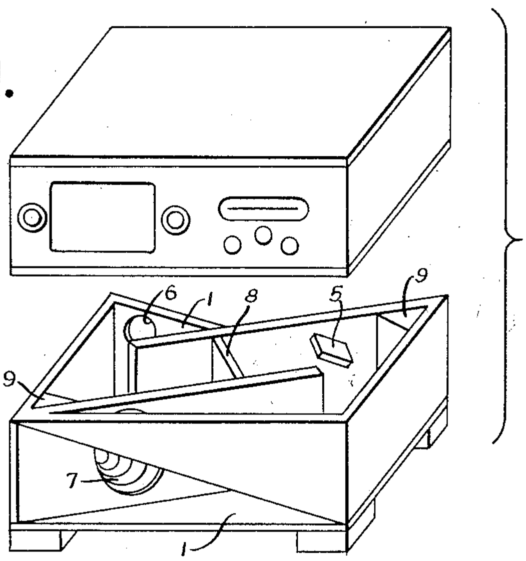
Dec. 17, 1957 J. E. KARLSON 2,816,619

ACOUSTIC TRANSDUCERS

Filed Dec. 4, 1951

FIG. 1.



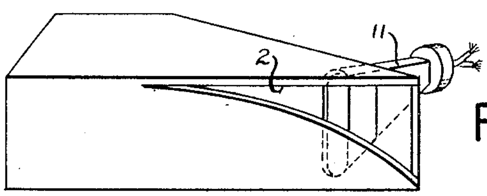
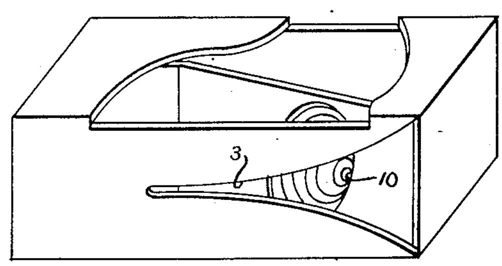


FIG. 2.

FIG. 3.



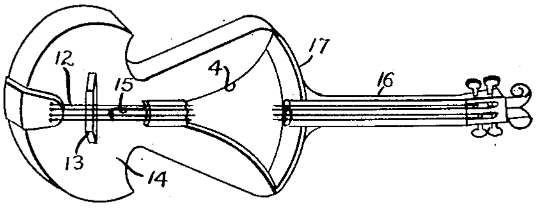


FIG. 4.

INVENTOR
JOHN E. KARLSON.

BY Samuel J. Stoce
ATTORNEY

United States Patent Office
2,816,619
Patented Dec. 17, 1957

2,816,619

ACOUSTIC TRANSDUCERS

John E. Karlson, West Hempstead, N. Y.

Application December 4, 1951, Serial No. 259,831
9 Claims. (Cl. 181—27)

My invention relates to acoustic transducers and has for its object the more effective transformation of the energy in a vibrating device into sound, so that musical instruments and loudspeaker enclosures may have improved listener appeal. It is also the object of my invention to provide a simple apparatus for overcoming the deficiencies in frequency and transient response usually found in all but the most expensive loudspeaker enclosure units. These principles are also intended for use with microphones since these deficiencies also exist with units designed for the detection of sound. Similarly, it is the object of this invention to provide the basic concept for a series of musical instruments having a more uniform resonance and tone quality throughout their musical range than is found in conventional designs.

