Nov. 7, 1950 A. M. WIGGINS 2,529,467

SECOND ORDER DIFFERENTIAL MICROPHONE

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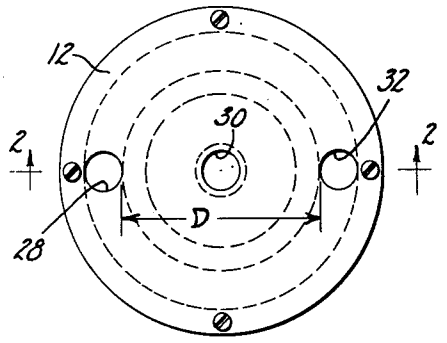


FIG. 1

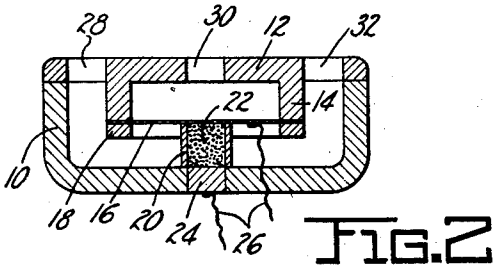


FIG. 2

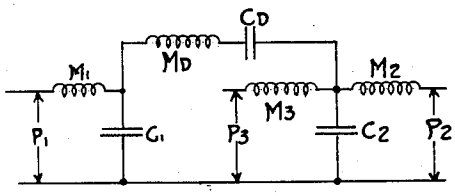


FIG. 4

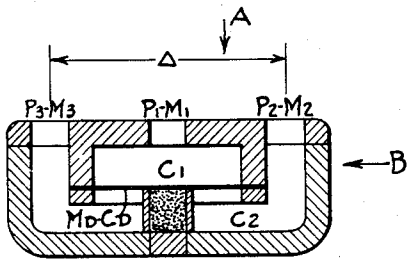


FIG. 3

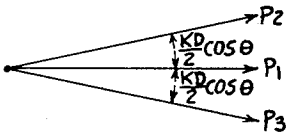


FIG. 5

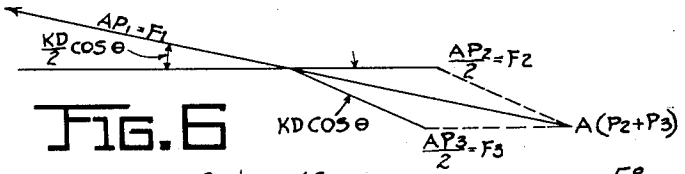


FIG. 6

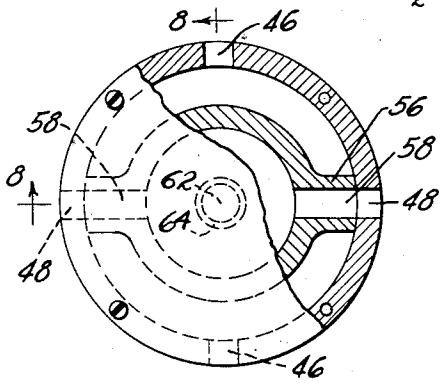


FIG. 7

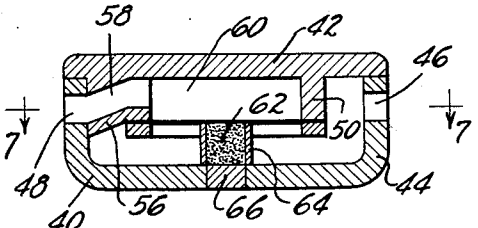


FIG. 8

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SECOND ORDER DIFFERENTIAL MICROPHONE

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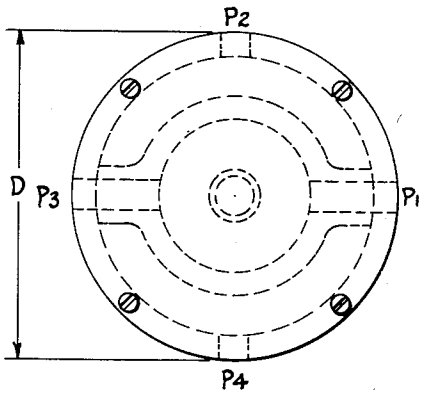


