

June 14, 1932.

E. H. SMYTHE

1,863,072

SOUND RADIATOR AND METHOD OF MAKING THE SAME

Filed Dec. 26, 1929

2 Sheets-Sheet 1

Fig. 1.

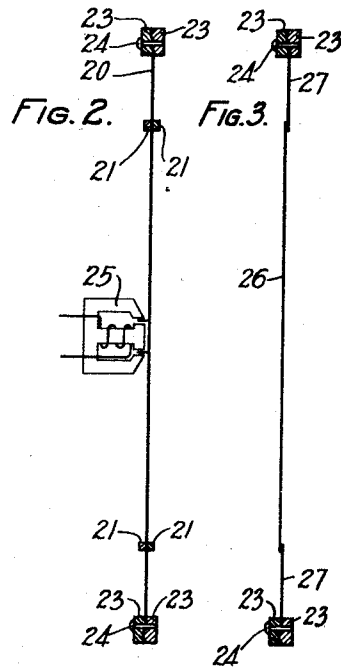
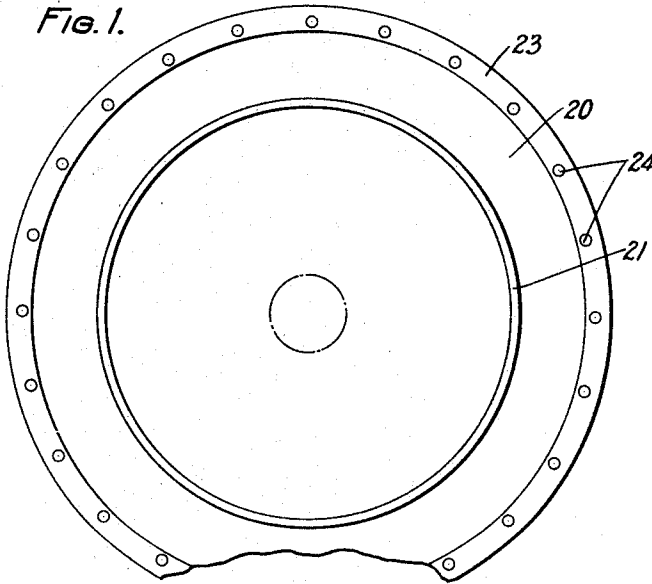


Fig. 4.

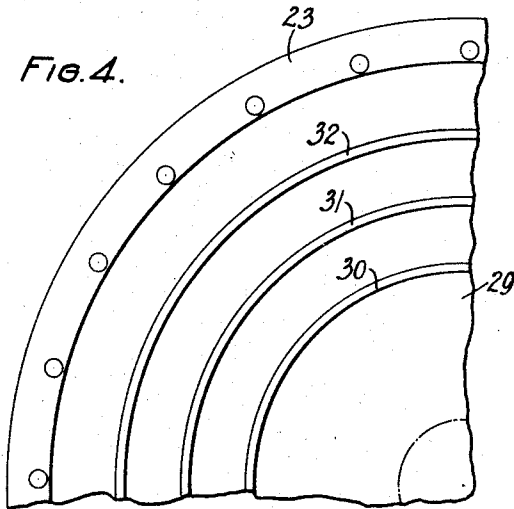


Fig. 6.

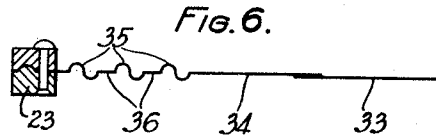


Fig. 7.

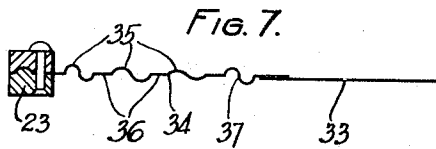


Fig. 5.

