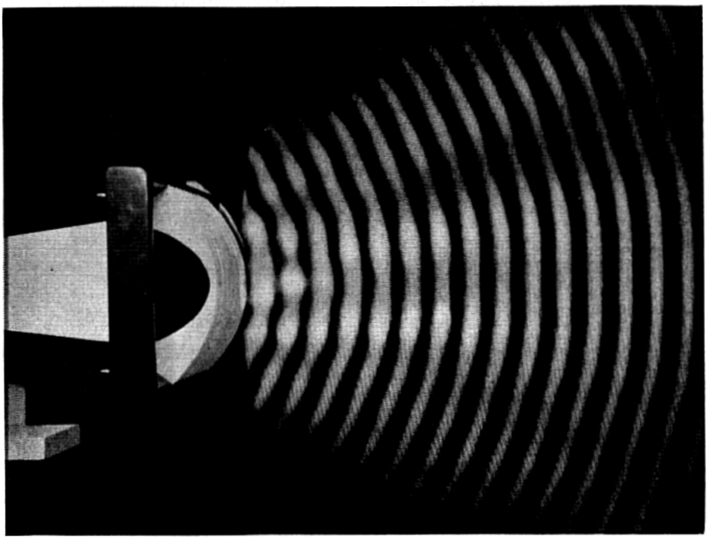

Fig. 22—A diverging acoustic lens in the aperture of the horn in Fig. 21 converts the straight line waves into circular waves with their greater angular coverage. f = 9 KC.

appears in Fig. 21. As in the pure amplitude pattern of this horn (Fig. 4), the directivity of this aperture is seen to be fairly high and the sound energy is collimated into a fairly sharp beam. High frequencies emanating from this horn would be projected through a rather small angular region and such a horn by itself would not be a very desirable general purpose loud speaker. Figure 22 shows the same horn with a slant plate divergent lens (described in reference 2) placed in front of its aperture. The transformation of the flat phase fronts into circular fronts and the wider angle of coverage can be readily seen. A frequency of 9 KC was used for these tests.

When a large cone type loud speaker is operated at the higher frequencies it too becomes quite directive. Figure 23 is a radiation pattern of a 12-inch

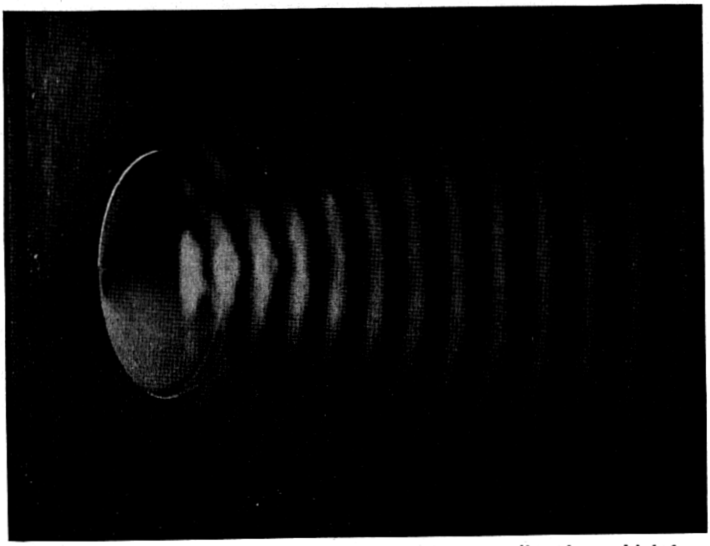

Fig. 23—A large aperture loud speaker (12 inch) also becomes directive at high frequencies as evidenced by the flat wave fronts in the beam. f = 8.5 KC.

loud speaker at 8.5 KC. The minor lobe formation is noticeable, indicating the presence of a central lobe surrounded by a region of low intensity.