Acoustic transducers of various types have been in use since the advent of sound and their purpose generally has been to convert the energy in vibrating skins, strings, membranes, and other devices into sound. The design of these transducers has varied from the elementary drum to the complex problems involved in the design of a superior violin. Antonius Stradivarius has achieved considerable acclaim for his unique ability in controlling the tone quality of his instruments. The principal techniques used on these violins consisted of (1) selecting a sound chamber which would not readily resonate at any frequency within the desired range, (2) introducing protuberances and continuously curved and irregular surfaces which would still further reduce the possibilities for direct reflections of sound which could build up to excessive resonance at some frequencies and too little at others, (3) selecting the proper woods for each section of the violin using very hard woods where maximum sound transmission was required and soft woods where maximum absorption and minimum reflection were required, (4) shaping and tapering the cross section of the wood in the sound chamber so that the absorption of sound into this wood would occur with minimum reflection and maximum efficiency and (5) finishing the violin with appropriate varnishes which would heighten either the absorption or transmission effects cited above. The above technique is obviously difficult and requisite of considerable experimentation, so much so that no violin maker since Stradivarius has been able to duplicate the excellence of his technique in spite of the existence and close study of many of his instruments.

Another major use of acoustic transducers is in connection with loudspeakers for radios, and other sound systems. The techniques presently used in designing the loudspeaker enclosures for use with these sound systems are very elementary in comparison with those mentioned above for the violin. This condition is largely due to economic necessity prohibiting the complete application of the best practices and to a general lack of recognition of the importance of properly designed enclosures. Although there are many commercially acceptable loudspeaker enclosures, the deficiencies of these units are readily apparent to the discerning listener. These deficiencies are exhibited by excessive boom and hangover at the lower frequencies, inadequate frequency response, and poor transient response giving rise to distortion and decreased intelligibility.

The acoustic transducer herein described overcomes these deficiencies by the use of a simple structure whose acoustic properties are inherently compatible with the requirements for exceptionally high fidelity reproduction of music and speech. Similarly, this structure can be used in the creation of music itself and as such provides an ideal sound chamber for stringed musical instruments.

Basically, my invention consists of a pipe or elongated chamber closed at one end and open at the other. The size and shape of the opening are controlled to give the desired acoustic properties and differs from horns and similar devices in that the principal radiation occurs with a directivity which is essentially normal or perpendicular to the axis of this pipe. Stated differently, the sound comes out of the side of the pipe rather than out of the end. The advantages of this approach and the theory thereof are explained in the following paragraphs.

When sound waves are initiated in a pipe they travel towards the ends of the pipe. At the closed end these waves are reflected back into the pipe and at the open end another reflection occurs due to the sudden rarefaction of the wave front of these waves. At certain wavelengths reinforcements of the incident waves occur due to these reflections which create the conditions for resonance. Therefore, a pipe open at one end and closed at the other end will resonate at a frequency whose wavelength is equal to four times the length of the pipe. The strength of this resonance is largely dependent upon the abruptness of the discontinuities at the ends of the pipe and the losses within the pipe. Thus, if only minor discontinuities exist at one end of this pipe, correspondingly weak reflections occur with the result that this pipe can only be weakly resonant. Also, if the energy within the pipe were gradually dissipated before it reached the end of the pipe, resonance would be further weakened. When these conditions hold for a wide range of frequencies then we have the essentials for a non-resonant enclosure for use as an acoustic transducer for wide band applications.

This invention relates to a practical means of accomplishing these objectives. In order to present a minimum discontinuity at the open end of said pipe, a small opening is made in the pipe near the closed end of said pipe; said opening gradually being made wider until a maximum width of the aperture thus formed is realized at the other end of the pipe. The cross section of the pipe is also narrowed so that the energy being propagated toward the open end of said pipe is gradually forced through the opening formed by this tapered aperture. This action continues until a minimum cross section at the widest end of the tapered aperture forces the remaining energy out of the enclosure. By this means, it is therefore possible to present a minimum discontinuity at any point in the opening in said pipe while at the same time providing a means of gradually dissipating the energy in said pipe in a useful fashion.

This invention meets the needs of many acoustic transducers, the best known of which are loudspeakers, microphones and musical instruments in general. For a better understanding of the above indicated features of my invention and others which will hereinafter appear, reference may be made to the accompanying drawings forming a part of this application, wherein:

Fig. 1 is a perspective view of a practical embodiment of my invention in a radio-television set.