FIG. 9

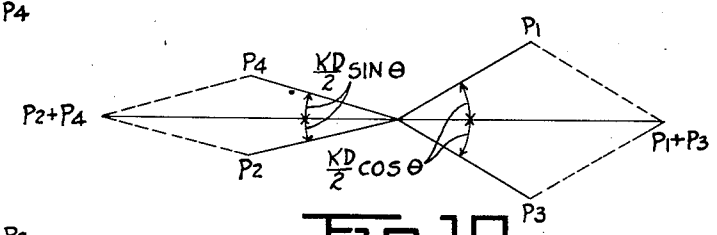


FIG. 10

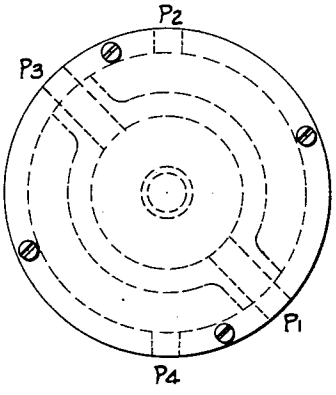


FIG. 11

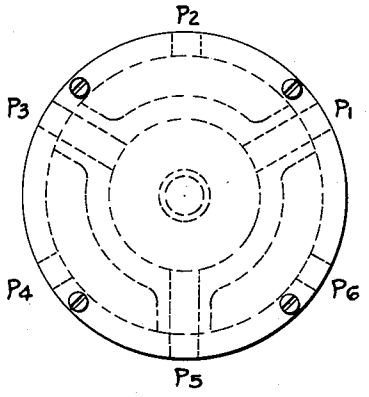


FIG. 12

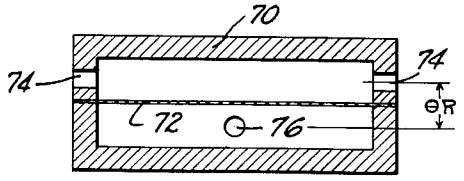


FIG. 13

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UNITED STATES PATENT OFFICE

2,529,467

SECOND ORDER DIFFERENTIAL MICROPHONE

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Application August 4, 1948, Serial No. 42,369

12 Claims. (Cl. 179—135)

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This invention relates to improvements in differential microphones.

Differential microphones as here considered are of the general type illustrated in and disclosed in Patent No. 2,350,010, granted May 30, 1944, to F. C. Beekley. A microphone of this type may be defined as a pressure gradient microphone which has two or more sound entrances spaced by an acoustic distance which is small compared to the wave lengths of sound which may pass through said entrances to impinge upon sound responsive generating means incorporated in the microphone, whereby the resultant of the forces acting on the generating means in response to random sounds of distant origin is attenuated, while the resultant of the forces acting on the generating means in response to sounds of close origin is preponderantly that resulting from the sound pressure at the entrances nearest to the sound source. In other words, a differential microphone is one having a proximity effect rendering the microphone highly sensitive to sounds of close origin directed preponderantly at one sound entrance and much less sensitive to random sounds of distant origin, so that sounds of close origin are transmitted intelligibly, and random sounds of distant origin are substantially ineffective upon the generating means or have such diminished effect thereon as not to detract materially from the intelligibility of the translation of the sounds of close origin by the microphone.

This invention relates particularly to a second order differential microphone which has a very high discrimination against random sounds of distant origin and which is responsive only to the difference between two differential resultant forces of pressure gradients. One form of such a second order differential microphone is illustrated in my co-pending application, Ser. No. 775,869, filed September 24, 1947.

The primary object of this invention is to provide a novel, simple and inexpensive microphone having a discrimination of the second order which requires only one sound responsive membrane or vibratory element and one generating element operable by said membrane or vibratory member.