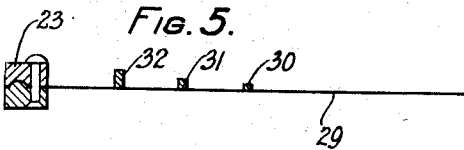
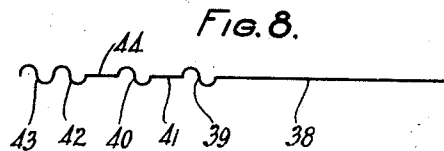


Fig. 8.



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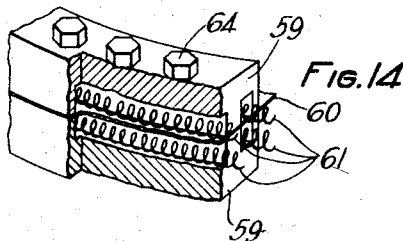
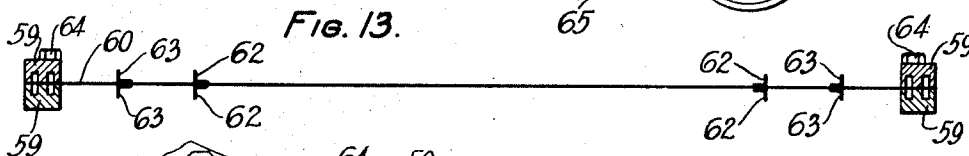
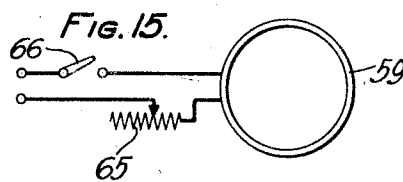
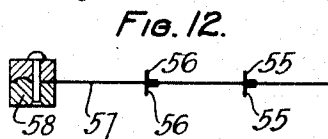
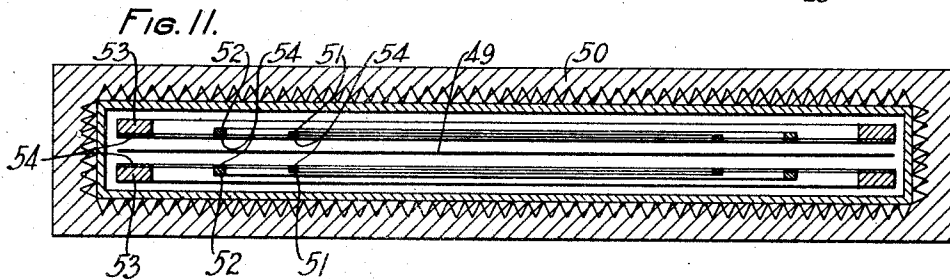
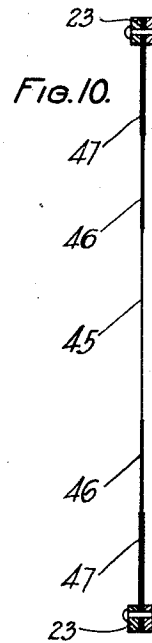
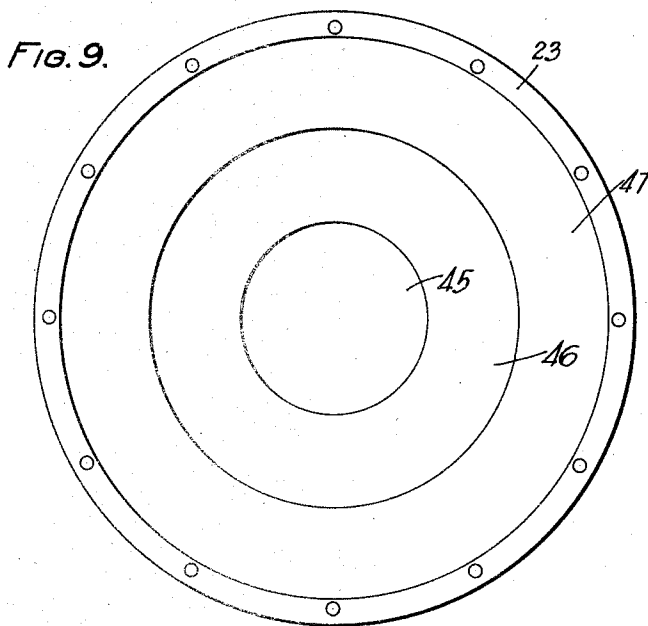
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2 Sheets-Sheet 2



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SOUND RADIATOR AND METHOD OF MAKING THE SAME

Application filed December 26, 1929. Serial No. 416,394.