Fig. 2 is another perspective view showing a basic acoustic transducer embodying my invention using a horn type driver for loudspeaking purposes. If this driver unit is also used as a microphone a more effective sound pickup will be realized. Note that the tapered aperture is asymmetrically formed in respect to the axis of the enclosure.

Fig. 3 is still another perspective view showing an embodiment of my invention using a conventional cone type loudspeaker. The front loading of the cone is accomplished by the tapered aperture acoustic transducer while the back loading of the cone is effected by a conventional infinite baffle type of construction which merely consists of a closed chamber. In this instance the tapered aperture is symmetrical in respect to the axis of the enclosure.

Fig. 4 is a perspective view which represents an embodiment of my invention in a stringed musical instrument resembling a violin.

Be reference to the drawing accompanying this specification it can be seen that the several embodiments of my invention include tapered apertures of different dimensions and shapes used in combination with varying structures and equipments. In spite of these differences, a closer examination will reveal that they all employ an elongated chamber or duct which includes a tapered aperture extending along a major portion of the length of said chamber. The several figures of the drawing illustrate what is meant by the term "major." It will also be noted that the greatest width of the tapered aperture constitutes an appreciable portion of the width of the chamber and again, reference to the several figures of the drawing will indicate what is meant by "a major portion" of the width of the chamber.

An elongated chamber is used in all these designs in order to take advantage of the propagation effects inherent in a sound duct whose length is not small relative to the wavelengths transmitted. The parameters associated with these structures may then be regarded as distributed constants and the ensuing action may be analogous to electrical transmission lines and antennas.

The tapered apertures used in these figures although of different dimensions and shapes present a means for gradually varying the distributed constants of said chambers so that the high impedance driving sources may be adequately matched to the low impedance of the air.

The shape of the aperture largely determines the rate of release of the energy being propagated toward the open end of any individual chamber. In order to have a minimum pressure gradient introduced at any point of efflux, it is necessary that equal amounts of energy be released for equal increments of distance along the aperture. This is done in several embodiments of my invention by varying the width of the aperture as the square of the distance along the axis of the elongated chamber. Other rates of release of the included energy may be realized by changing the rate of taper. Fig. 1 shows a radio-television set having a tapered aperture (1) whose width varies directly as the distance along the effective axis of the folded chamber. Fig. 2 shows an exponentially tapered aperture (2) which is asymmetrical with respect to the axis of its associated chamber. Fig. 3 also shows an exponentially tapered aperture (3) which is symmetrical with respect to the longitudinal axis of the coupling chamber. Fig. 4 illustrates the use of a symmetrical aperture (4) in a stringed musical instrument.

The lengths of the tapered apertures in Figs. 1, 2, 3, 4 are shown to be a major portion of the overall length of the associated coupling chambers. This factor is important in that it determines whether or not a continuously uniform response over a wide band of frequencies will be obtained with the tapered aperture enclosure. This is due to the fact that sound waves are composed of alternate compressions and rarefactions of the propagating meduim. When these sounds are transmitted down a duct such as the elongated coupling chamber, these compressions and rarefactions cause forces to be exerted on the surrounding medium. The strength of the forces exerted on any particles located at the boundary of the surrounding medium will be related to the pressure gradient between the surrounding and conducting mediums. Since these sound waves go through alternate cycles of compression and rarefaction, it is evident that at periodic intervals, relatively small pressure differentials exist between the conducting and surrounding media with the result that very little force is exerted on the surrounding medium during such intervals. By Newton's second law we also know that

$$f=ma$$

where (f) is the force required to move a particle of mass (m) with an acceleration (a). Thus, in addition to this boundary effect, a resistance to the propagation in the surrounding medium is created by the inertia of the particles in this medium. This inertia effect is further heightened when the direction of propagation is essentially parallel to the boundary line of the surrounding meduim. When the frequency of the sound waves is increased, the acceleration (a) is correspondingly increased with the result that these boundary effects become quite pronounced at high frequencies.

