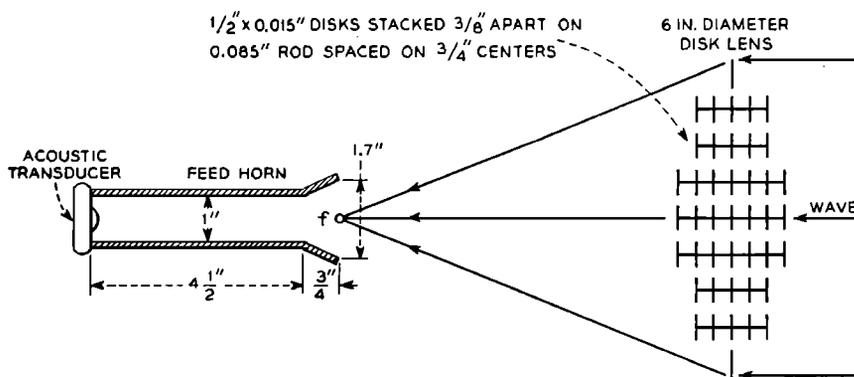


FIG. 7. Construction of the disk lens and its feed horn.



path than the unguided wave would normally take.*** This method of obtaining wave delay has likewise been employed for focusing electromagnetic waves.⁷

The principles of operation of the path length lenses can be described in connection with the right-hand section of Fig. 2. If parallel plates are presented to plane acoustic waves, little effect will be produced on the progress of the waves, providing that the plates are flat and aligned along the direction of propagation, as shown in the top of the figure. If, however, the plates are bent into serpentine shape, as shown in the middle figure, the sinuous path l , inside the plates, will be longer than that outside, l_0 , and delay will be produced. Likewise, if the plates are tilted so that they form an angle with the direction of propagation, as shown in the bottom figure, a delay will be produced since the waves will be forced to traverse the longer inclined path.

Evaluation of the Index of Refraction

If planes are drawn perpendicular to the direction of the approaching unguided wave at the entrance and exit points of the conduit, then the distance between these entrance and exit planes is equal to the path length l_0 , the unguided wave would normally travel (see Fig. 2). If l is the path length in the conduit, then the index of refraction is

$$n = v_0/v = l/l_0, \tag{7}$$

where v_0 is the velocity of the unguided wave in air and v is the velocity across the conduit structure bounded by the entrance-exit planes.

If the conduit is formed by slanted parallel plates, then,

$$n = l/l_0 = 1/\cos\theta \tag{8}$$

where θ is the angle between the slanted plates and the direction of the oncoming wave.

In such path length devices, n remains constant with frequency up to the point where the plate spacing becomes a half wave-length. A second mode can then be propagated which interferes with the normal action.

*** An acoustic radiator using tubes of varying lengths to obtain the proper phase correction for focusing has been suggested by W. P. Mason, U. S. patent 2,225,312, 1940.

⁷ W. E. Kock, Proc. Inst. Radio Eng. 37, 852 (1949).

GENERAL CONSIDERATIONS

Determination of the Lens Profile

Two general classes of construction have now been discussed which act to reduce the velocity of sound waves. Devices using either of these constructions are delay mechanisms and act like the refractors of optics. An example of a design procedure for a convergent lens follows.

The profile of a lens (plano-convex) of the obstacle type can be determined from the desired aperture radius y , the focal length f and the known index of refraction n (see Fig. 3). For the phase length of parallel rays leaving the lens to be equal after starting from a common focal point, the following must hold:

$$f/v_0 + x/v = [(f+x)^2 + y^2]^{1/2}/v_0, \tag{9}$$

where v_0 is the velocity of sound in free air and v the velocity through the lens.

Since $v_0/v = n$, (9) becomes

$$f + nx = [(f+x)^2 + y^2]^{1/2}, \tag{10}$$

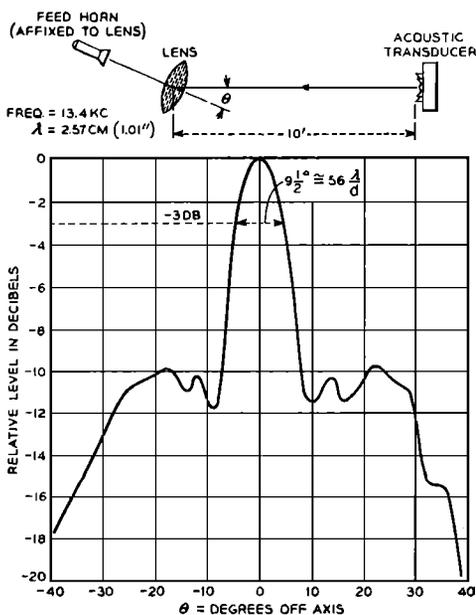


FIG. 8. Directional pattern of the disk lens and horn combination.

and this can be reduced to

$$(n^2 - 1)x^2 + 2fx(n - 1) - y^2 = 0. \quad (11)$$

It can be readily verified that (11) is the equation of a hyperbola. This equation need not be followed exactly; lenses having spherical surfaces approximating the hyperbolic shape will also exhibit appreciable focusing effect.