This invention relates to sound radiators of the stretched diaphragm or membrane type, and a method of making the same and more particularly to large diaphragms adapted to radiate directly waves of the frequency of speech or music.

An object of the invention is to minimize the production of standing waves, or resonance effects, in the diaphragm due to wave reflection at the peripheral support.

The occurrence of standing waves in a diaphragm is due to the fact that the transverse motion imparted to the diaphragm at its driving point is propagated to the other parts of the diaphragm with a finite velocity determined by the mass and the tension of the stretched diaphragm, and to some extent by its shape. As the motion is propagated outwardly some of the vibratory energy is imparted to the air and some is lost in the molecular friction in the material of the diaphragm, but, in general, only part of the vibratory energy is dissipated by the time the wave reaches the support. At the periphery of the diaphragm the waves are reflected and the energy is returned to the driving point where it may again be reflected. At certain frequencies the reflected waves reinforce the outgoing waves, giving rise, in a well known manner, to standing waves or resonance effects. The presence of such standing waves results in greatly intensified sound radiation at the frequencies at which they occur, and in large distortions of the frequency-response characteristic of the radiating device.

In accordance with this invention these resonance effects are substantially diminished or eliminated by increasing the energy dissipation of the waves in their path from the driving point to the periphery whereby the reflected waves are so diminished in amplitude that they are ineffective to cause serious resonance effects. The increased energy dissipation is obtained by so constructing the diaphragm that the propagation velocity of the vibrations is progressively diminished as the wave travels outwardly from the driving point. In this way the wave length in the outer regions is shortened, the time required for a disturbance to travel the distance from

the driving point to the supporting edge and back is increased, and on account of the greater number of wave lengths in the path traversed, the waves are more strongly attenuated in traversing this distance.

The diminution of the wave velocity is effected by progressively reducing the tension in the diaphragm or membrane in the regions more remote from the driving point, for example, by dividing the diaphragm into zones of diminishing tensions separated by light rigid members of sufficient strength to sustain the tensional difference between adjacent zones. This arrangement substantially reduces or wholly eliminates objectionable effects that may arise from the reflection of energy from the support. Furthermore the zones of different tensions are as nearly as possible matched in impedance so as to minimize the reflection of energy as the wave passes from zone to zone; and the reduction of the propagation constant in the outer peripheral portion causes the central area or zone of the sound radiator to operate as a piston over a wide range of frequencies.

A feature of the invention relates to the method of tensioning the large diaphragm and securing the marginal terminating rings between zones of different tensions. In one embodiment the diaphragm is clamped in a frame having a large coefficient of expansion and the frame is heated electrically to stretch the diaphragm to its ultimate tension. A light and rigid ring is fastened to the diaphragm to form the central zone. The heating of the frame is then reduced to relieve the tension on the outer zone of the diaphragm by a desired amount and a larger ring is fastened to the diaphragm to form another zone of different tension. This process may be carried further to obtain a diaphragm having any desired number of zones of various tensions diminishing from the center toward the periphery, to produce a sound radiator in which reflection losses are minimized and the energy imparted to the air made substantially uniform over the frequency scale.

Another feature of the invention relates to stretching the diaphragm mechanically by

attaching the diaphragm to a corrugated annular supporting section and forming an additional corrugation close to the juncture of the diaphragm and supporting sections to tension the diaphragm to a uniform maximum value and simultaneously form regions of gradually decreasing tension in the corrugated section toward the periphery.

