Theater Loudspeaker System Incorporating an Acoustic-Lens Radiator

By JOHN G. FRAYNE and B. N. LOCANTHI

This paper describes a two-way loudspeaker system having an extended frequency range and exceptionally uniform distribution. These characteristics, which effectively meet the requirements for the presentation of stereophonic sound in motion-picture theaters, are obtained by the use of an acoustic lens. Spherical and elliptical lens elements accommodate the distribution pattern to variously shaped auditoria. Design features of the low-frequency horn provide a clean response which is essentially free from resonance.

THEATER loudspeaker systems have been steadily improved through the past years so that, for single-channel operation, the audience receives an impression that it is listening to a reasonable likeness of the original sound. This has been pointed out in a paper previously presented before the Society.[1] This steady improvement in performance has been achieved largely by technical advancements in the design of driver units and in the case of the low-frequency speaker by the replacement of folded horns with short, front-loaded horns.

The advent of stereophonic and pseudostereophonic presentation in the theater has introduced new requirements which call for a re-examination of loudspeaker performance.[2] In stereophonic presentation, exceptionally uniform distribution of high frequencies is particularly desirable in order to obtain a realistic auditory perspective. If loudspeakers have a high-frequency distribution characteristic which varies materially with frequency or if there are sizable level changes over the angle of distribution, the localization of the apparent source of sound will appear to be different from various points in an auditorium.

Since fidelity in stereophonic localization is almost entirely attributable to the upper register of the frequency spectrum, the major problem is the design of satisfactory high-frequency sound-dispersing mechanisms. In approaching this problem, it was arbitrarily decided that two types of units, one having 50° and the other 80° horizontal distribution, would be provided. Using two of either of these units provides 100° or 160°, respectively, of horizontal coverage. The vertical coverage in all cases was set at approximately 50°.

The high-frequency driver unit is of the permanent-magnet type and provides approximately 21,000 gauss at the voice coil. The diaphragm is approximately 4 in. in diameter and is of 0.003-in. thick aluminum. A typical power-output curve of the driver unit is shown in Fig. 1. This curve was made by measuring the sound pressure at the sending end of a tube which was filled with a long, tapered, sound-absorbent wedge and which was driven by the high-frequency unit. The sound-measuring device was a 640AA microphone. The results of this test are believed to be accurate to approximately 9 kc.

For uniform distribution over the required angles of auditorium coverage, the principle of the acoustic lens has been employed. This involves the use of a type of structure which refracts and diverges sound waves and is similar in function to certain electromagnetic-wave lenses in that it consists of arrays of obstacles which are small compared to the wavelengths involved. These obstacles create an effect which is equivalent to increasing the effective density of the air which results in a reduced propagation velocity of sound waves passing through the array. This reduced velocity is synonymous with refractive power, effecting a refractive index higher than unity. The theory of this type of lens is ably set forth in a paper by Winston E. Kock and F. K. Harvey of the Bell Telephone Laboratories.[3]

Several types of acoustic lenses have been described[3] and of these, two are used — a perforated-disk type having an index of refraction of about 1.2 which provides a horizontal-distribution angle of 50° and a slant-plate type having an index of refraction of about 1.5 which is easily capable of providing a horizontal-distribution angle of 80°. By using two of either type of lens, the horizontal coverage is increased to 100° or 160°, respectively. In all cases the vertical-distribution angle has been set at approximately 50°.

It may be well to discuss briefly the principle of operation of the two types of lenses currently being used. The first depends upon increasing the effective density of the sound-transmitting medium within the boundaries of the lens. Refraction occurs in media consisting of arrays of individual discrete particles, providing that the particles and distances between them are small compared to the wavelength of the wave propagation under consideration. In other words, if an array of small, rigid particles, having infinite mass for our acoustical consideration, is set up in space, the combination of rigid particles immersed in air results in a new medium having an index of refraction which is greater than unity. Since the velocity of propagation of sound is inversely proportional to the square root of the density of the medium, it will be less through an obstacle array than in free air. Depending on the profile or shape of the obstacle array, the sound waves can be focused or diverged as desired. This obstacle-array type of lens is limited for practical reasons to an index of refraction of about 1.2. A series of perforated metal plates, properly shaped and spaced, can provide similar lens effects and is suitable for loudspeaker applications where the required angle of distribution is not excessive.