My invention utilizes these factors in producing a coupling chamber which is weakly resonant over a broad range of frequencies due to this boundary effect. If the coupling chamber is made long enough to be effectively a quarter wave resonator at the lowest frequency limit desired, then this boundary effect will create pressure break through areas in the aperture adjacent only to the points of maximum pressure gradient. Since the positions at which these break through areas occur will be determined by the wavelengths of the sounds being propagated, this coupling chamber will virtually change its length for resonance at the desired frequencies. This follows since every break through area thus created in the aperture presents a virtual discontinuity in the chamber. Thus, at some arbitrary frequency (f_1) the break through area may be at the end of the coupling chamber and as the frequency is increased the break through areas will automatically position themselves closer to the other end of said chamber. A quarter wave pipe is also resonant at the odd harmonics of its fundamental frequency. Therefore when the frequency has increased to $(3f_1)$ the open end of the pipe again becomes resonant. This factor therefore precludes the necessity of extending the aperture along the entire length of the coupling chamber. It also determines the length this aperture must have in order to present continuous resonance conditions for all frequencies up to (nf_1). The term n is any number determined by the design conditions.

If the aperture is made longer than the minimum length required, continuous resonance conditions still exist with the result that the length of this aperture is not critical beyond the minimum length required. Shorter lengths of the aperture will require additional dissipative devices or built in discontinuities within the chamber for reasonably broad band results.

The introduction of discontinuities in a coupling chamber may offer both advantages and disadvantages.

Said discontinuities may be in the form of a protuberance 5 or an opening 6. Protuberances may consist of blocks of wood, felt, or other suitable materials whose general purpose is to produce reflections of controlled strength at a predetermined frequency or frequencies. An opening creates a similar result by employing some form of aperture or hole in the coupling chamber, since reflections will also result at some frequencies due to this type of discontinuity.

If a loudspeaker or other transducer having a defective frequency response is combined with said tapered aperture coupling chamber, corrections can be made in this response by the proper use of such devices. These discontinuities may be designed and positioned to offer more favorable impedences at the frequencies involved with the result that these deficiencies may be overcome. If low frequency compensation is required, an opening **6** may be used since the hole thus presented can be designed to have little or no effect at the high frequencies and therefore acts like a high pass filter. Similarly, if this compensation is required only at the high frequencies, felt pads or the equivalent **5** may be fastened to the inner walls of the coupling chamber to present the required reflections at the high frequencies. At the lower frequencies these protuberances are less effective and therefore act like a low pass filter.

The techniques suggested in the above paragraph may be extended to yield almost any desired frequency response, the theory involved being analogous to that used in electrical filter theory.

Another type of discontinuity which may be introduced when necessary is one which would reduce spurious effects due to propagations of energy transverse to the longitudinal axis of said elongated chamber. This discontinuity would simply consist of a ridge or protrusion within said chamber along the length of said chamber or along any portion thereof, said protrusion being in the path of transverse modes of propagation within said chamber while offering little or no obstruction to longitudinal modes of propagation with said elongated chamber. This device is particularly useful in large installations using several loudspeakers in one chamber.

It is also obvious from the above that deleterious results can be obtained from the improper use of such devices.

Other variables may be introduced into the design of said coupling chamber which should also be considered within the scope of my invention.

The discussions on said tapered aperture have been largely based on an essentially open or unrestricted hole in the coupling chamber. However, it is also the intent of my invention to include a tapered aperture which consists of a series of holes or perforations. A tapered aperture so constructed also presents possibilities for further control of the characteristics of said coupling chamber by a variation in the size and the multiplicity of said holes. These holes can be made both resistive and reactive in nature with the result that a great variety of effects may be introduced by this means.