These and other features of the invention will be more fully disclosed in the following detailed description taken in connection with the accompanying drawings.

Fig. 1 is a front view of a sound radiator showing a plurality of zones of different tension in accordance with this invention;

Fig. 2 is a cross-sectional view of Fig. 1 showing an electro-dynamic unit for driving the sound radiator;

Fig. 3 is a cross-sectional view of a modified form of the invention illustrating the central zone held under tension by an outer zone of heavier material;

Fig. 4 is a sectional view of another form of the invention showing a sound radiator having multiple zones decreasing in tension toward the periphery;

Fig. 5 is a cross-sectional view of an outer fragmentary portion of a sound radiator similar to Fig. 4 except that the rings are of different cross-sectional form and are secured to only one side of the diaphragm;

Figs. 6 and 7 are cross-sectional views of portions of a radiator in which the stretching is performed mechanically;

Fig. 8 is a sectional view of modified form of the invention in which the corrugated edge supports the tension of the diaphragm;

Fig. 9 is a front view of another form of the invention showing a composite sound radiator in which the tension of the central section is maintained by several outer annuli of different materials;

Fig. 10 is a cross-sectional view of Fig. 9;

Fig. 11 shows in cross-section a method of heating the diaphragm and attaching the marginal rings;

Fig. 12 is a cross-sectional view of a portion of a sound radiator having tension supporting rings of angular cross-section shown diagrammatically;

Fig. 13 illustrates another method of stretching the diaphragm by electrically heating the master ring and attaching the tension rings at graduated temperatures;

Fig. 14 is an enlarged detail view in perspective of a section of the master ring shown in Fig. 13 with a portion cut away to show the cavities containing the heating elements; and

Fig. 15 represents a schematic circuit for regulating the heating of the master ring shown in Fig. 13.

The sound radiator or diaphragm according to this invention comprises a stretched membrane having zones of different tension

to reduce reflection losses and more efficiently and uniformly radiate energy to the air over a wide range of frequencies of speech and music. The diaphragm material preferably employed, in accordance with this invention is a metallic alloy composed of approximately 98.5% aluminum, and 1.5% manganese, which is rolled down to a thickness less than 0.005 inch and preferably 0.001 or 0.002 inch. This material has the desirable property of high tensile strength such that the diaphragm may be stretched, without going beyond its elastic limit, to give it such a degree of tensional stiffness that the velocity of transverse vibration therein is at least one-quarter of the velocity of sound in air. Other properties of this material are low mass per unit area and low flexural stiffness. While this material has been found satisfactory for the purpose of this invention, other materials having similar properties may be used.

Referring to Fig. 1 the circular membrane 20, assumed in the present case to be of two mil aluminum alloy, is clamped in a master frame (not shown) and stretched uniformly to a high degree, for example, forty pounds per square inch, or, if desired, to a higher degree just safely short of the elastic limit of the membrane. While the membrane is maintained under this tension a light and rigid metallic ring or marginal termination 21, preferably of aluminum and in two parts, is fastened to the surface of the membrane, for instance by solder. This ring surrounds a central area or zone and forms an edge which is strong enough to resist the ultimate differential tension between zones of the inward radial pull of the membrane, and to maintain the tension of the central zone. When the two-part ring 21 is securely fastened to the membrane the tension of the outlying portion of the diaphragm 20 may be reduced a sufficient amount so that the tension exerted on this portion is lower than in the central zone. A supporting termination or ring 23 may then be attached to the periphery of the outer zone by screws 24, the membrane being clamped between the two halves of the ring, and the membrane may then be cut away from the master ring and trimmed at the outer edge of the supporting ring 23. The membrane may be driven at its center by an electro-dynamic unit 25, of the moving coil type, as shown schematically in Fig. 2. If the mass of the ring 21 is small the central zone and ring will vibrate as a whole over a certain range of frequencies. The outlying zone between the central zone and the supporting ring by the proper proportioning of its mass and tensional restoring force is as nearly as possible matched in impedance with the central zone and ring; and the reduced propagation constant, due to the lower tensional elasticity and increased mass of this zone, acts to re-

duce objectionable effects that may arise from reflection of energy from the supporting ring.

