July 28, 1931. M. C. HOPKINS 1,815,945

LOUD SPEAKER

Filed Dec. 22, 1925 3 Sheets-Sheet 1

Fig. 1.

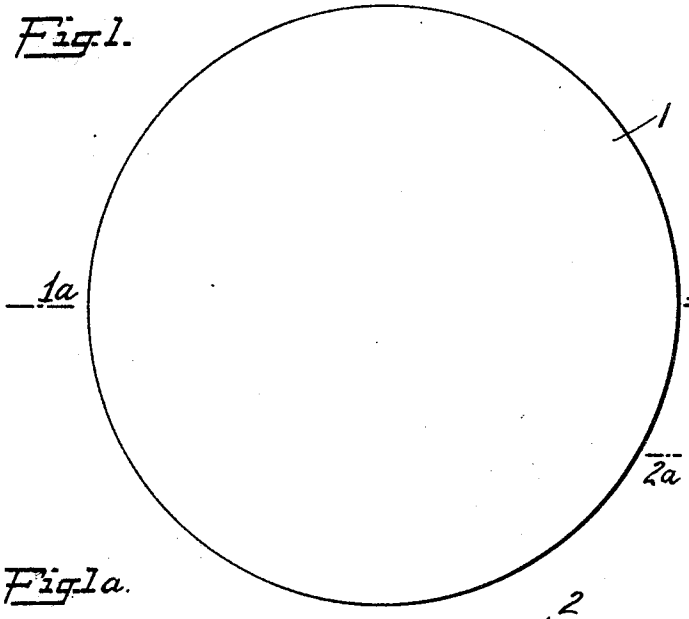


Fig. 2.

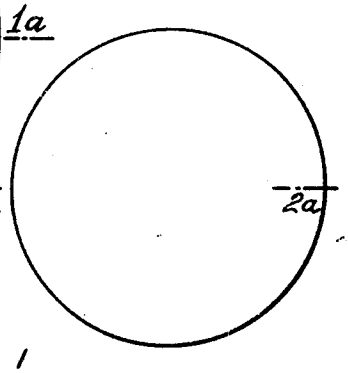


Fig. 1a.



Fig. 2a.

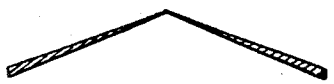
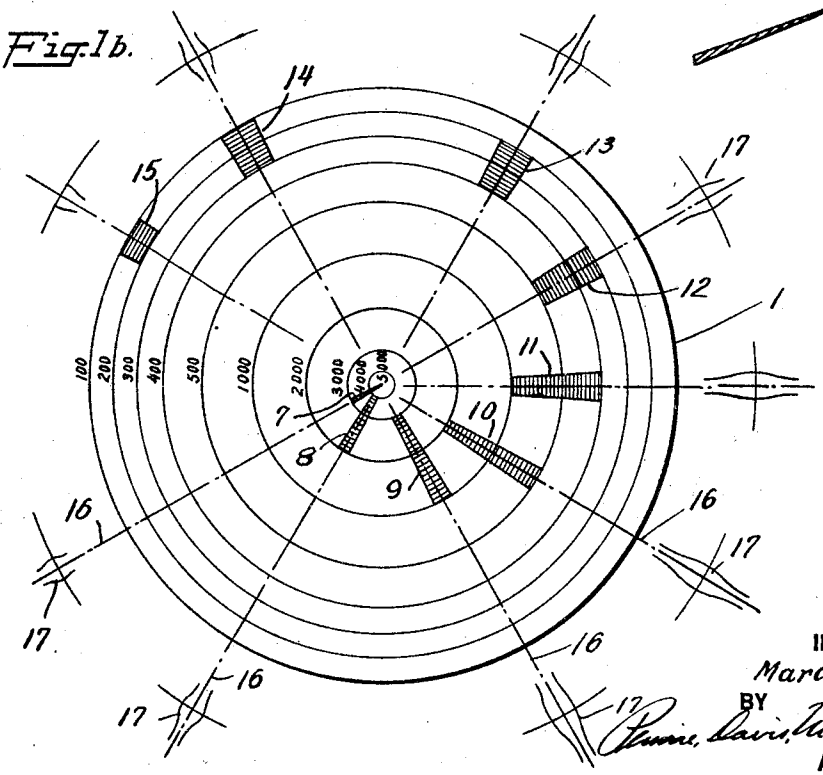


Fig. 1b.



