

Jan. 14, 1958

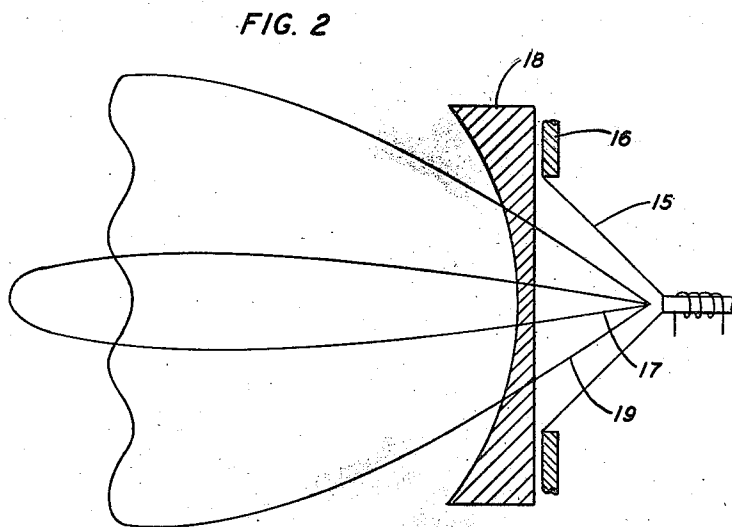
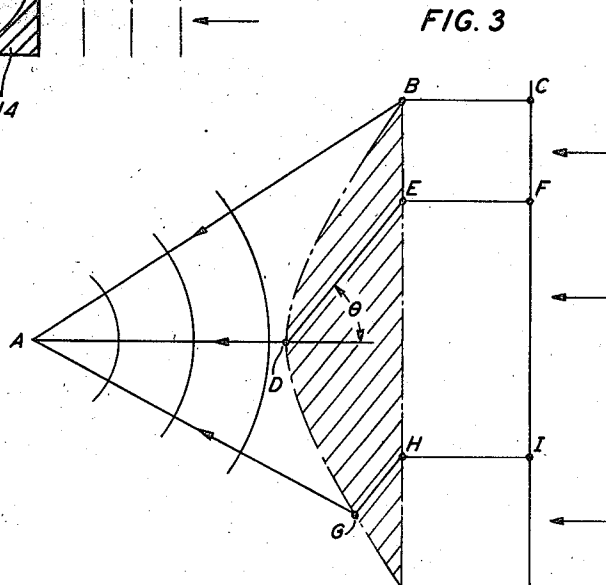
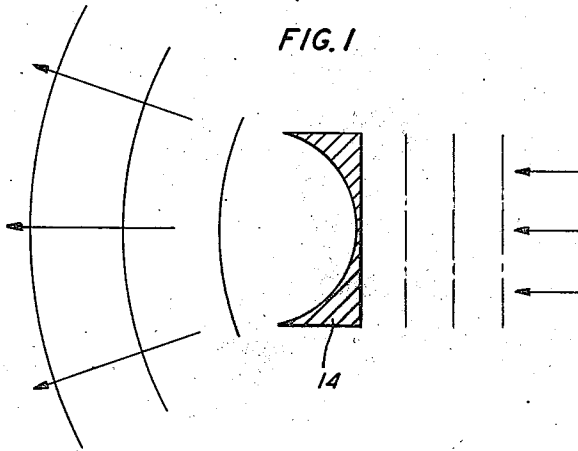
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2,819,771