A similar result may be accomplished as shown in Fig. 3, in which a stretched membrane 26 is connected directly to a flat ring or annulus 27 of sheet metal, of either the same or different material, having its weight and flexural restoring force so proportioned as to tend to produce the desired impedance and propagation constant. If the outer edge of the membrane 26 while under tension is firmly and permanently secured to the inner edge of the flat annulus 27, the inward radial pull exerted by the stretched membrane on the outlying flat ring will gradually be converted from a radially inward tension on the grains of the material at the inner edge of the ring to a peripheral or circumferential compression upon the grains as the outer portion of the ring 27 is approached. The toughness of the annulus 27 will be sufficient to resist the inward radial pull, and the increased mass and reduced elastic restoring force of the annulus toward the outer periphery, which force gradually becomes a purely flexural restoring force, provide the mechanical constants necessary to tend to produce the desired matched impedance and reduced propagation constant. The outer edge of the flat annulus 27 is fastened to the supporting ring 23 to constitute the outer boundary of the radiating surface. The supporting ring however in this case is not called upon to support any of the inwardly directed radial tension, as that has been converted into circumferential compression by the time the supported periphery is reached. If desired the flat interposed annulus 27 may have its constants progressively changed toward the periphery by being slotted or perforated or by being loaded with masses so disposed as not to increase its flexural rigidity.

A sound radiator having multiple zones under different tensional stresses is shown in Fig. 4 and comprises a large metallic membrane 29 stretched to a high tension of say, forty pounds per square inch, in a manner similar to the stretching of the diaphragm described in Fig. 1. A light rigid zone termination or ring 30 is permanently fastened to the boundary of the central area of the diaphragm concentric with the periphery thereof. The tension of the diaphragm is then reduced to, say thirty pounds per square inch and a peripherally more rigid and slightly heavier termination or ring 31 is fastened to the boundary of a circular area or zone outside of the termination 30. Reducing the edge tension further to, say, twenty pounds per square inch and placing a more rigid and slightly heavier termination or ring 32 on the boundary of the third zone and finally reducing the tension of the diaphragm to, say, ten pounds per square inch

and placing the outer supporting ring 23 on the periphery of the diaphragm surface produces a progressively decreasing propagation constant in the diaphragm surface from the driving point to the periphery thereof. It will be apparent that the tensional restoring force is gradually reduced and the mass gradually increased until the outer retaining and supporting ring is reached. The tensional restoring force and mass of each marginal zone is then related so as to tend to produce the effect of matched impedance and gradually reduced propagation constant.

Fig. 5 shows a similar arrangement to that of Fig. 4 except the tension supporting terminations or rings 30, 31 and 32 are cemented or otherwise secured to only one side of the diaphragm surface, and are of increasing cross-section from the central portion to the periphery and are of light rigid material so as not to materially increase the mass of the sound radiator.

Figs. 6 and 7 show a method of stretching a metallic membrane to provide zones of tapered tension toward the periphery of the diaphragm. This is accomplished by attaching, untensioned, a circular zone or membrane 33 of aluminum alloy to the inner edge of an annular portion 34, of similar or heavier material, having a plurality of concentric corrugations 35 near the periphery with intervening flat zones 36. The composite diaphragm may then be mounted in the supporting ring 23, and an extra corrugation 37, as shown in Fig. 7, formed in the flat zone 36 that immediately adjoins the membrane or central zone 33 to tension the membrane to a maximum uniform value. The tension in the outer corrugated zone will be decreased in successive steps toward the periphery, the corrugations serving as circular compression members to take up successive parts of the converted radial tension. The depth and slope of the corrugations and the separation between them may be employed to control the mass and stiffness factors for the purpose of securing the desired impedance and propagation constant relations between the center and the periphery of the diaphragm. The peripheral corrugations may be of any desired number.