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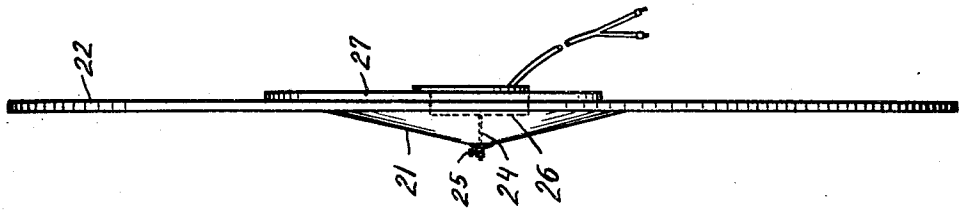


Fig. 4.

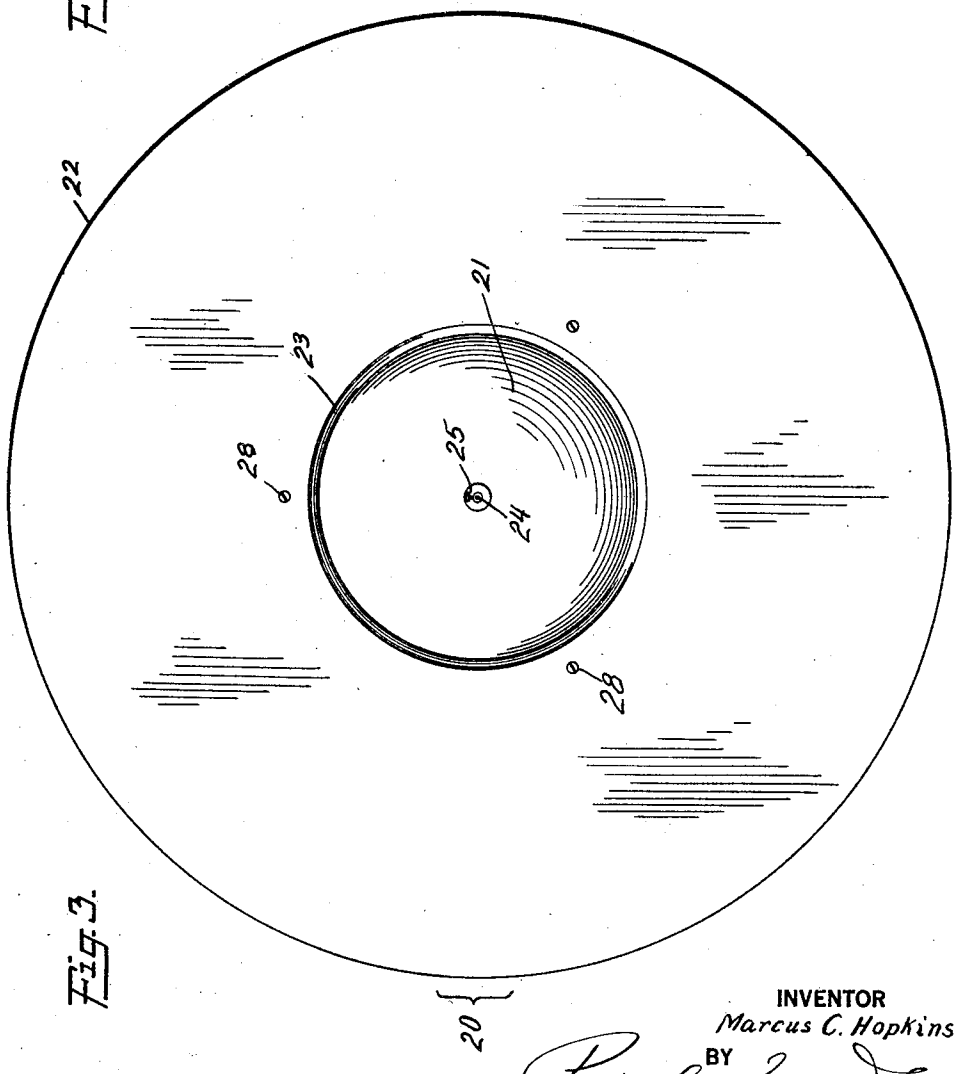


Fig. 3.

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LOUD SPEAKER

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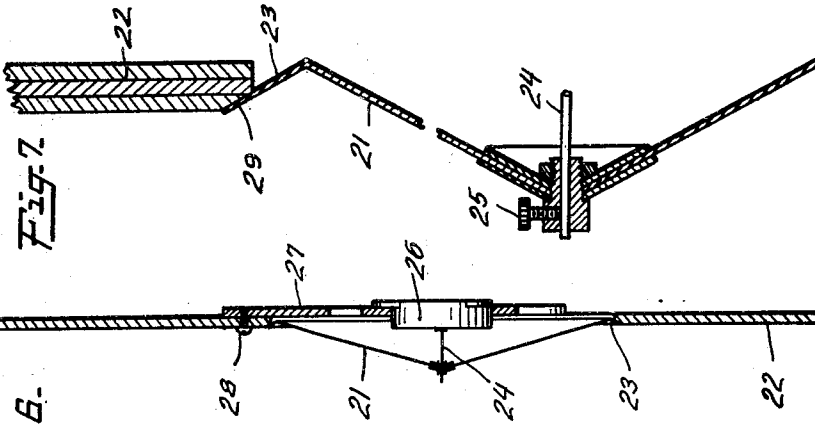


Fig. 7.

Fig. 6.