These formulas can be used on other lens shapes also. For example, a plano-concave lens can be calculated on the basis that f equals the *virtual* focus and x the depth of the concave surface, assuming of course, that parallel rays strike the plane surface. Double convex, double concave, and other lenses can thus be designed in sections.

Although the path length lens can generally be calculated from the formulas of the obstacle lens it is not always safe to do so because of the sidewise displacement of the wave which may accompany transmission through the lens. In the design of a slant plate lens (Fig. 4) the lens contour is adjusted to make the path lengths equal for rays which start at a common focal point and emerge simultaneously from the plane surface of the lens. This provides a plane wave front. In the example shown, the lens turns out to be symmetrical and the lens formulas can be used. If however, the lens should be reversed so that the rays starting from the focal point strike the flat surface, then the contour of the curved surface would have to be readjusted to an asymmetrical shape for a plane wave to emerge from it.

The upper frequency limits for the two types of delay mechanisms have already been suggested in the sections dealing with the index of refraction. The effectiveness of

lenses of either type at low frequencies is a function of the size of the array. Since, as discussed below, a lens can only focus energy to a minimum diameter of the order of $\frac{1}{2}$ -wave-length it is obvious that when the lens diameter is smaller than $\frac{1}{2}$ -wave-length, little focusing action will be exhibited.

The Diameter of the Focal Spot of a Lens

In dealing with acoustic lenses where the wavelengths used may be measured in feet and inches, it may be more pertinent to talk about a focal area of a

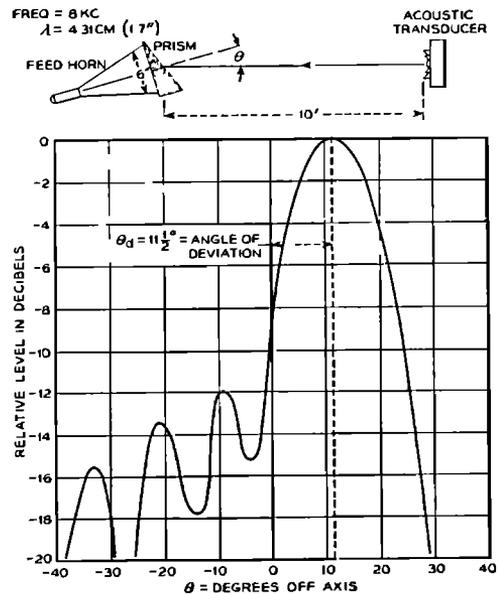


FIG. 10. Angular shift of the directional pattern of a 6-in. aperture horn caused by the prism of Fig. 9.

lens rather than the focal point. In any device which causes plane waves to be brought to a focus, diffraction sets a limit on the focal area.

The effect of diffraction can be obtained as in optics.⁸ A properly designed lens will produce a diffraction pattern which consists of alternate concentric rings of minima and maxima surrounding a circular area of maximum energy. The diameter of this focal area as determined by the first minimum is approximately

$$d_1 = (2.4F\lambda)/d, \quad (12)$$

where F is the distance from the lens aperture to the focal area and d the aperture diameter. For a lens with an f 1.0 rating, the diameter of the focal area is 2.4λ with a plane wave incident.

The central circular area receives approximately 80 percent of the lens energy. The maximum intensity at the first ring is 0.0174 (-17.6 db) of that at the center point. From this a directional pattern using a point source receiver at the focus would show the first minor lobe to be 17.6 db down.

⁸ Hardy and Perrin, *The Principle of Optics* (McGraw-Hill Book Company, Inc., New York, 1932), p. 128.

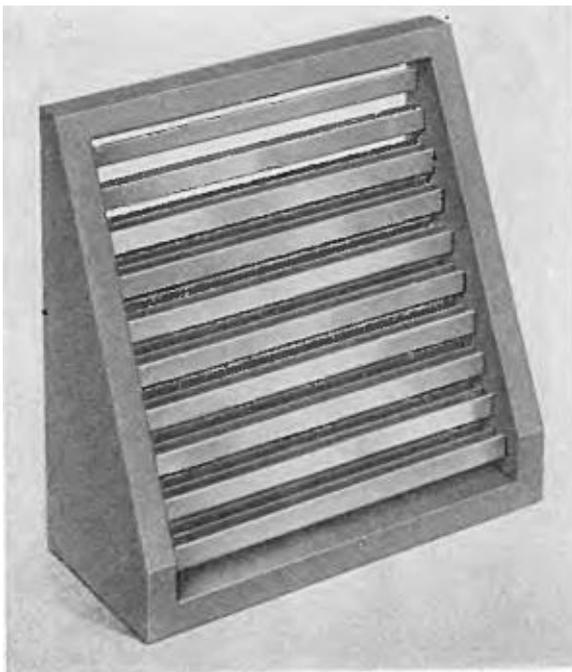


FIG. 9. A strip prism.