A further object is to provide a microphone of this type having a single vibratory element whose opposite surfaces are exposed to sounds traveling through different paths, the mouths of said paths being located in substantially the same plane and the openings being at least three in number with two thereof leading to one face of the membrane, being spaced equally from and arranged oppositely with respect to the mouth of a passage leading to the opposite surface of the membrane.

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Other objects will be apparent from the following specification.

In the drawing:

Fig. 1 is a face view of one embodiment of the invention.

Fig. 2 is a transverse sectional view taken on line 2—2 of Fig. 1.

Fig. 3 is a diagrammatic view similar to Fig. 2 illustrating the forces and the electrical conversion values encountered in the operation of the device.

Fig. 4 is the equivalent electrical circuit of the device.

Fig. 5 is a diagrammatic view illustrating pictorially the application of the forces and the angular relationship thereof in the operation of the device.

Fig. 6 is a diagrammatic illustration of the forces acting upon the device.

Fig. 7 is a face view of another embodiment of the invention with parts thereof shown in section, taken on line 7—7 of Fig. 8.

Fig. 8 is a transverse sectional view taken on line 8—8 of Fig. 7.

Fig. 9 is a schematic view of the embodiment illustrated in Fig. 7, illustrating the application of the forces to the device.

Fig. 10 is a vector diagram of the pressures when applied as illustrated in Fig. 9.

Fig. 11 is a diagrammatic view of a modification of the embodiments of the invention illustrated in Figs. 7 and 8.

Fig. 12 is a diagrammatic view of another embodiment of the invention illustrated in Figs. 7 and 8.

Fig. 13 is a sectional view similar to Figs. 2 and 8, illustrating another embodiment of the invention.

Referring to the drawings, and particularly to Figs. 1 to 6 thereof, the numeral 10 designates the housing of a microphone which is of substantially cup-shape and whose open end is adapted to be spanned by a closure plate 12. The closure plate 12 mounts an annular flange 14 and a diaphragm 16 spans the flange 14 and is fixedly secured thereto as by the retainer ring 18. The translating medium or generating system is preferably of the carbon granule type, and, for this purpose a suitable annular retainer 20, which may be formed of glass wool or other readily compressible material having certain properties of resilience, is positioned between the diaphragm

16 and the base of the casing 10. Carbon granules 22 are confined within the retainer 20 and engage a button or other conductor member 24 carried by the housing 10 and also are adapted for engagement with the diaphragm 16. Electrical leads 26 extend respectively from the conductor button 24 and the diaphragm 16.

The face plate 12 has three openings 28, 30 and 32 formed therein. The openings 28 and 32 communicate with the space exteriorly of the diaphragm mounting flange 14 so that they may pass into impingement with the inner or bottom surface of the diaphragm 16 as illustrated. The opening 30 is formed within the outline of the annular flange 14 and provides access for sound to act upon the upper or outer face of the diaphragm 16. As here illustrated, the diaphragm 16 is positioned substantially centrally between the top and bottom walls of the casing, and the openings 28, 30 and 32 are arranged in line, as best seen in Fig. 1. The openings 28 and 32 are located on opposite sides of the opening 30 and are spaced equally therefrom. While carbon button generating system has been illustrated herein for purposes of convenience, any other generating system, such as piezo electric element, a condenser, and ribbon or a moving coil, may be utilized if so desired. While the opening 30 has been illustrated as positioned concentrically with respect to the diaphragm, that centered condition is not essential. The alignment of the openings 28, 30 and 32 for maximum second order differential effect is essential, however. Departures from such alignment produce the same action, which will be discussed hereafter with respect to the construction illustrated in Fig. 13.