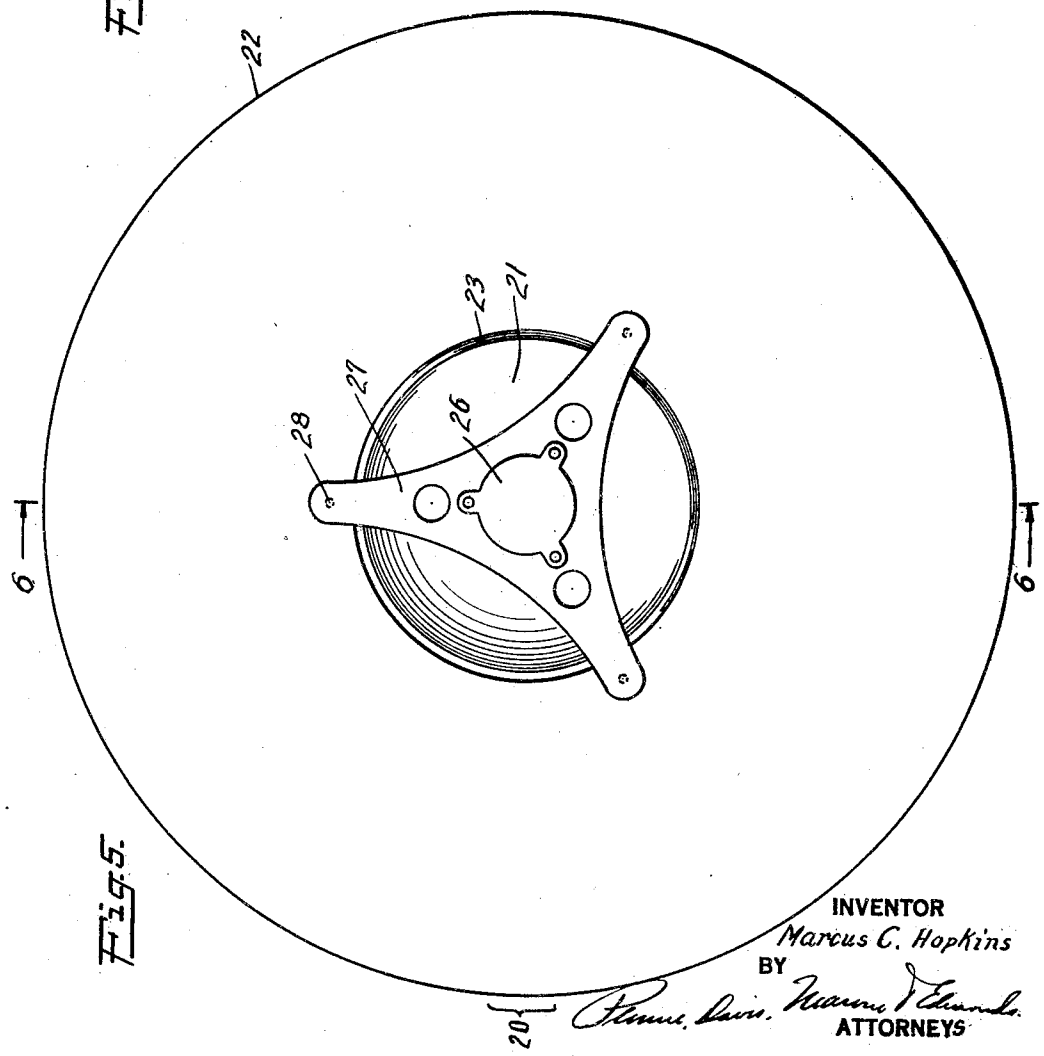


Fig. 5.

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UNITED STATES PATENT OFFICE

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LOUD SPEAKER

Application filed December 22, 1925. Serial No. 77,032.

The object of this invention is to provide a highly efficient "loud speaker" reproducing, or loud speaking receiver, capable of regenerating or reproducing sound waves directly in free air, and below, at or above their original sound intensity, without distortion as in a horn or other amplifying device having resonance phenomena, which regenerated or reproduced sound waves are substantially directly proportional both quantitatively and qualitatively to the actuating force, the sound so regenerated retaining substantially the same balance of high and low tones as the original sound from which the actuating force was derived.

To this end, a super-diaphragm is provided which in its preferred form is exposed to unconfined air and has such capacity for transmitting vibrations, and likewise such area, that it is capable of regenerating at high efficiencies directly in free air all sounds and tones throughout the gamut of the audible frequencies from the highest audible frequencies—the high treble tones, to the lowest audible frequencies—the low or bass tones, and with a balance of high tones, intermediate tones and low tones substantially the same as that of the original sound from which the actuating force is derived and quantitatively and qualitatively proportional to the actuating force even though the sound thus regenerated or reproduced is much louder than the original sound of which it is a reproduction.

Heretofore with loud speaking devices it has been possible to obtain only what may be termed an approach to a balance of low tones as compared to intermediate and high tones, that is, sufficient low tones were capable of being reproduced, so as to be noticeable to a listener, but the balance of high tones to low tones characterizing the original sound was not retained in the regenerated sound, since the gamut or range of frequencies of the regenerated sound over which such loud speakers were capable of operating, did not extend sufficiently into the low note ranges. Moreover, loud speakers heretofore proposed are not efficient, in that only a small amount of the available actuating force is actually transformed into audible sound.

To the end that the intermediate and low note ranges may be reproduced and regenerated, together with the high note ranges and all in proper balance, for example, the balance of a symphony orchestra wherein the majority of the instruments are playing, it is necessary that the proper areas of free air be set into vibration at the proper frequencies and amplitudes so that the effect on the listener is that of the original instruments, whether the volume of the sound be high or low.