Another variable in the design of these coupling chambers can be introduced by the termination of the elongated chamber in the end opposite that of the tapered aperture. It has been previously indicated that this end was closed. Since reflections also occur at an abrupt opening in the chamber, this type of construction may also be used. In fact, tapered apertures may be used at both ends of the elongated chamber if the increased size thus realized is secondary to the improved loading inherent in this arrangement. In order to generate an essentially plane wave front said double tapered aperture chamber should be one wavelength long at the lowest frequency required. An assembly of this type would be most appropriate for use in large auditoriums with electronic organs and sound systems.

Some economies in space requirements may be realized by folding said elongated coupling chamber. Fig. 1 shows a practicable construction of this type using two tapered aperture coupling chambers for both front and back loading of the cone type loudspeaker depicted.

For maximum economy, a linear tapered aperture Fig. 1—**1** is used in both coupling chambers. The loudspeaker used may not necessarily be a high cost unit since deficiencies in its response may be compensated for by the discontinuities introduced in said chambers. Fig. 1—**6** shows a typical means of introducing an aperture and Fig. 1—**5** depicts the use of a protuberance. A simple block of wood Fig. 1—**8** is used to divide the two chambers while additional blocks **9** are used to properly reflect the sound waves so that the continuity of the coupling chamber is maintained. Also important in this regard are the

finishes employed within the coupling chamber. If these do not present sufficiently hard and smooth surfaces a loss in the high frequency response may be expected due to the absorption of these sounds. The selection of suitable finishes for this purpose will also be necessary in all designs of said tapered aperture chambers, if optimum results are desired.

The purpose of this design is to obtain the lowest frequency response possible for a given volume together with a flat response for the other frequencies included in the spectrum response of the loudspeaker. This objective is realized in this design with a minimum increase in cost over conventional radio and television cabinets.

An examination of Figs. 1, 2, 3, 4 will show that all of said tapered aperture coupling chambers have been designed with a diminishing interior cross section starting near the apex of each aperture and narrowing down to a minimum at each base of said aperture. The inclined planes thus presented to the energy being propagated toward the tapered aperture end of each coupling chamber deflects said energy upward through said tapered aperture. This action assures a more uniform release of said energy over the entire length of said aperture than would be normally experienced by a uniform cross sectional area. In addition to this feature a minimum discontinuity is also presented at the open ends of said coupling chambers by this structural design.

A less obvious result of the inclined plane so created in the path of the enclosed sound waves is in its influence of the radiation pattern of said coupling chamber. Properly designed relative to the rate of taper in the aperture, a uniform distribution of energy can be realized over the entire length of said aperture, especially for the high frequencies. When this occurs a roughly semi-cylindrical wave front results. This constitutes an ideal manner of propagation of these sound waves since the high frequencies will not be sharply beamed in any one direction.

If the angle that said inclined plane makes with the plane of said tapered aperture is greatly increased, several effects may be observed. Among these are (1) lower frequency limit (2) increased reverberation time (3) poorer transient response and (4) less uniformity in the radiation pattern throughout the frequency range. Obviously, optimum results for any particular application would be subject to some trial and error tests.

One of the principal applications of said tapered aperture coupling chamber is in the reproduction of music and speech, where conventional loudspeaker units are used as the sources of acoustic energy within said chamber. Fig. 1 shows how a conventional cone type speaker **7** may be applied with said chamber. Fig. 3 depicts a similar unit **10** in a different type chamber, while Fig. 2 illustrates how a horn type driving unit can be combined with said chamber. Each of these speakers is shown mounted on the inclined plane opposing the tapered aperture. This mounting position is not mandatory for the proper operation of said coupling chamber, but for these applications excellent results have been obtained with speakers in these relative positions. The position of the speaker relative to the base of said tapered aperture is largely determined by the size of the speaker cone. A cone type speaker which is large relative to the total area of the aperture should be positioned near the base of said aperture, while a smaller cone speaker should be positioned nearer the apex of said aperture. The reason for this is that the coupling chamber constitutes an impedance matching device transforming one level of impedance into another. The impedance near the closed end of said coupling chamber would be a maximum at said closed end and a minimum at the open end. Since the cone loudspeakers represent in between values of acoustic impedances, they are located accordingly. Microphones may be substituted in place of the loudspeakers previously mentioned and then said coupling chamber may be utilized as a means for detecting sound. The acoustic properties of said coupling chamber would then be reciprocal to those obtained while transmitting said sound waves.