Microwaves and Sound

The lenses employed in the preceding photographs were originally conceived and constructed for use at the very short radio wavelengths known as microwaves.[8] The strip lens is, in fact, a small scale model of the type used in the antenna systems of the New York-Chicago microwave relay circuits of the Bell System for telephone and network television. A similar type of dual-purpose delay lens using disks instead of strips is shown in the

[8] W. E. Kock, "Metallic Delay Lenses," *Bell Sys. Tech. Jour.*, *27*, 58 (1948).

next pair of pictures. In Fig. 24 the disks are arranged in an open construction so that sound waves as well as microwaves will pass through. An acoustic amplitude pattern is shown taken at a frequency of 12 KC ($\lambda = 1.13''$). In Fig. 25 the disks are copper foil and are supported on polystyrene foam which is transparent for radio waves but opaque for sound waves. The pattern now shows the intensity distribution of the microwave field being focused by the lens. The frequency was 9100 megacycles ($\lambda = 3.3$ cm. or $1.3''$).

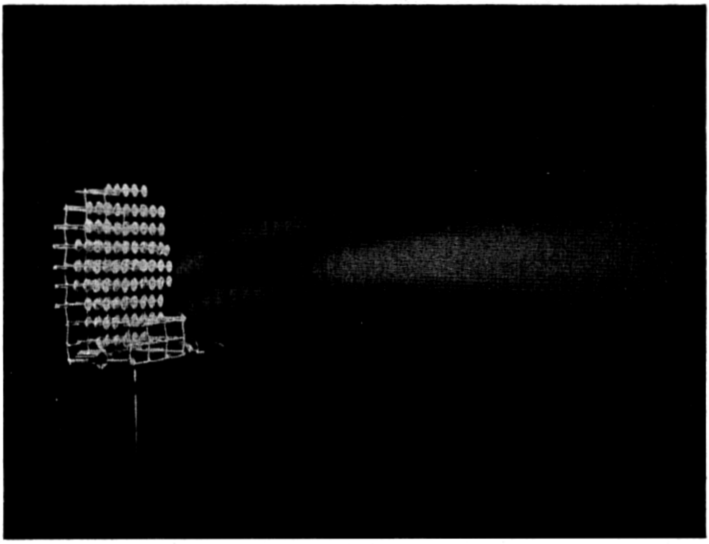

Fig. 24—A sound field pattern of a disk array lens originally designed for 3 cm. radio waves. $f = 12$ KC. ($\lambda = 1.13''$).

To obtain this microwave picture, the loud speaker was replaced by a microwave radiator and the pickup microphone replaced by a tiny dipole and crystal detector. The microwaves are modulated with 120∽ pulses so that the same audio frequency amplifiers are used as before with sound waves. However, with this low frequency supplied to it, the neon lamp trace appears as a series of dots.

In the next pair of pictures is shown a phase advance lens which likewise is effective only for microwaves. It uses parallel conducting plates in a waveguide construction.[4] Because the phase velocity is increased in passing through this medium, a concave lens is required for focusing (see Fig. 26). When the waveguide source (off to the left of Fig. 26) is brought in nearer so as to be at the focal point of the lens, the wavefronts straighten out and

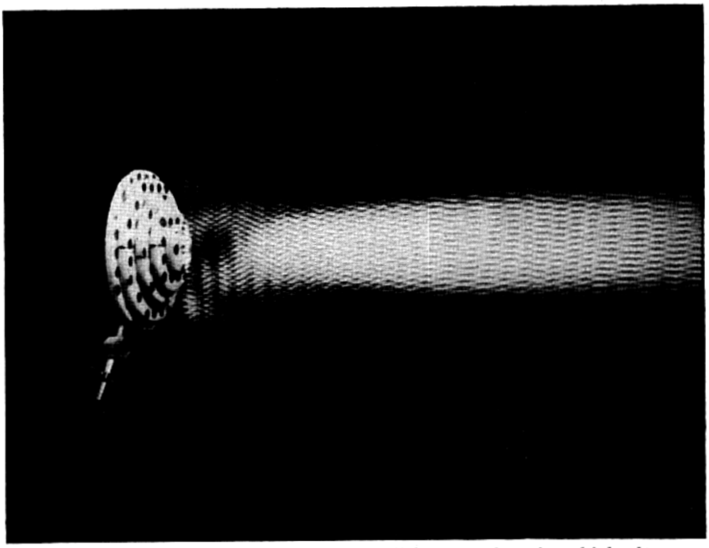

Fig. 25—An electromagnetic field pattern of a disk array lens in which the copper foil disks are mounted on polystyrene foam sheets. f = 9,100,000 KC (λ = 1.3″).