A diaphragm in accordance with the present invention may be made in a number of forms, having varied cross sections and contours, but for simplicity, a diaphragm having a circular periphery and possessing a varying vibratory impedance from its polar zone to its peripheral or outer zone, will be described, that being one of the preferred forms.

The polar zone is that at or near the center, or, more strictly speaking, is the zone within which the actuating force is applied. A diaphragm constructed in accordance with the invention may also be considered to have intermediate zones located between the polar zone and the peripheral or outermost zone.

By suitably proportioning the relative mass, stiffness and area of each zone of the diaphragm a progressively varying vibratory impedance will characterize the structure as a whole and in such a way as to provide a plurality of over-lapping responsive annular areas, each capable of being vibrated to best effect by a definite frequency band, but which areas will cooperate with one another to produce a regenerated sound having a balance of high, intermediate and low tones substantially identical with the balance in the original sound from which the actuating force was derived. This progressive variation in mass, stiffness or area may be uniform from the force center outward to the periphery, or within reasonable limits may be non-uniform, and a non-uniformity in mass may be equalized in part at least by a coordinated non-uniformity in stiffness or area, that is

to say, uniformity in all three characteristics mass, stiffness and area is not vital if variation in one is used to offset variation in the other.

While I have not as yet been able to work out a definite rule or empirical formula, which would inevitably lead one by the use of simple mathematics to the desired diaphragm having structural characteristics such as form, contour, thickness, weight, stiffness and the proper variation of vibratory impedance to produce the desired results, my experiments indicate that it is comparatively simple to produce a speaker having the desired properties by cut and try methods following the concepts of my invention.

Referring now to the drawings:

Fig. 1 illustrates a diaphragm having at least one of its sound regenerating surfaces located in one plane; Fig. 1*a* is a cross-section of Fig. 1 along the lines 1*a*—1*a*; Fig. 1*b* illustrates a schematic or diagrammatic analysis of the result of using a progressively varying vibratory impedance, with particular reference to the form of diaphragm illustrated in Fig. 1.

Fig. 2 shows a diaphragm having a cone shaped contour; Fig. 2*a* is a cross-sectional view of Fig. 2 taken along the line 2*a*—2*a*;

Fig. 3 shows a diaphragm of large area, which is in the nature of a compromise between the arrangements of Figs. 1 and 2 and which comprises the combination of a vibratory cone or diaphragm coupled to a vibratory skirt or sound board.

Fig. 4 is a side view of the diaphragm shown in Fig. 3;

Fig. 5 is a rear view of the diaphragm shown in Fig. 3;

Fig. 6 is a cross-sectional view taken along the line 6—6 of Fig. 5; and Fig. 7 is an enlarged detailed sectional view of the central zone portion and the character of its coupled relationship to the sound board, for the general form of diaphragm shown in Fig. 3.

The arrangement shown in Fig. 1 and 1*a* may consist of a diaphragm 1, say 4 feet in diameter, in which the surface 2 is a plane surface and the opposite surface 3 is concaved inwardly toward the plane surface. In this form, the diaphragm may be constructed of some light material, such as paper or wood, or parts may be built of paper and parts of wood. 3-ply fir with the grain of the inner ply arranged transverse to the grain of the outer plies is suitable.

When the vibratory energy is impressed upon the diaphragm at the polar zone the lowest frequencies will produce maximum vibration of the diaphragm in a zone where the characteristics of the diaphragm cause that zone to be fully responsive for that frequency. In the present instance the most responsive zone for the low frequencies is near the periphery of the diaphragm. Likewise, the intermediate frequencies will produce maximum vibration of the diaphragm at those zones where the characteristics of the diaphragm are such as to cause these zones to be fully responsive to the intermediate frequencies. These zones, in the present instance, are the intermediate zones of the diaphragm. Similarly the high frequencies will produce maximum vibration of that zone the characteristics of which cause it to be fully responsive to the high frequencies. This zone, in the present instance, is the polar zone. Vibrations set up in those zones which are not fully responsive to a particular frequency may be considered forced vibrations because the diaphragm at these zones does not respond freely and in complete harmony with the impressed energy.