Fig. 4 shows a stringed musical instrument using the tapered aperture coupling chamber as a means for obtaining a more pleasing and uniformly resonant tone. The strings **12** rest on a bridge **13** which in turn causes a vibration in the top wall **14**, which top wall acts in a manner similar to the cone of a loudspeaker exciting vibrations in the air column of said chamber **15**. This energy is dissipated in the same manner as previously described. In order to add to this effect, a good transmission path from the other ends of the strings is created by the hard woods used in the neck **16** and base **17**. This secondary source of vibration adds to the sounds already created thereby contributing to the richness of the tone of said instrument.

The applications for my invention herein described will suggest a great many more variations to those skilled in the art. Obviously, all of these applications cannot be included herein. Therefore, only the basic applications for my tapered aperture coupling chamber have been mentioned.

Having thus described my invention, what I desire to secure and obtain by Letters Patent is:

1. In an acoustic transducer, a sound source, a plurality of walls adjacent said sound source forming an enclosure, and a single tapered opening formed in one of said walls which serves as a passageway for the sound waves from said sound source, said tapered opening extending along a major portion of the length of said enclosure and its greatest width constituting a major portion of the width of said enclosure, said sound source being so located relative to said tapered opening that a gradual release of energy is effected along its longitudinal dimension, said tapered opening being adapted to constitute and function as the passageway through which substantially all of the energy from the sound source passes.

2. In an acoustic transducer, a sound source, a plurality of walls adjacent said sound source forming an enclosure, and a single substantially triangular opening formed in one of said walls to serve as a passageway for the sound waves from said sound source, said triangular opening extending longitudinally of the enclosure, the longitudinal dimension of said triangular opening constituting a major portion of the longitudinal dimension of said enclosure and the greatest transverse dimension of said triangular opening constituting a major portion of the transverse dimension of the enclosure, said sound source being so located relative to said triangular opening that a gradual release of energy is effected through said triangular opening along its longitudinal dimension, said triangular opening being adapted to constitute and function as the passageway through which substantially all of the energy from the sound source passes.

3. In an acoustic transducer, a plurality of walls forming an enclosure, a sound sensitive pick-up means situated within the enclosure, a sound source situated outside of the enclosure, and a single substantially triangular flared opening formed in one of the walls of said enclosure to serve as a passageway for the sound waves from said sound source to said sound sensitive pick-up means, said triangular opening extending longitudinally of the enclosure, the longitudinal dimension of said triangular opening constituting a major portion of the longitudinal dimension of said enclosure and the greatest transverse dimension of said triangular opening constituting a major portion of the transverse dimension of the enclosure, said pick-up means being so located relative to said triangular opening that a gradual reception of energy is effected through said triangular opening along its longitudinal dimension, said triangular opening being adapted to constitute and function as the passageway through which substantially all of the energy received by said pick-up means passes.

4. In an acoustic transducer, a plurality of walls forming a sound chamber, a sound source situated within said chamber, and a single elongated opening formed in one of the walls for the escape of sound waves from said sound source, said elongated opening being relatively narrow at one end and relatively wide at its opposite end, the length of said elongated opening constituting a major portion of the length of the chamber and the width of said elongated opening at its relatively wide end constituting a major portion of the width of said chamber, said sound source being so located relative to the ends of said elongated opening that a gradual release of energy is effected through said elongated opening along its length, said elongated opening being adapted to constitute and function as the passageway through which substantially all of the energy from said sound source passes.