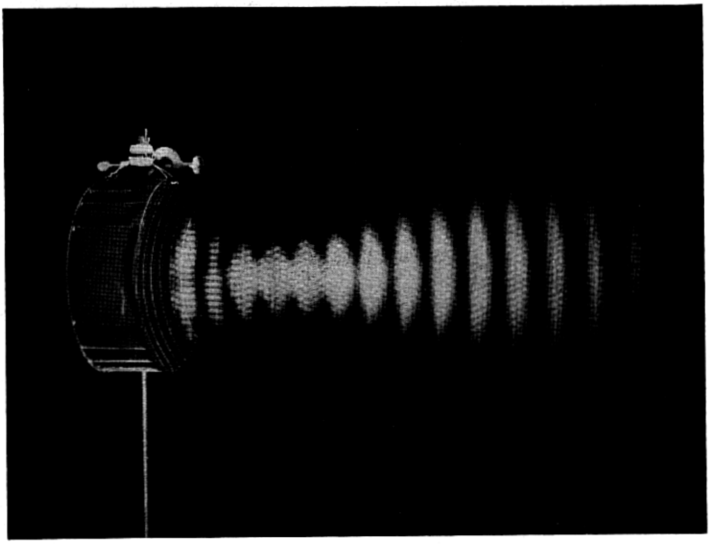

Fig. 26—A microwave field pattern of a waveguide type metal lens. Phase has been added, showing the curved wave fronts approaching and leaving the focal point. f = 9.1 KMC.

the energy is collimated into a beam (Fig. 27). The reference signal for these phase patterns was obtained by the method illustrated in Fig. 28. A secondary microwave source was employed which was fed from the main source

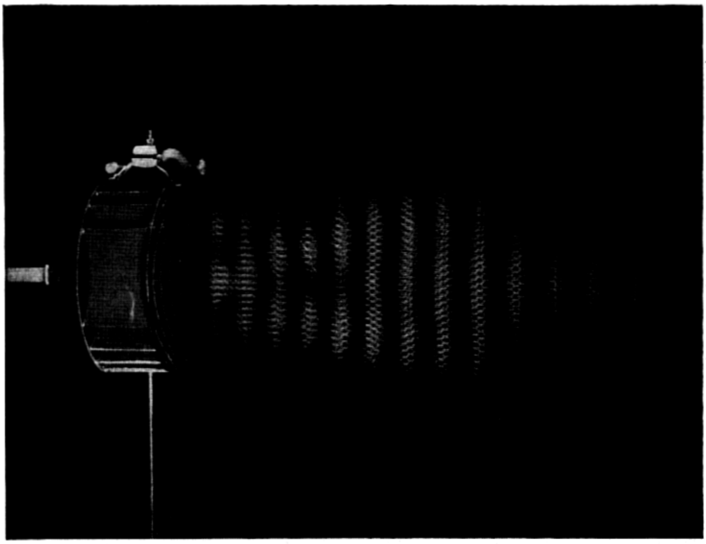

Fig. 27—When the waveguide feed of the lens of Fig. 26 is brought closer to the lens, a beam of flat wavefronts is produced. f = 9.1 KMC.