ARTIFICIAL DELAY STRUCTURE FOR COMPRESSIONAL WAVES

Original Filed Oct. 1, 1948

3 Sheets-Sheet 1



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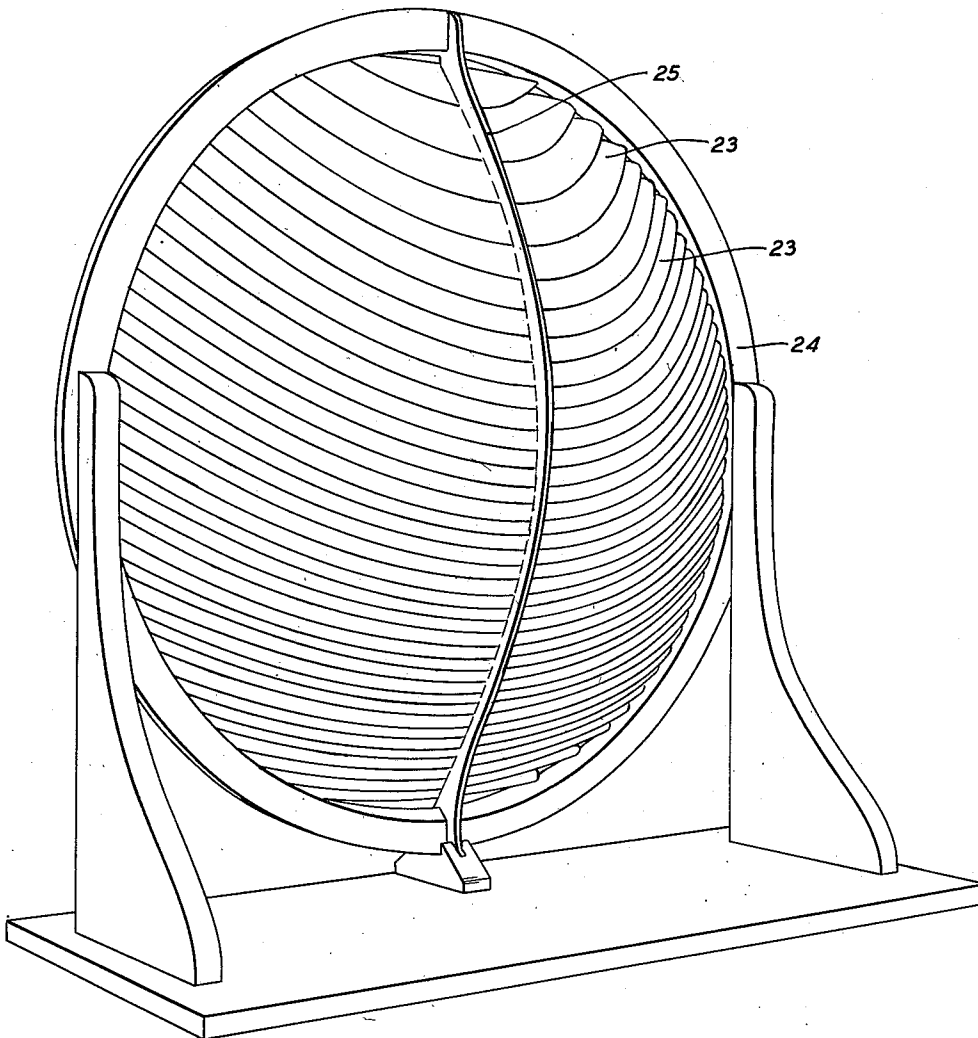
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FIG. 4