It will, therefore, be understood that the diaphragm 1 will regenerate the high frequencies by the vibration of responsive areas within its polar zone; will regenerate the intermediate frequencies by the vibration of the responsive area within its intermediate zone; and will regenerate the low or lowest frequencies by the vibration of responsive areas within its peripheral zone. The polar zone not being effectively responsive to the intermediate or lower frequencies but being mechanically coupled to the intermediate and peripheral zones will pass on the intermediate and lower frequencies and these in turn will cause the vibration of responsive areas in those zones at the proper amplitudes to reproduce the intermediate and lower frequencies.

Referring now to Fig. 1*b*, the diaphragm 1 is illustrated as being capable of reproducing or regenerating directly in free unconfined air sound frequencies within the audible range of 100 vibrations per second to 5000 vibrations per second, although its range may be extended, and a diagrammatic showing has been made of the approximate distribution of the fully responsive annular areas which are vibrated when the diaphragm 1 has had impressed thereon a vibratory actuating force of varying frequencies from 100 vibrations per second to 5000 vibrations per second.

In this figure the sectors numbered 7 to 15 respectively diagrammatically represent radial sections taken through the diaphragm. The center line 16 of each of these radial sections has been extended beyond the diaphragm and with each center line there is a representation 17 of the character and amplitude of the vibration which takes place within the zone represented by the shaded portion of the corresponding sector. For instance, considering the sectors in an anticlockwise direction the radially extended line 16 of the sector 7, together with the representation 17 indicate that the maximum vibration of the diaphragm for a frequency

of 4000 cycles takes place within the shaded area of the sector 7. Likewise, for a frequency of 3000 cycles the maximum vibration of the diaphragm takes place within the shaded area of the sector 8 and so on for the various frequencies. For a frequency of 5000 cycles the maximum vibration of the diaphragm would take place very near the center of the diaphragm, whereas for a frequency of 100 cycles the maximum vibration of the diaphragm would be at the extreme edge thereof, as indicated by the shaded area for the sector 15.

It will be understood that the relative widths of these fully responsive areas now being compared vary in harmony with many factors, such as the stiffness of the material, the relative thickness of the areas being compared, and their diameters, etc. It is conceivable that a vibration of any particular frequency will be responded to by all parts of the diaphragm, but it is certain that particular parts of the diaphragm respond to that frequency more readily than remote areas, and are more effective in transmitting the energy to the air as regenerated sound. The distribution of the areas and rough identification of the areas most responsive to any given frequency can be verified experimentally, and in that way proper balance between the high, the intermediate and the low frequencies can be obtained in general practice.

The weight and elasticity of the surrounding air is a factor to be considered in constructing the diaphragm because there is what might be called a mechanical coupling between the air and any vibrating zone or area of the diaphragm. That area in working against the air to produce the desired regenerated sound must have energy imparted to it and this energy must be of such frequency that the particular area of the diaphragm under consideration is the area best adapted to effectively transfer that energy to the air. The resonance phenomena of that particular area does not persist for any appreciable time after cessation of the applied energy because of the damping effect of adjoining areas which are not fully responsive to that particular frequency.

It is well known that a large volume of air at the lower frequencies must necessarily be vibrated in order to produce a low tone of intensity equal to that of a high tone produced by the vibration of a smaller volume of air. As the result of this a diaphragm of circular or conical outline is well shaped to obtain that balance of low tones, intermediate tones and high tones which will correspond more nearly to the original sound being translated by the actuating mechanism. In other words, regeneration of the original sound can be effected without distortion of the tone balance. This is true within a wide range of working limits whether the volume of the regenerated sound be great or small.

The operation of the diaphragm shown in Fig. 2 is substantially the same as that shown in Fig. 1, and has the additional advantage that because of its conical contour its structure is improved through greater stiffness and lightness throughout its structure, this being of particular importance with respect to the polar zone where extreme lightness coupled with stiffness will give best results in the regeneration of very high frequencies.