The microphone illustrated in Figs. 1 and 2 responds to the gradient of the gradient of sound pressure even though it uses only the single diaphragm 16. The equivalent electrical circuit of this microphone is shown in Fig. 4, and the conversion units occur and are derived from the elements as indicated in Fig. 3. Thus, referring to Fig. 3, the openings M1, M2 and M3, being in line, are provided to have approximately the same acoustic impedance. Sound pressure from direction A originating at a large distance away from the device will arrive at the three openings in phase and at equal amplitude, so that there will be no movement of the diaphragm for sound from this direction. Sound from direction B originating at a large distance away from the microphone will arrive at the openings at equal amplitudes but in different phase relation. Fig. 5 is a vector diagram of the pressures at the three openings. The vector diagram of Fig. 5 applies for any angle of incidence of sound from direction B which is coincident with the axis of the microphone, or, stated differently, with which the diaphragm and the planes of the mouths of the three openings are parallel. Referring to Fig. 5, K equals $2\pi/\lambda$ where λ is the wave length. Further referring to the indicia upon Fig. 5, D is the distance between the two outside openings M2 and M3, or 28 and 32 referring to Fig. 2.

Fig. 6 is a diagram of the forces acting on the diaphragm due to the sound pressure pectorially illustrated in Fig. 5. The force on the front of the diaphragm is acting in the opposite direction from the force on the back of the diaphragm, and the magnitude of the sum of F2 and F3 is equal to F1. A further condition illustrated in this diagram shows the value $A(P2+P3)$ is less than the force F1.

The diaphragm responds to the following rule (P2—P1) minus (P1—P3).

Since P2—P1 or P1—P3 is the pressure gradient, the microphone responds to the difference in the pressure gradient which is the gradient of the pressure gradient.

By referring to Fig. 5, the change in pressure which is available for actuating the diaphragm may be written

$$\Delta(\Delta p) \text{ equals } P\left(\cos\left[\frac{KD}{2}\cos\theta\right]\right)+ j\sin\left[\frac{KD}{2}\cos\theta\right] \text{ minus 2 plus } \cos\left[\frac{KD}{2}\cos\theta\right] \text{minus } j\sin\left[\frac{KD}{2}\cos\theta\right]$$

Since for small angles

$$\cos\left(\frac{KD}{2}\cos\theta\right) \text{ equals 1 minus } \frac{K^2D^2\cos^2\theta}{4}$$

$$\Delta(\Delta p) \text{ equals } P\frac{K^2D^2}{2}\cos^2\theta \qquad 1$$

The equation shows that the force for actuating the diaphragm is proportional to the square of the frequency for distant sounds and the microphone response rises approximately 12 db per octave. The equation further shows that the force has a polar curve proportional to $\cos^2\theta$. The random efficiency may be calculated by the following equation:

$$\text{Eff. equals } \tfrac{1}{2}\int_0^{\pi} F^2(\theta)\sin\theta\, d\theta \text{ equals } \tfrac{1}{2}\int_0^{\pi}\cos^4\theta\sin\theta\, d\theta$$

Efficiency equals $\frac{1}{5}$.

For close sounds the pressure available for actuating the diaphragm is predominantly the pressure at one sound opening.

Assuming that the pressure for close talking is predominantly the sound pressure at the center opening in the embodiment illustrated, and also assuming that this sound pressure is the same as that due to a distant source, the discrimination against random sound originating at a distance may be written

$$\text{Dis. equals } \frac{4\sqrt{5}}{K^2D^2}$$

The discrimination for either of the two openings used for close talking purposes is

$$\text{Dis. equals } 2\frac{\sqrt{5}}{K^2D^2}$$

As shown from Equation 1, the microphone has a directional response which is proportional to $\cos^2\theta$. This is more sharply directional than present well known bidirectional microphones whose polar response is proportional to $\cos\theta$. This may be desirable in microphones intended for some uses for applications.