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FIG. 6

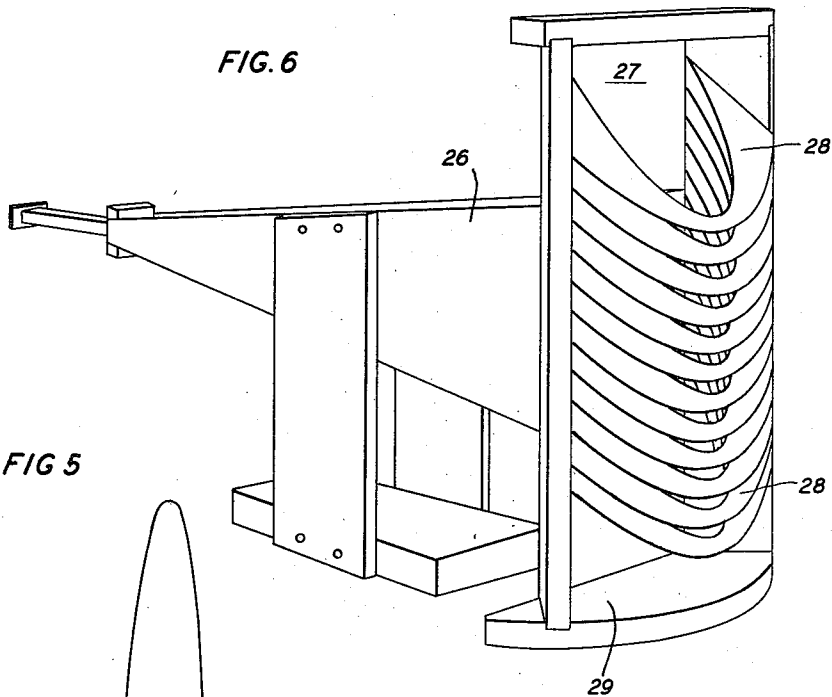


FIG. 5

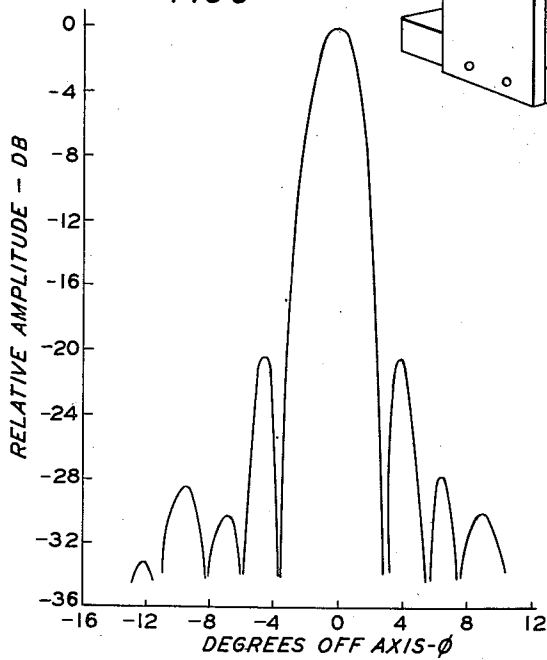
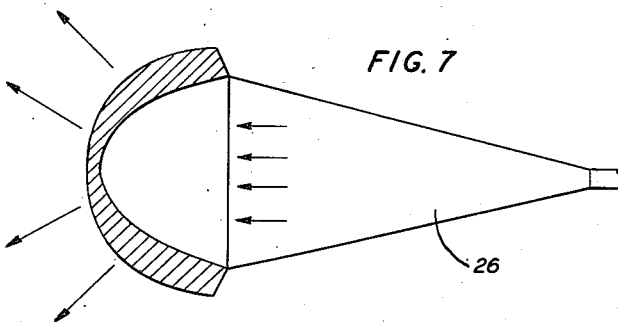


FIG. 7



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ARTIFICIAL DELAY STRUCTURE FOR COMPRESSIONAL WAVES

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Original application October 1, 1948, Serial No. 52,350, now Patent No. 2,684,724, dated July 27, 1954. Divided and this application June 1, 1954, Serial No. 433,660

4 Claims. (Cl. 181—5)

This invention relates to sound, acoustic, and other compressional wave refracting devices and particularly to those which comprise a plurality of rigid elements mounted in an array.

This application is a division of my copending application Serial No. 52,350, filed October 1, 1948, which matured into United States Patent 2,684,724 granted July 27, 1954, and in which are claimed sound refracting devices and an artificial delay structure made up of rigid elements having one or more, or in some cases all, of their dimensions small compared with the wavelength of the sound wave to be refracted and in certain cases spaced apart at intervals which are small compared with the wavelength.

The present application claims alternative forms of arrays, formed of rigid parallel plates (designated as "slant plates") set at an angle with respect to the direction of approach of sound waves, whereby the waves are forced to take inclined paths which are longer than the free space paths, thereby introducing phase delay. The arrays are made in the form of lenses, prisms, etc., by substantially filling with such spaced rigid elements a volume of space having the shape of an optical lens, prism, or other refracting device.