The diaphragm 20 illustrated in Fig. 3 is in the nature of a compromise between the arrangement of Figs. 1 and 2 and it presents the simplest manner now known to me by which a marketable diaphragm structure may be obtained. With this structure the balance between high, intermediate and low tones is entirely satisfactory, both at high volumes and low volumes.

The diaphragm 20 comprises a conical tympanum 21 adapted to reproduce all of the higher notes or tones and some of the intermediate notes and tones, coupled to a vibratory flange, or sound board skirt 22 by means of a semiflexible coupling 23, explained more in detail hereinafter.

The vibratory flange 22 is adapted to be vibrated through its flexible coupling 23 by means of vibratory energy transferred thereto by the vibratory cone or diaphragm 21. While the transfer of energy from the cone to the flange is not gradual as in the cases of Figs. 1 and 2 wherein the translation of the vibratory energy from one zone to another takes place in a homogeneous structure of like character throughout, but with a varying vibratory impedance, it is accomplished with fair efficiency by means of the semiflexible coupling 23 so that in fact the cone may be considered as a persistent forced oscillator at the lower frequencies and the vibratory skirt or flange as a good free radiator or regenerator at the lower frequencies, the low frequency energy being properly impressed on the vibratory skirt or flange through the semi-flexible coupling 23.

It will be recognized that the vibratory impedance at the inner circumference of the vibratory flange 22 is necessarily different from the vibratory impedance of the cone at its periphery and that some means of transition must necessarily be provided in order that there may be an effective smooth or continuous variation of vibratory impedance from the conical tympanum 21 to the vibratory flange 22. This is accomplished by means of the semi-flexible coupling in such a way as to permit a proper transfer of vibratory energy and yet not produce a reaction which would interfere with the transfer of the vibratory energy or interrupt the effective con-

tinuous variation of the vibratory impedance of the diaphragm.

After careful experimentation I have found that a cone of approximately 17 inches outside diameter and constructed of paper known as Castillian cover paper functions very well with a vibratory skirt or flange of 3-ply light fir wood in the form of a cross grain veneer 3/8 inch in thickness. The outside diameter of the skirt or flange may vary within wide limits. Excellent results have been obtained with a flange having an outside diameter of 4 feet.

Fig. 4 shows a side view of the diaphragm 20, its conical section 21 and its vibratory flange section 22. The vibratory actuating force is supplied to the polar area of the cone by means of a rod or wire 24 which is adapted to be maintained in fixed relation with the cone by means of a set screw 25. The rod 24 may be actuated by electro-magnetic mechanism housed in the casing 26.

Fig. 5 shows a rear view of the diaphragm 20 illustrated in Fig. 4 and shows the method of mounting the casing of the electro-magnetic actuating mechanism so that the vibratory energy may be impressed upon the cone. The casing 26 of the electro-magnetic actuating mechanism is attached to a support 27, which is affixed to the vibratory flange by means of screws 28 in the manner illustrated in Fig. 6.

Fig. 7 illustrates a cross-sectional fragmentary view which makes clear the character of the semi-flexible coupling and the manner of affixing the upturned rim of the cone to the vibratory flange.

In commercial manufacture the conical paper diaphragm is made up from a flat sheet. The stock is cut from a flat sheet and then shaped into conical form and glued along a radial seam. Near the outer edge of the cone thus formed the paper is creased and then folded up to form a forwardly flaring brim. This brim naturally assumes an angle to the plane of the base equal to the angle between radial elements of the cone and that base. In gluing or cementing the brim to the beveled edge 29 of the wood sounding board it is important that a part of the brim be left free to form a hinge on which the cone may float. Thus with a brim 3/4" wide the cemented portion may have a width of 1/4 more or less and the remainder of the brim may be left free to swing.