Fig. 8 represents a half section of a sound radiator in which the material is of the same thickness, preferably a two mil circular sheet of aluminum alloy, which is provided with concentric zones of different tension similar to the devices described in connection with Figs. 4 and 5 except that in Fig. 8 the radiator is not provided with tension rings but the tension is sustained in the separate zones by substantially rigid corrugations. The radiator or diaphragm 38 is provided with a corrugation 39 by spinning or pressing in a suitable die to tension the central area of the diaphragm to say 30 lbs. per square inch.

During this operation the free rim of the diaphragm outside the circle of the corrugation 39 is untensioned so that the greatest tension is exerted on the central area of the diaphragm. In order to maintain the initial tension in the central area and at the same time provide outlying zones of different tension, it is necessary to leave the die in contact with the corrugation 39 until the complete tensioning process has been performed. A similar die of larger circumference is then placed on the zone adjacent the central area of the diaphragm and the corrugation 40 is spun or pressed into the diaphragm on a circle of larger diameter than the circle of corrugation 39 so that there is an intervening zone 41 between the two corrugations. The pressing of the corrugation 40 is so performed that the diaphragm material in the zone 41 is stretched during the pressing to a tension of say 20 lbs. per square inch. A similar corrugation 42 or a double corrugation such as represented by 42 and 43 may be formed on a circle which will define the periphery of the diaphragm. This pressing, of course, is performed while the two previously described dies are in engagement with the diaphragm so that the tension applied to the zone 44 between corrugations 40 and 42 will be of such value as to present an area 44 of less tension than the tension of the zone or area 41, say approximately 10 lbs. per square inch. It is, of course, understood that this method of forming the separate zones of different tension may be carried out to any desirable degree and also to provide an integral termination for the sound radiator, as, for instance, the double corrugations on the periphery of the diaphragm 38 to form a rigid and light boundary. When the spinning operations are completed the dies are removed and the diaphragm will present a surface having zones of different tension from the central area to the periphery and in which the differential tension of the separate zones is maintained by the concentric corrugations formed in the material.

The general principles of this invention may be carried out in another form, as shown in Figs. 9 and 10, in which the stretched aluminum alloy embrane 45 is joined to the inner edge of a flat annulus or zone 46 of different material, such as copper, having its mass and elastic restoring force so proportioned as to tend to mechanically match the impedance of the central zone of the diaphragm. The outer edge of the zone 46 is joined to the inner edge of a zone of a still different material, such as a flat annulus or zone 47 of lead, which has still greater mass and less flexural restoring force per unit area. The outer edge of the terminating zone may be supported in the circular frame or ring 23. In this embodiment reliance may be placed primarily upon ordinary flexural rigidity and restoring force

in the intermediate and outlying zones instead of tensional elasticity as previously described in other forms of the invention, for proportioning the impedances and propagation constants to reduce or eliminate reflection effects.