In the drawings:

Fig. 1 is a diagram showing the effect of a plano-concave sound refractor in converting a plane wave into a diverging wave;

Fig. 2 is a diagram showing the combination of the plano-concave lens of Fig. 1, and a loudspeaker, together with a typical sound pattern for the combined arrangement and a typical sound pattern for the loudspeaker alone;

Fig. 3 is a diagram showing a cross-sectional view of a slant-plate type of refractor to indicate equal path lengths whereby plane waves may be brought to a focus;

Fig. 4 is a perspective view of a convex refractor made up of inclined rigid plates mounted in a circular frame;

Fig. 5 is a directional radiation pattern of a refractor of the type shown in Fig. 4;

Fig. 6 is a perspective view of an acoustic horn with a cylindrical slant-plate type of sound refractor mounted at the opening of the horn for dispersing sound waves in a diverging pattern from the mouth of the horn; and

Fig. 7 is a plan view and diagrammatical representation of the horn and refractor of Fig. 6.

By "rigid" herein is meant that a body to which the term is applied is substantially invariable in shape, size, and position under the application of the forces exerted by the waves to be refracted.

Corresponding to optical terminology, an array of elements possesses an "index of refraction" different from that of the undisturbed medium.

Because waves passing through the array of elements are slowed down, they will be "refracted" as in the optical case. Thus, waves incident upon an array at an angle α_1 , relative to the perpendicular to the front surface of

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the array, will, because their velocity v_1 inside the array, is less than v_0 (their velocity outside), be bent towards the perpendicular. The bending is determined by the well-known optical relation called Snell's Law,

$$\frac{\sin \alpha_1}{\sin \alpha_2} = \frac{v_0}{v_1} = n$$

where α_1 and α_2 are the angle of "incidence" and the angle of "refraction" respectively (as they are called in Optics) and v_0 and v_1 are the velocities in the medium and in the array, respectively, and n is the index of refraction. When as here v_1 is less than v_0 , n is greater than unity and the ray is bent towards the normal. When v_1 is greater than v_0 , the ray is bent away from the normal.

Convex lenses of a medium which delays the waves cause a converging of rays when plane waves strike them. If the lens is made concave, however, the rays will diverge as shown in Fig. 1, where the cross-hatched area 14 represents the plano-concave contour of an acoustic lens. Plane waves arriving from the right diverge as they pass through the lens.

Use can be made of diverging lenses with loudspeakers to avoid the beaming of the high frequencies along the axis. The result is shown in Fig. 2. Here 15 is a loudspeaker cone operating as an acoustic piston in a baffle plate 16. Its directional pattern at high audio frequencies will be very sharp, that is, "beamed" along the axis as shown in the curve 17. This is because the cone, acting as a piston, produces approximately plane waves at the baffle opening and the rays are therefore traveling perpendicular to the baffle, i. e., along the axis. As shown in Fig. 1, however, a concave lens can cause the rays to diverge and the energy will spread out in a manner to be desired, for example as in curve 19.

The lens 14 or 18 may be considered as constituting an artificial medium for sound waves, the velocity of wave propagation through this medium being different from the velocity of wave propagation in a free space medium. The lens medium may be composed of spaced obstacles as disclosed and claimed in my copending application, supra. Another kind of artificial medium for sound waves disclosed in my said copending application and claimed herein may be constructed of rigid, spaced, parallel plates set at an angle with respect to the direction of propagation of sound waves incident upon the medium. Such a medium will be called a "slant-plate medium" and a lens composed of this medium will be called a "slant-plate lens." A slant-plate medium may be used to force sound waves to travel a longer path than they would in free space, and a slant-plate lens may equalize the time of arrival of sound waves at a focus just as effectively as if the rays had passed through a lower velocity medium. The effective index of refraction of the slant-plate medium is evidently $1/\cos \theta$, where θ is the angle of slant of the plates measured as shown in Fig. 3 from the axis normal to the plane of the refractor, this being also the direction of propagation of sound waves incident upon the medium.