Another embodiment of the invention is illustrated in Figs. 7 and 8 wherein the microphone has a housing 40 of substantially cup-shape closed by a cover plate 42, and the side walls 44 of the casing 40 have a plurality of openings formed therein constituting the openings 46 which are arranged diametrically opposite each other and the openings 48 which are arranged diametrically oppositely. In this embodiment the cover 42 has an annular flange 50 depending therefrom which is spanned by the diaphragm 52 secured in place by a retainer ring 54. The annular flange 50 is of smaller diameter than the housing wall 44 and is spaced inwardly therefrom but is provided at points in register

with the openings **48** with enlargements **56** which have passages **58** therein communicating with the passages **48** in the cup-shaped housing. The openings **58** lead to the cavity **60** at the upper side of the diaphragm **52** as viewed in Fig. 8. The openings **46** are open for the passage of sound for impingement upon the bottom side of the diaphragm **52** as viewed in Fig. 8. The microphone has a generating element, here shown as a group of carbon granules **62**, encased within a retainer ring **64** spanning the space between the diaphragm **52** and the bottom wall of the casing **40**, and the bottom wall of the casing **40** has a button **66** therein engaged by said carbon granules **62**.

The response characteristics of this microphone are those of a second order differential similar to the conjoint use of two first order differential microphones connected differentially and placed side by side with their diaphragms located in a common plane. One form of such a microphone is illustrated in my co-pending application, Ser. No. 775,869. One of the important characteristics of this microphone is that the four sound openings **46** and **48** are located in the same plane and it will be observed from the construction that two of these openings, namely the openings **46**, lead to the back of the diaphragm, whereas the openings **48** lead through the passage **58** to the front of the diaphragm. The openings **46** and **48** lead to opposite faces, are alternately arranged around the circumference of the microphone, and the spacing of one opening **46** from an adjacent opening **48** should be the same as the spacing between the other opening **46** and the other opening **48**. The acoustic result or action of any one pair of openings comprising one opening **46** and one opening **48** is the action of a first order differential microphone, and that of the other pair is the equivalent of the action of another first order differential microphone connected in opposition to the one first named.

Fig. 9 is a diagram illustrating the manner in which the pressure forces acting upon the microphone at the various openings are applied. Fig. 10 is a vector diagram of the pressures acting on the diaphragm of the microphone. From Fig. 10 it will be observed that the angle of incidence of sound assumed entails a condition where P2 plus P4 is greater than P1 plus P3. Also in Fig. 9, D is the distance between opposite entrances to the same side of the diaphragm of the microphone. P1, P2, P3 and P4 are the pressures at the various sound entrances.

The change in the pressure gradient available for actuating the diaphragm is the vector sum of all the pressures acting on the diaphragm. This may be written

$$\Delta^2\rho \text{ equals } 2P\left(\cos\left[\frac{KD}{2}\cos\theta\right] \text{minus } \cos\left[\frac{KD}{2}\sin\theta\right]\right)$$

For small angles

$$\cos\left(\frac{KD}{2}\cos\theta\right) \text{ equals } 1-\frac{K^2D^2\cos^2\theta}{4} \quad \cos\left(\frac{KD}{2}\sin\theta\right) \text{ equals } 1-\frac{K^2D^2\sin^2\theta}{4}$$

Therefore,

$$\Delta^2\rho \text{ equals } \frac{PK^2D^2}{2}(\sin^2\theta-\cos^2\theta) \qquad 2$$

The Equation 2 shows that the force available for actuating the diaphragm is proportional to the square of the frequency and the polar curve is given by $\sin^2\theta-\cos^2\theta$.

The random efficiency is given by the following formula

$$\text{Eff. equals } 2\int_0^{\pi/4}\frac{(\sin^2\theta-\cos^2\theta)\sin\theta\,d\theta}{\int_0^{\pi/4}\sin\vartheta\,d\theta}$$

Eff. equals .182

Assuming the pressure for close talking to be predominantly the sound pressure at one opening, and also assuming that this pressure is the same at the microphone as that pressure at the microphone due to a distant source, the discrimination against random sound may be written

$$\text{Dis. equals } \frac{2}{\sqrt{.182}\,K^2D^2}$$

The holes or openings need not all be equally spaced around the diaphragm or equispaced around the circumference of the casing, as shown in Figs. 7 and 9. Instead, they may be arranged as illustrated in the diagram in Fig. 11. Such a configuration will give a different polar pattern which may be calculated in the same manner as calculated above.