5. In an acoustic transducer, a plurality of walls forming a sound chamber, a sound source situated within said chamber, and a single elongated opening formed in one of said walls for the escape of sound waves from said sound source, said elongated opening being substantially triangular in shape and having flared side edges, said elongated opening extending along a major portion of the length of said chamber and its greatest width constituting a major portion of the width of said chamber, said sound source being so located relative to the ends of said elongated opening that a gradual release of energy is affected along the length of said elongated opening, said elongated opening being adapted to constitute and function as the passageway through which substantially all of the energy from said sound source passes.

6. In an acoustic transducer, a plurality of walls forming a sound chamber, a sound source situated within said chamber, and a single elongated tapered opening formed in one of said walls for the escape of sound waves from said sound source, the length of said opening being at least half of the length of the sound chamber, the width of said opening at its larger end constituting at least a major part of the width of said sound chamber, the sound source being so located relative to said elongated opening that a gradual release of energy is effected through said elongated opening along its length, said tapered opening being adapted to constitute and function as the passageway through which substantially all of the energy from the sound source passes.

7. In an acoustic transducer, a sound source, a plurality of walls adjacent said sound source forming an enclosure, and a single tapered opening formed in one of said walls which serves as a passageway for the sound waves from said sound source, said tapered opening extending along a major portion of the length of said enclosure and its greatest width constituting a major portion of the width of said enclosure, said sound source being so located relative to the tapered opening that a gradual release of energy is effected along the length of said opening from its narrow to its wide end, said elongated opening constituting substantially the entire avenue of escape for the sound waves from said sound source, said sound chamber being substantially closed throughout save for said elongated opening.

8. In an acoustic transducer, a sound source, a plurality of walls adjacent said sound source forming an enclosure, and a single tapered opening formed in one of said walls which serves as a passageway for the sound waves from said sound source, said tapered opening extending along a major portion of the length of said enclosure and its greatest width constituting a major portion of the width of said enclosure, said tapered opening being adapted to constitute and function as the passageway through which substantially all of the energy from the sound source passes, said sound source being so located relative to the tapered opening and the rate of taper of said tapered opening being such that a gradual release of energy is effected therethrough.

9. In an acoustic transducer, a sound source, a plurality of walls adjacent said sound source forming an enclosure,

and a single tapered opening formed in one of said walls which serves as a passageway for the sound waves from said sound source, said tapered opening extending along a major portion of the length of said enclosure and its greatest width constituting a major portion of the width of said enclosure, said tapered opening being adapted to constitute and function as the passageway through which substantially all of the energy from the sound source passes, said sound source being so located relative to the tapered opening and the rate of taper of said tapered opening being such that substantially equal amounts of energy are released for equal increments of distance along the longitudinal dimension of said tapered opening.

References Cited in the file of this patent

UNITED STATES PATENTS

1,481,634	Thomas	Jan. 22, 1924
1,550,697	Haug	Aug. 25, 1925
1,643,284	Blieberger	Sept. 20, 1927
1,678,214	Graham	July 24, 1928
1,843,524	Stenger	Feb. 2, 1932
1,960,449	Midgley	May 29, 1934
2,020,166	Swinyard	Nov. 5, 1935
2,044,807	Noyes	June 23, 1936
2,129,184	Roy	Sept. 6, 1938
2,224,919	Olson	Dec. 17, 1940
2,373,692	Klipsch	Apr. 17, 1945
2,718,272	Olson et al.	Sept. 20, 1955

FOREIGN PATENTS

227,545	Great Britain	Jan. 22, 1925
342,369	Great Britain	Feb. 5, 1931
22,086	Australia	Apr. 23, 1936
661,887	Great Britain	Nov. 28, 1951