Fig. 3 is a diagrammatical representation of a cross section through a plano-convex slant-plate lens, the section being the one passing through the central axis of the lens in a plane perpendicular to the slant plates. As shown in Fig. 3, the spacing between the plates defining individual paths is small as compared with the maximum width dimension of the larger of the plates (those near the center of the refractor at Fig. 3). The angle θ is indicated. A number of paths are shown as rays, the ray FEDA being equal in length to the ray CBA which in turn is equal to IHGA. A plane wave arriving from the right converges upon the point A, as shown by the equi-phase plane CFI which becomes circular and convergent

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after passage through the lens, the center of curvature being the focal point A.

Fig. 4 is a perspective view of a 30 inch diameter lens of this type which was actually built and tested, its cross section being similar to that shown in Fig. 3. The slant plates 23 are set in a circular frame 24 with a curved brace 25. Fig. 5 is a radiation pattern of this lens taken at an acoustic frequency of 11,000 cycles per second using a three inch feed horn at the focal point. A strong concentration of energy is observed.

The "slant-plate" refractive medium can also be used to produce diverging lenses as shown in Fig. 6 representing a long acoustic horn 26 of six inch aperture having a cylindrical diverging lens 27 before it. The lens is composed of slant plates 28 set in a rectangular frame 29. Because the horn is long, approximately plane waves emerge from the horn and they are caused to diverge as they leave the lens as shown in Fig. 7.

In the slant-plate type of device it is advantageous to have the plates set with their longitudinal axes parallel to each other and perpendicular to the axis of the refractor. Conveniently and as shown in Figs. 4 and 6 of the drawings, the plates may all be of substantially the same thickness although this is not critical.

In applications where it is desired to have a constant index of refraction over an extended frequency band it is advantageous to have the spacings between adjacent elements small compared to the wavelengths involved.

Earlier known forms of lenses for compressional and acoustic waves have been in the form of a bladder containing a gas, a steel lens immersed in water, etc., in which cases the particles of which the lens is composed move with the compressional wave or sound wave. The lenses herein disclosed are composed of rigid elements or particles which do not move with the wave.

The devices in accordance with the invention are capable of use with compressional waves of various modes, including longitudinal and transverse modes of vibration.

The invention is not to be construed as limited to the particular embodiments, arrangements, or details disclosed herein.

What is claimed is:

1. An artificial delay structure for compressional waves having a normal axis, said structure comprising an assembly of a plurality of plane, rigid, compressional wave baffle plates, said plates being of uniform thickness, the widths of each plate varying and the maximum widths

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of successive plates varying, said plates being mounted opposite one another and parallel to each other, the spacing between plates being small relative to the maximum width dimensions of the larger of said plates, the planes in which said plates lie being at a substantial angle with respect to the normal axis of said structure.

2. A compressional wave refractor having a normal axis, said refractor comprising an assembly of a plurality of thin, rigid, plane, parallel plates, said plates varying in width and varying in maximum width with respect to each other, said plates being spaced apart a distance which is small with respect to the maximum width of the larger of said plates, said plates occupying substantially the whole of a volume of space having the shape of an optical refractor, the planes in which said plates lie being inclined at a substantial angle with respect to the normal axis of the refractor.

3. A compressional wave lens comprising an assembly of a plurality of rigid, plane, parallel plate members each of said members having a pair of opposed longitudinal edges and varying in width between said edges, said members being spaced apart a distance which is small with respect to their maximum width dimension, said members taken collectively filling substantially the entire volume of a space of the shape of a cylindrical lens having a normal axis, the planes in which the said plates lie being inclined to the normal axis of said lens by a material angle of inclination.

4. A plano-convex lens for compressional waves comprising a rigid circular frame, a plurality of thin rigid plate members secured to said frame and mounted parallel to each other, said plate members being inclined at a material angle with respect to the plane of said frame and the exposed edges of said plate members lying in the surface of a volume of space having the form of a plano-convex lens with the said frame forming a circular aperture for said lens.

References Cited in the file of this patent

UNITED STATES PATENTS

1,845,080	Eyring et al.	Feb. 16, 1932
2,617,030	Rust et al.	Nov. 4, 1952

FOREIGN PATENTS

798,986	France	Mar. 14, 1936
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