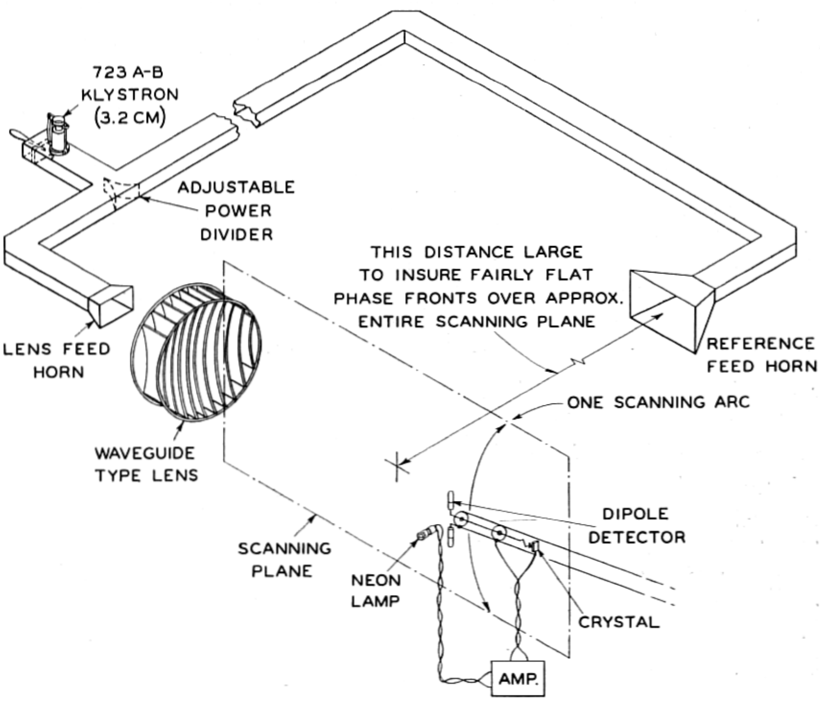

Fig. 28—The method of adding a constant-phase constant-amplitude microwave signal to the lens signals of Figs. 26 and 27 so as to portray the wave fronts.

and located on a line perpendicular to the scanning area and passing through its center. It was sufficiently far away to ensure that its wave front was approximately plane, i.e., of uniform phase and amplitude, over the scanned area. The scanning microwave probe thus picked up a nearly constant phase, constant amplitude signal from this secondary source in all positions of scan, and in addition sampled the variable intensity, variable phase microwave field coming from the lens.

Microphone Patterns Using Transposition Techniques

In the analysis of directional properties of acoustic or microwave radiators such as lenses, reciprocity can be employed, which is the property that equivalent directional characteristics will be exhibited whether the transducer is used as a transmitter or receiver. Some electro-acoustic transducers are not reversible, however, and the directive properties of a carbon microphone, for example, cannot be easily ascertained unless some means is employed which measures its characteristics while it is receiving acoustic energy, i.e., in the microphone condition. In all of the preceding photographs the scanning device probed an actual sound field. In the analysis of a microphone, however, we are interested in its ability to pick up sound coming from various directions in space. We can therefore replace the sound source in the preceding photographs with the microphone under test, and replace the probe microphone with a scanning sound source. As the source scans the space in front of the microphone, the signal in the microphone will vary depending upon the ability of the microphone to receive sounds from a particular spot in the scanned area. If this microphone signal is used to control the brilliance of the lamp (still affixed to the scanner), the resulting photo will indicate the directional characteristics of the microphone by itself or in combination with a directional device such as a lens. As in the preceding photos, phase can be added by combining a constant amplitude signal with the microphone signal. The end result of all this is simply to interchange the connections of source and sink.

Figure 29 shows a microphone pick-up pattern in which the strip lens has been placed in front of the microphone (not shown in the photo). Although this picture is now a representation of the microphone response for sound emanating from various points in the scanned space, it is seen to be nearly identical with the pattern of Fig. 7 which is an analysis of an actual sound field. This fact is simply a consequence of the principle of reciprocity. An interpretation which applies equally well to either of these two phase pictures is that the lines in each pattern are contours of equal phase length between the fixed and scanning transducers.