The structure as a whole may be suspended by cords or chains either in vertical position or in horizontal position and when supported in horizontal position can be suspended from the ceiling of a room. It is best not to have the diaphragm too close to the ceiling because it plays on the back as well as on the front. A spacing of three or four feet is satisfactory.

The diaphragm can be ornamented by painting designs on the exposed surfaces, and when constructed in large sizes the paint or varnish on the wood and paper does not appear to impair the sound producing action of the device. When built in small sizes it is best not to apply paint, varnish, or any similar filling material to the paper surface, for best results are had when the paper is very light in weight and crisp in texture.

The structure illustrated in Figs. 3 to 7, inclusive, offers many advantages for large scale commercial production, but the specimens shown in Figs. 1 and 2 are likewise commercially feasible even though they have been described above largely for the purpose of making clearer the fundamental principles on which, in a generic sense, my present invention as hereinafter claimed is based.

In the foregoing it has been assumed that the actuating force is equally efficient for all frequencies. In other words, the efficiency of the actuating force has been neglected. It is difficult to construct electro-magnetic actuating mechanism for loud speakers which is equally efficient for all frequencies. In nearly all electro-magnetic actuating units for loud speakers so far developed there is one particular frequency, or perhaps a narrow band of frequencies, at which the mechanism is most efficient and will exert the maximum driving power depending upon the impedance of the unit. The diaphragm herein disclosed is well adapted for use with an electro-magnetic actuating unit even though the unit is not equally efficient for all audible frequencies. For instance, the diaphragm may be so constructed that the various fully responsive zones are properly proportioned to obtain the correct balance of high, intermediate and low tones in spite of the fact that for some frequencies the driving force exerted by the actuating movement is not so great as for other frequencies. If it is known that the actuating unit is not as efficient for certain frequencies as for others, the diaphragm may be so proportioned as to mass, stiffness, area and form that the zones which are intended to be fully responsive for those frequencies may be proportioned and properly constructed to compensate for the inefficiency of the unit for these frequencies. It is therefore possible to employ an actuating unit of the type usually used for radio loud speakers in spite of its inefficiency for certain frequencies, and still obtain a proper balance of high, intermediate and low tones because of the above mentioned compensating action which is possible in constructing the diaphragm. It may therefore be said that the different zones are matched with the efficiency or driving ability of the actuating unit for the various frequencies.

Various changes may be made in the elements of the device as shown in Figs. 3 to 7 and in their size and relative proportions

without departing from the spirit of the invention as defined by the appended claims.

I claim:

1. A loud speaker comprising a diaphragm having sufficient area to produce directly in the surrounding air clearly audible sounds or tones throughout the gamut of audible frequencies when actuated by impressed vibratory energy of audible frequency, said diaphragm having a polar zone and at least one surrounding zone, the mass of the surrounding zone or zones being greater than that of the polar zone whereby the polar zone will be freely responsive to the higher frequencies and the surrounding zone or zones will be freely responsive to the lower frequencies, and means for impressing vibratory energy on said diaphragm at the polar zone.

2. A loud speaker comprising a diaphragm having sufficient area to produce directly in the surrounding air clearly audible sounds or tones throughout the gamut of audible frequencies when actuated by impressed vibratory energy of audible frequency, said diaphragm having a central polar zone and an external surrounding zone, the surrounding zone being of greater thickness than the polar zone and being freely responsive to the lower frequencies, and means for impressing vibratory energy on said diaphragm.

3. A loud speaker comprising a diaphragm having sufficient area to produce directly in the surrounding air clearly audible sounds or tones throughout the gamut of audible frequencies when actuated by impressed vibratory energy of audible frequency, said diaphragm having a plurality of zones which so differ in vibratory impedance that a plurality of vibratory areas are provided each of which is freely responsive to a given frequency, and actuating means for the diaphragm, each of said zones being so proportioned as to mass, stiffness, area and form that its sound regenerating properties are correlated or matched with the efficiency of the actuating means for the particular frequency at which that zone is fully responsive.

In testimony whereof I affix my signature.

MARCUS C. HOPKINS.