Another embodiment of this invention is shown in Fig. 12. This embodiment is analogous to a three-phase network, and its polar response may be calculated as in the case of Fig. 9. Other embodiments of the invention are possible by increasing the number of openings above six, as shown in Fig. 12.

In all of these embodiments the openings must be symmetrical, that is, the adjacent pairs leading to opposite sides of the diaphragm must be spaced the same distance apart and must have their mouths located in the same plane to realize the full second order discrimination against distant sounds. If the mouths of the openings are not all in the same plane, there will be a first order effect with its accompanying decrease in discrimination. Such a condition is illustrated in Fig. 13 where a casing **70** has a diaphragm **72** located squarely therein to divide the interior of the chamber into two substantially equal compartments. Access to one of these compartments is provided by two or more openings **74**, and access to the other compartment is provided by an equal number of openings **76**. The adjacent pairs of openings **74**, **76** are spaced circumferentially the same distance as explained above and are spaced longitudinally or axially, that is, in a direction perpendicular to the diaphragm **72** by the distance θ R as shown in Fig. 13. If the distance θ R between the openings of the two sets is only slightly out of the same plane, there will be a slight first order effect and the microphone will still be within the spirit of the invention. Thus, while for practical considerations best results are obtained when the mouths of the openings are in the same plane, conditions may exist which prevent this ideal arrangement. Departures from the coplanar arrangement are practical if the total distance longitudinally and circumferentially between the adjacent openings of opposite sets and leading to opposite sides of the diaphragm is greater than twice the distance θ R by which the mouths of said openings are disaligned from a common plane, that is, twice the spacing of the plane of said openings in a direction transverse of the diaphragm.

The Fig. 13 embodiment therefore will have the same first order effect, assuming that the re-

quirements above mentioned are observed, but the discrimination, even though not as great as a second order differential effect, will be considerably more than it would be possible to obtain with a first order differential microphone of equal spacing of sound entrances.

In all of the embodiments illustrated in this application, the generating system has been shown as a carbon granule type for convenience. It is to be distinctly understood, however, that the invention is not limited to microphones utilizing carbon granule generating systems, and any other type of generating system may be used, such as a dynamic system including the voice coil and ribbon types, a magnetic system, a piezo electric system or a condenser system. Also it will be understood that the structural chracteristics illustrated here are illustrative and are not intended to be limiting and that structural changes may be made in the microphone from those herein shown within the scope of the appended claims without departing from the spirit of the invention.

I claim:

1. A microphone comprising a housing, a single diaphragm mounted in said housing and dividing said housing into two chambers, a generating element actuable by said diaphragm, a plurality of openings in said housing each having substantially the same acoustic impedance and substantially the same spacing from said diaphragm, at least one of said chambers being in communication with two of said openings, and at least one opening communicating with the other chamber, the mouths of all of said openings being located in a common plane and the mouths of the first named openings being equally spaced from the mouth of the last named opening whereby said diaphragm is responsive only to the difference of the difference in the sound pressure directed by said openings to opposite surfaces of the diaphragm.

2. A microphone comprising a housing, a single diaphragm mounted in said housing, a generating element actuable by said diaphragm, said housing having a plurality of spaced sound passages therein leading to opposite faces of and substantially equi-spaced from said diaphragm, said openings being spaced at different distances from any sound source, at least two spaced passages leading to one face of said diaphragm and the mouth of each being spaced from the mouth of a passage leading to the other face of said diaphragm an equal distance, the mouths of all passages being located in a substantially common plane, said diaphragm being responsive to the second differential of the sound pressure applied thereto through said passages with respect to the various distances between the source of sound and the mouths of said passages.