With this transposition technique, however, we are now able to examine

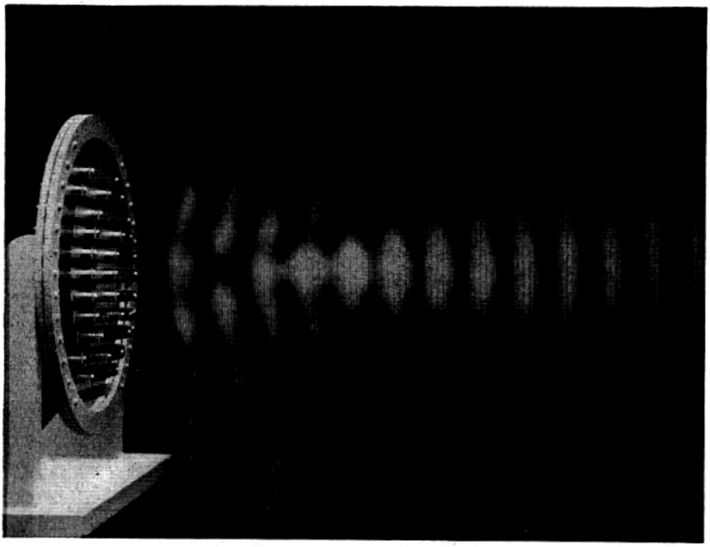

Fig. 29—A pattern taken with the microphone and loud speaker transposed. The sound source now scans and the pickup microphone is fixed (behind the lens). The phase signal is still employed indicating contours of equal phase "length" between the fixed and scanning transducers. The similarity to Fig. 7 can be observed. $f = 9$ KC.

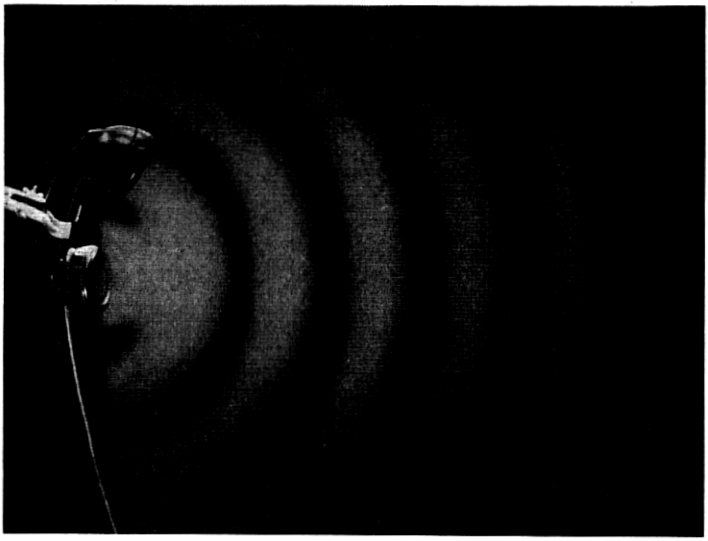

Fig. 30—A pattern of a carbon telephone transmitter obtained by the transposition method of Fig. 29. The phase fronts are those which would be observed if the microphone were radiating sound. $f = 4$ KC ($\lambda = 3.4''$).

the spatial response of a non-reversible transducer such as a carbon microphone. This is shown in Fig. 30 for an F-1 carbon telephone transmitter. It is also the directional characteristic the unit would have if it were capable of radiating.

The addition of phase to a microphone directional pattern may seem superfluous but a knowledge of phase can often be useful. For example, in highly directional microphone arrays, the wave fronts in the close-in field

