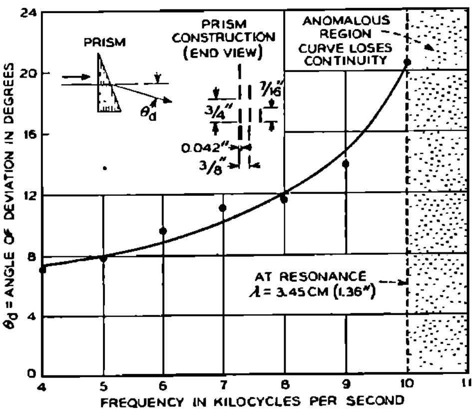
An inspection of Eq. (12) shows that even for small f ratings a lens diameter of $\lambda/2$ would yield a focal area comparable to the lens itself. Hence for low frequency sound waves, appreciable focusing action can only be produced with very large lenses.

Reciprocity

According to the law of reciprocity, equivalent directional characteristics will be exhibited whether the lens under test is used as an acoustic radiator or receiver. Consequently, in the measuring techniques to be described, the combination under test is sometimes considered as transmitting and at other times receiving.



11. Dispersion produced by the strip prism of Fig. 9.

Gain Definition

The gain of an acoustic radiator will be defined[9] as the ratio if its maximum radiation intensity (power flow per unit area) to the maximum radiation intensity of a source which radiates uniformly in all directions, i.e., an isotropic radiator. When the gain is compared to that of this isotropic source, it is defined as the absolute gain of the radiator.

A radiator of given aperture area exhibits maximum gain when the energy distribution and phase are uniform across its aperture; the gain of such a "uniphase, uniamplitude" radiator is then

$$G=4\pi A/\lambda^2, \qquad (13)$$

where A is the aperture area. This equation is queit accurate for apertures exceeding one or two wavelengths.

EXPERIMENTAL

The Disk Array as a Convergent Lens

One of the first microwave devices to be investigated acoustically was an array of $\frac{1}{2}$-in. disks in the shape of a 6-in. diameter convergent lens (see Fig. 5). The tests were conducted in the free space room of the Bell Telephone Laboratories at Murray Hill, New Jersey. A high frequency radiator was set up in one corner of the room and the lens placed on a stand 10 ft away (see Fig. 6). A microphone was fitted to a small horn to act as a directional pick-up and the combination fastened to an adjustable support for exploring the sound field (see Fig. 7).

A focusing run taken at 13.4 kc showed the focal length at this frequency to be about 13 in., from which the index of refraction would appear to be 1.14. From the formula involving the elementary obstacle dimensions, but without the addition of a resonance correction, $n=1.10$. This is a fair check.

As in the optical case, the lens can be tilted about a diametral axis without much adverse effect on the transmission. Here a tilt of $\pm 40°$ produces only a 3 db change in response at the focal point.

Directional patterns were taken on the lens and horn together by fixing the latter to the lens and then rotating the combination about an axis through the vertical lens diameter. A pattern at 13.4 kc ($\lambda=2.57$ cm) shows the beam width at the 3 db points to be about $9\frac{1}{2}°$ with the minor lobes 10 db down (see Fig. 8). This is roughly equivalent at this wave-length to the theoretical beam width of a uniformly excited aperture 6 inches in diameter, and is another indication that the receiving horn (feed horn) is not sufficiently directive. The large minor lobe "masses" also are evidence of appreciable spill-over which is present due to too small an aperture feed horn.†

FIG. 12. A double convex strip lens 10 in. in diameter. The strip size and spacing is the same as that used in the prism of Fig. 9.

[9] H. Levine and J. Schwinger, Phys. Rev. 73, 383 (1948).

† In most tests of these lenses no serious attempt was made to use a horn at the focus having optimum size and directivity to achieve maximum gain from the particular lens under test. As will be seen below, in the case of the slant plate lens, attention to this detail ensures high gain (comparable to other types of radiators such as parabolic reflectors) and desirable directional characteristics.