3. A microphone comprising a housing, a single diaphragm mounted in said housing, a generating element actuable by said diaphragm, said housing having a plurality of spaced similar sound passages therein leading to opposite faces of and substantially equally spaced from said diaphragm, at least two spaced passages leading to one face of said diaphragm whereby the diaphragm is subjected to the differences between sound pressure applied through each thereof and a pressure applied to the opposite face of said diaphragm, the mouths of said passages being located in a substantially common plane and the mouths of said two passages leading to one side of said diaphragm being located at opposite sides of the mouth of a passage leading to the other whereby the difference in the distances from a source of sound to the mouths of one pressure difference applying pair of passages leading to opposite faces of the diaphragm is substantially equal to the difference of the distances for said source of sound to the mouths of another pressure difference applying pair of passages leading to opposite faces of the diaphragm.

4. A microphone comprising a housing, a single diaphragm mounted in said housing, a generating element actuable by said diaphragm, said housing having a plurality of spaced similar sound passages therein leading to opposite faces of said diaphragm and having substantially the same acoustic impedance, at least two spaced passages leading to one face of said diaphragm whereby the diaphragm is subjected to the differences between sound pressure applied through each thereof and a pressure applied to the opposite face of said diaphragm, the mouths of all of said passages being spaced and located with respect to the plane of said diaphragm a small fraction of the spacing between different openings leading to opposite sides of said diaphragm.

5. A microphone comprising a housing, a diaphragm mounted in said housing and dividing said housing into two compartments, and a generating element actuable by said diaphragm, said housing having three openings therein whose mouths lie in a common plane substantially parallel to said diaphragm and whose axes lie in another common plane substantially perpendicular to said first plane and are spaced apart uniformly, the two end openings communicating with one of said compartments and the intermediate opening communicating with the other compartment.

6. A microphone as defined in claim 5, wherein the mouths of said openings are arranged with one thereof displaced laterally from alignment with the other two a distance less than one-half the distance between adjacent openings.

7. A microphone as defined in claim 5 wherein the mouths of said openings are arranged and displaced from a common plane by an amount less than one-half the distance between adjacent openings.

8. A microphone comprising a casing having a substantially flat wall, a diaphragm mounted in said housing substantially parallel to said wall and dividing said housing into two compartments, and a generating element actuable by said diaphragm, said housing having two similar sound passages communicating with one chamber whose mouths open at said wall and a third passage of substantially the same acoustic impedance as said first passages communicating with the other chamber whose mouth opens at said wall between and equi-spaced from the mouths of said first passages and substantially in line therewith.

9. A microphone comprising a houing having a substantially flat wall, an annulus carried by said wall and projecting into said housing, a diaphragm mounted on and spanning the inner end of said annulus intermediate the depth of said housing, an electrical generating element actuable by said diaphragm, said wall having an opening therein communicating with the space within said annulus and having two openings therein communicating with the interior of said casing outwardly of said annulus, the mouth of said first opening being equispaced from and substantially aligned with the mouths of the other open-

ings and all openings having substantially the same acoustic impedance.

10. A microphone comprising a housing having a chamber and defined in part by a removable wall portion having a substantially flat outer surface, a diaphragm carried by said wall and spanning and dividing said chamber and substantially parallel to said outer wall surface, a conductor carried by the portion of said housing opposite said wall portion, a retainer interposed between said diaphragm and conductor, and a body of granular conductive material confined by said retainer in contact with said conductor and an intermediate portion of said diaphragm, and at least three passages of substantially equal acoustic impedance open at said wall in equispaced substantially aligned relation with alternate passages substantially equally spaced from said diaphragm and communicating with different portions of said chamber to impress sound against opposite faces of said diaphragm.

11. A microphone comprising a housing having a chamber and a peripheral wall, a diaphragm spanning said chamber, and an electrical generating element actuable by said diaphragm, said wall having a plurality of pairs of passages therein of similar acoustic impedance and whose mouths are substantially equally spaced from

said diaphragm, one passage of each pair impressing sound upon one face of said diaphragm and the other passage impressing sound upon the other face of said diaphragm, the passages of each pair being displaced the same distance and the axes of the mouths of all of said passages lying substantially in a common plane.

12. A microphone as defined in claim 11, wherein the openings of each pair bear the same relation to each other peripherally and longitudinally and any displacement of the passages of a pair in a longitudinal direction is less than one-half the total distance between the openings of each pair.

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