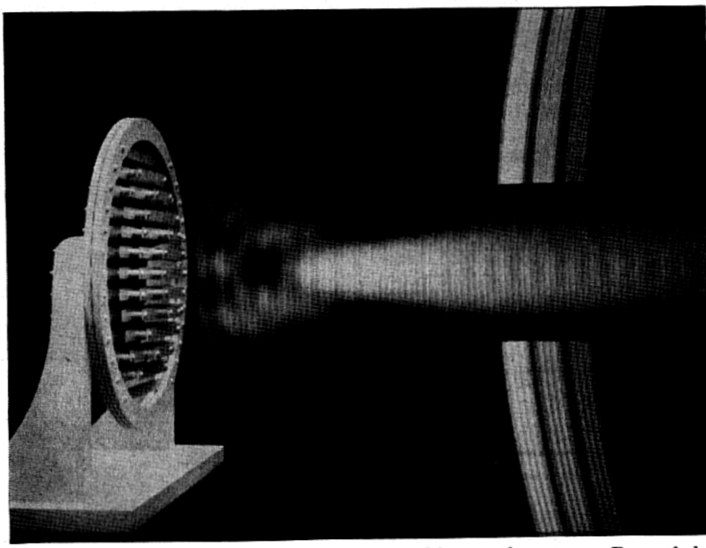

Fig. 31—A procedure for calibrating the photographic sound patterns. Part of the photo is scanned a second time with a constant signal on the lamp. Successive reductions of the signal (by 3 db steps in this case) produce the calibration arcs. (A mask between the camera and the scanner prevents the calibration arcs from registering in the pattern area.)

give information on the directional properties in the distant (far-field) region.

Additional Details

This concluding section will describe in more detail the scanning mechanism, the photographic procedure and methods for calibrating the photograph to provide a measure of the relative field intensities.

The scanning arm rocks up and down over an angle of about 60°, making one stroke every two seconds. The vertical travel of the lamp in the course of a stroke is adjustable up to 40″ while the horizontal travel is fixed at $\frac{1}{10}$ of an inch per stroke to provide a fine grain picture. The average picture is built up with about 300 lines or strokes corresponding to a 10-minute scanning time. However, pictures up to twice this length are occasionally taken.

To make a picture (see Fig. 1) the loud speaker is turned on to provide a steady sound field. A filter in the microphone amplifier is tuned to the signal frequency to reduce the interference from external noises. Absorbing blankets are sometimes desirable on nearly reflecting surfaces. The scanner is first moved manually to sample the sound level at various points so as to determine the proper gain settings and then placed in a starting position close to the acoustic lens whose pattern is to be taken. The room is darkened, the camera shutter opened, and the scanner started. Because the scanning process is relatively slow, the observer sees only the individual strokes of the flickering lamp. However, all the strokes are recorded on the camera film and form the desired pattern. When the scanning is completed, the shutter is closed and the room lights turned on. The film is then re-exposed for a few seconds to add the image of the acoustic lens. A dark background is provided so that the sound pattern will not be obliterated.

The miniature glow lamps used for these pictures have been neon and argon types having no base resistances, e.g., the NE17, NE51, or AR4 and AR7. Neon seems to produce smoother gradations in intensity but argon is sometimes desirable because the film is blue sensitive. The lamps operate only over a voltage range from 70 to 120 volts, so that compression must be used in the amplifier circuit if the pattern is to show the maximum amplitude variations encountered which are of the order of 10 to 30 db. Many of the patterns were taken by just connecting the lamp to a high impedance circuit in the output of a power amplifier, the compression being obtained by the decreasing resistance characteristic of the lamp with applied voltage.

In this as in any photographic process, the operator can control the effects pictured, intensifying or subduing images as desired by adjusting the film exposure and the circuit compression. When directivity is to be displayed and the major lobe is of main interest, the minor lobes may not even be exposed; when the phase fronts are desired in weak regions, the maximum range of the film and largest circuit compression may be used.

When quantitative information is desired, the relative intensity of the sound field in the amplitude patterns can be ascertained by a calibration test performed before or after each run. This is illustrated in Fig. 31. A signal equal to the maximum signal the lamp receives during the scanning run is fed at constant level to the lamp while it is scanning the unused part of the photograph at the right. Successive reductions of the signal by a known amount of attenuation (3 db steps in this case) give a series of arcs of decreasing brightness. These can be compared to the various scanned portions of the photograph to get a measure of the amplitude.