Another method of slowing down a progressive wave is to guide it through a conduit or the equivalent, which provides a longer path than that which the unguided wave would normally take. Thus, if a series of parallel plates of varying length are tilted at an angle to the direction of propagation, a delay will

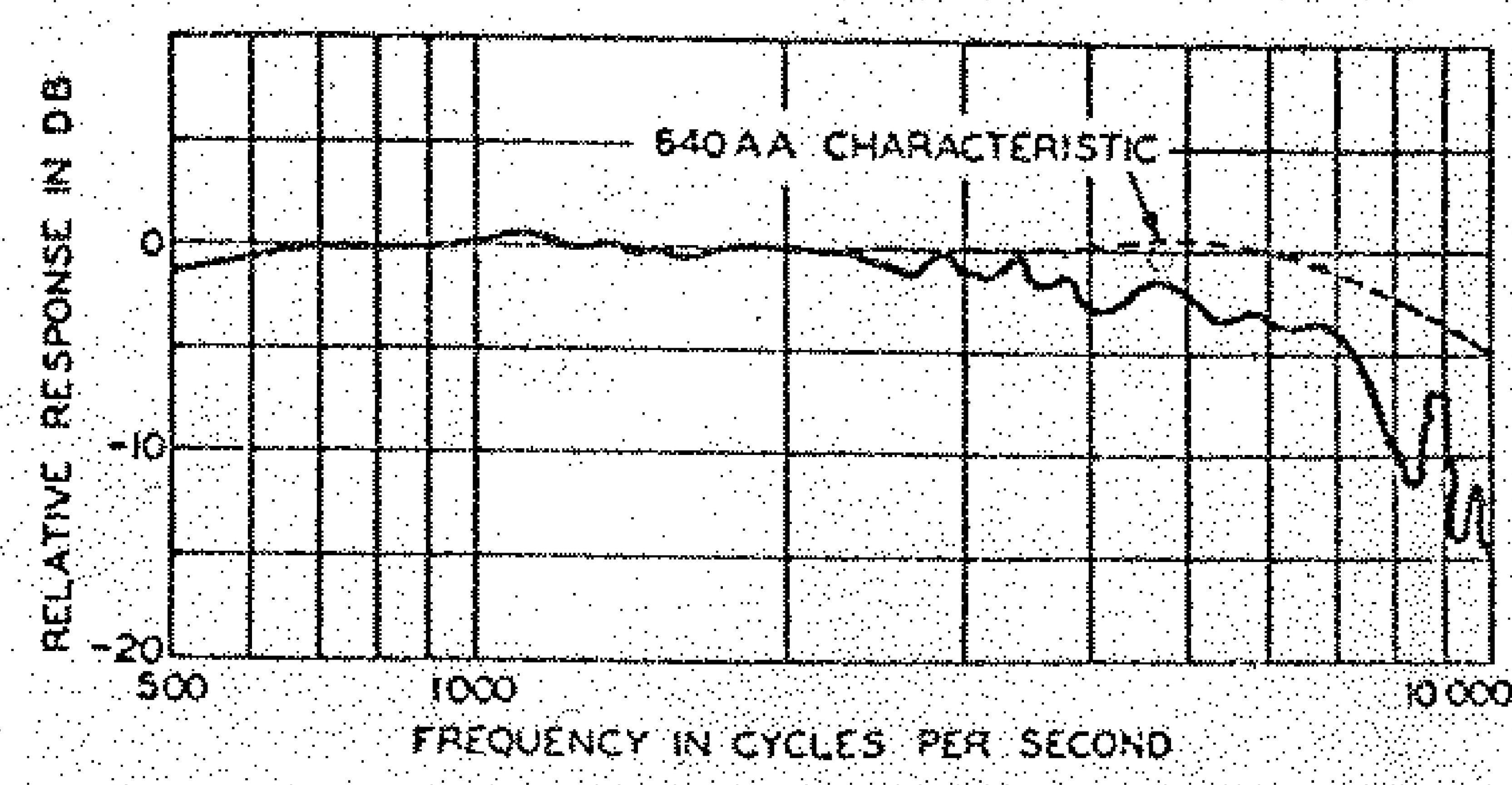

Fig. 1. Power-output curve for T530A loudspeaker.

Presented on May 5, 1954, at the Society's Convention at Washington, D.C., by John G. Frayne (who read the paper), Westrex Corp., 6601 Romaine St., Hollywood 38, and B. N. Locanthi, Consultant, 2552 Boulder Rd., Altadena, Calif. (This paper was received on June 4, 1954.)