Another of forming zones of different tension on a stretched membrane and providing light marginal terminations about each zone for supporting the tension of the several zones may be practiced in a manner shown in Fig. 11. A circular diaphragm 49 such as a thin sheet of aluminum alloy of convenient size is placed in an electric oven 50 with a plurality of pairs of light rings 51, 52 and 53 concentric with each other and with the periphery of the diaphragm. One member of each pair of rings underlies and the other overlies the diaphragm surface and the cooperating pairs of rings are preferably of increasing mass and circumferential compression strength from the inner ring to the outer ring. The rings are of a material having a coefficient of expansion less than the coefficient of expansion of the aluminum alloy diaphragm. The proximate surfaces of each pair of rings are coated with a layer of fusible metal or aluminum alloy solder 54, the melting point of the solder being highest for the inner pair of rings 51, a lower value for the solder on the intermediate pair of rings 52, and the melting point of the solder on the outer pair of rings 53 being still lower. The furnace 50 may be electrically heated to raise the temperature high enough to melt the fusible metal or solder on all the rings, and then the temperature is gradually lowered. As a result, when the temperature lowers past the melting point of the solder on the inner pair of rings 51, the rings are soldered or sweated to opposite sides of the membrane. The further reduction of the temperature causes the solder on the intermediate pair of rings 52 to solidify and set on the diaphragm, and the final pair of rings 53 are soldered to the periphery of the diaphragm and each other when the temperature is lowered past the melting point of the solder on these rings. The tensioning of the several zones encompassed by the marginal terminating rings may be explained in the following manner. If the solidifying point of the solder on the inner pair of rings 51 is, for instance, 400° F., then when the temperature of the diaphragm is reduced to room temperature or 70° F., the central zone of the membrane will be under a tension represented by a 330 degrees contraction of the aluminum alloy with reference to the lesser degree of contraction of the inner pair of rings for this temperature difference. If the solidifying point of the solder on the intermediate rings 52 is 350° F. then the tension of the zone between the rings 51 and 52 will be the differential contraction brought about

by the temperature drop of 350° minus the room temperature, or 280°. Similarly, if the solidifying point of the solder on the outer rings 53 is 300° F. then the tension of the zone between rings 52 and 53 will be represented by the differential contraction between the solidifying value and room temperature, or 230°. Thus there will be a step-by-step reduction in tensional elasticity in the diaphragm from the center to the periphery, to produce a decreasing propagation constant and thereby reduce reflectional waves interfering with the wave energy imparted to the diaphragm.

The marginal terminating rings separating the different zones may be formed as shown in Fig. 12 in which the inner and intermediate pairs of rings 55 and 56 are relatively light and rigid and have an angular cross-section. The proximate surfaces of these rings may be slightly wider than the height of the rings to provide a good contact with the diaphragm surface 57. These rings may be suitably attached to the membrane 57 by solder, cement or rivets and the periphery of the membrane may be supported by a heavy ring 58.

Another method of stretching the membrane and forming several zones of different tension is shown in Fig. 13 in which a supporting frame or ring 59 is clamped to the periphery of the metallic alloy diaphragm 60 by bolts 64 while both the membrane and frame are cold. The supporting ring 59 is preferably made of a material having a greater coefficient of expansion than the material of the diaphragm. The diaphragm can then be put under tension to any desired degree by heating the circular resistances 61 contained in the cavities of the ring, as illustrated, the diaphragm being in contact with the atmosphere and not heated to any substantial extent. With the maximum degree of heat in the ring and a corresponding maximum degree of tension in the diaphragm, due to the expansion of the ring, the central area of the membrane may be held under the maximum degree of tension by soldering or cementing an aluminum ring or pair of rings 62 to the boundary of the central area or zone. The temperature of the supporting ring 59 may be controlled, for instance, by regulating the heating of the ring 59 as shown in Fig. 15 in which the variable resistance 65 may be adjusted, to reduce the heating and consequently the tension in the zone surrounding the central ring, and a second ring or pair of rings 63 concentric with and outside of the rings 62 may then be attached to the boundary of this zone to support the stress placed on the grains of this intermediate zone. Of course this process may be repeated as many times as desired depending on the size of the membrane and the number of zones of graduated tension desired from the center to the periphery of the

membrane. When the desired number of zones of different tension are obtained the switch 66 may be opened to further reduce the tension in the peripheral zone of the diaphragm and a suitable permanent terminating ring 23 may be attached to the diaphragm within the master heating ring 59.