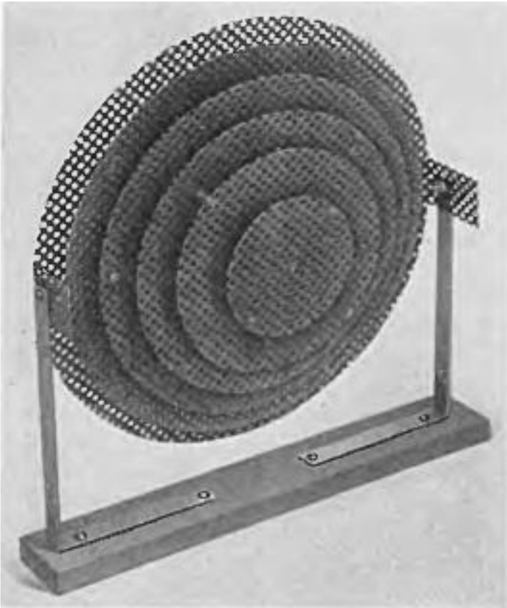


FIG. 13. A plano-convex perforated metal lens 10 in. in diameter. The perforated sheets simulate a crossed strip construction.

The Strip Array as a Prism

An array of $\frac{7}{16}$-in. wide strips made up in prism form has been found very effective in demonstrating the refraction of sound (see Fig. 9). A series of experiments were conducted with the prism placed over the mouth of a 30-in. long pyramidal horn having a 6-in. square aperture and a microphone coupled to its throat. The directional pattern (see Fig. 10) was measured acoustically at various frequencies and the angular position of maximum response plotted as a function of frequency (see Fig. 11). As in the action of dispersion in optics, it is seen that the angle of deviation (and therefore n) varies slowly at low frequencies but increases rapidly as the frequency of resonance is approached. At 10 kc resonance occurs, the strip width corresponding to approximately a half wave-length. Up to the region of resonance, the maximum transmission through the prism, measured at the optimum angle, is fairly constant. Near resonance, the index of refraction rises and reflection loss increases.

It should be noted that this prism produces a true dispersion of airborne acoustic waves and is not to be confused with diffraction devices such as gratings. Diffraction gratings and receivers depending upon path length differences of an integral number of half wave-lengths to differentiate frequencies have been used heretofore but such devices are wasteful of energy in that many spectral "orders" are produced. However, just as acoustic gratings can be used to analyze the

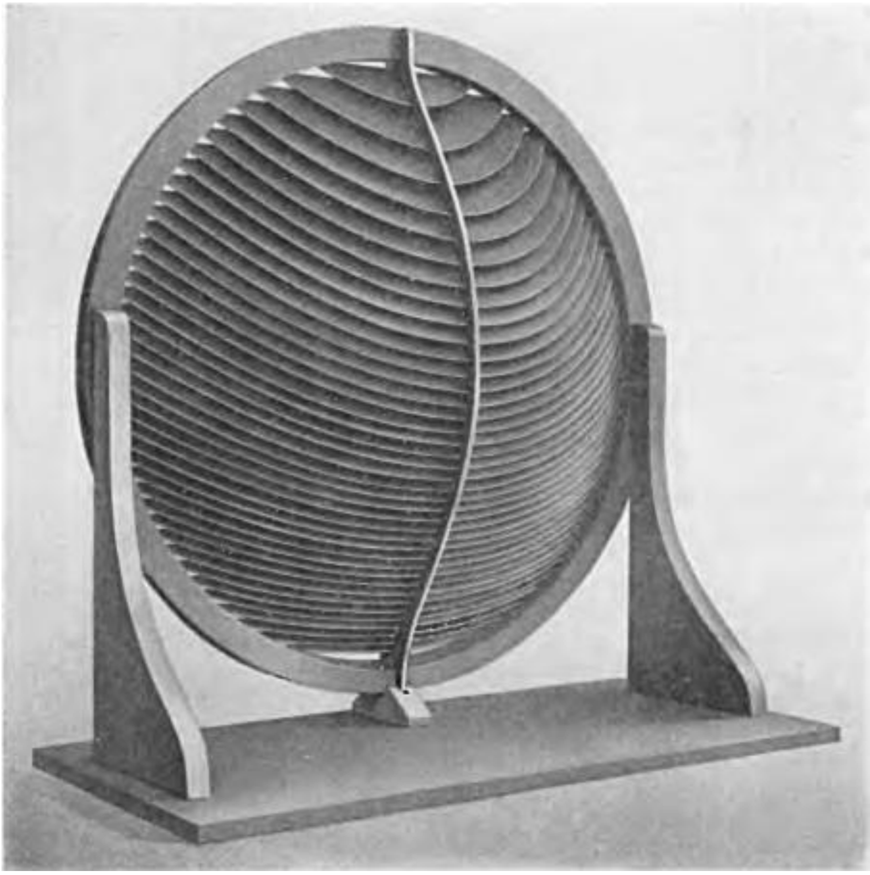


FIG. 14. A plano-convex slant plate lens 30 in. in diameter. The 48.3° tilt of the plates yields a refractive index of 1.5.