While the various methods described in accordance with this invention relate particularly to forming divided zones of different tension in the diaphragm surface, it is apparent that the methods may also be practiced to form a single peripheral ring on the edge of the diaphragm to support the tension in the diaphragm surface and act as a supporting frame for the membrane. It is also to be understood that the invention applies to shapes of membranes other than a circular membrane as described herein, and that the invention is only to be limited within the scope of the appended claims.

What is claimed is:

1. A sound radiator comprising a stretched membrane, certain portions of which have different propagation constants, and all of said portions having their characteristic impedances substantially matched.
2. A sound radiator comprising a stretched membrane having a plurality of divided sections under different degrees of tension.
3. A sound radiator comprising a stretched membrane having a plurality of sections under different degrees of tension, and means capable of sustaining the tension of successive sections from the center of said membrane to the periphery thereof.
4. A sound radiator comprising a stretched membrane having a plurality of sections under different degrees of tension, and means for each section for maintaining the tension in each section.
5. A sound radiator comprising a stretched membrane having a plurality of sections under different degrees of tension, and means for each section for maintaining the tension in each section, said means progressively increasing in mass.
6. A sound radiator comprising a stretched membrane having a central zone under a high tension, a supporting element, and a terminating zone between said central zone and element under a lower tension than said central zone.
7. A sound radiator comprising a stretched membrane having a central zone under a high tension, a supporting element, a terminating zone between said central zone and element under a low tension, and an intermediate zone between said central zone and terminating zone under a tension at a value between the tension of said other zones.
8. A sound radiator comprising a stretched membrane, and a terminating zone of material directly connected to said membrane, the mass and elasticity of said zone being so re-

lated to the mass and elasticity of said membrane as to produce the effect of substantially matched impedance and reduced propagation constant.

5 9. A sound radiator comprising a surface in which the tensional elasticity decreases and the mass increases to produce a lessening wave propagation velocity and an increasing value of wave energy attenuation.

10 10. A sound radiator comprising a stretched membrane having a central zone under a high tension, a surrounding zone under less tension, an outer zone under still less tension, and supporting rings maintaining the tensional differences between the individual zones.

11. A sound radiator comprising a stretched circular membrane, an intermediate annular member supporting the tension of said membrane, and an outer annular member attached to the periphery of said intermediate member.

12. A sound radiator comprising a stretched circular membrane of light metallic material, an intermediate annular member of heavier material supporting the tension of said membrane, and an outer annular member of still heavier material attached to the periphery of said intermediate member.

13. A sound radiator comprising a stretched circular membrane of light alloy metal, an intermediate annular member of heavier material and less flexural restoring force supporting the tension of said alloy membrane, and an outer annular member of still heavier material and minimum flexural restoring force attached to the periphery of said intermediate member.

14. A sound radiator comprising a membrane having a central zone under a high tension, and a surrounding circular member having its inner edge attached to said membrane, said surrounding annular member having corrugations to support the tension in said annular member.

15. The method of stretching a sound radiator comprising a diaphragm having a supporting frame on the periphery thereof, which comprises heating the frame electrically to expand the diaphragm to a maximum tension, maintaining a section of said diaphragm under the maximum tension, reducing the heating to lessen the tension outside of said section, maintaining the lesser tension in the surrounding section, and further reducing the heating to form an outer section of minimum tension.

16. The method of stretching a diaphragm comprising a circular plane surface and concentric marginal rings having layers of fusible material, which comprises heating the diaphragm and marginal rings to a high temperature, reducing the temperature to fuse the inner ring to the margin of a central zone, reducing the temperature to fuse the second

concentric ring to the margin of a surrounding zone, and further reducing the temperature to fuse the outer ring to the periphery of said diaphragm.

17. The method of stretching a diaphragm comprising a central section and an annular section having corrugations near the periphery thereof, which comprises forming an additional corrugation in said annular section between the outer corrugations and the central section.

18. The method of stretching a metallic diaphragm held in a master supporting member which comprises electrically heating the member to expand the diaphragm surface, and applying a permanent frame to the diaphragm before contraction of the surface.

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