June 13, 1944. R. W. CARLISLE 2,351,400

MICROPHONE

Filed July 29, 1940 3 Sheets-Sheet 1

Fig. 1

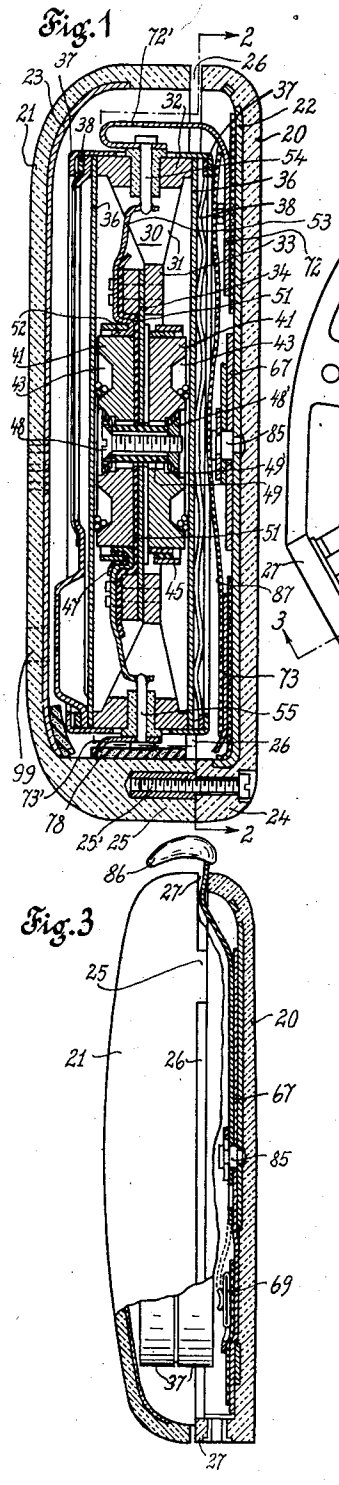


Fig. 2

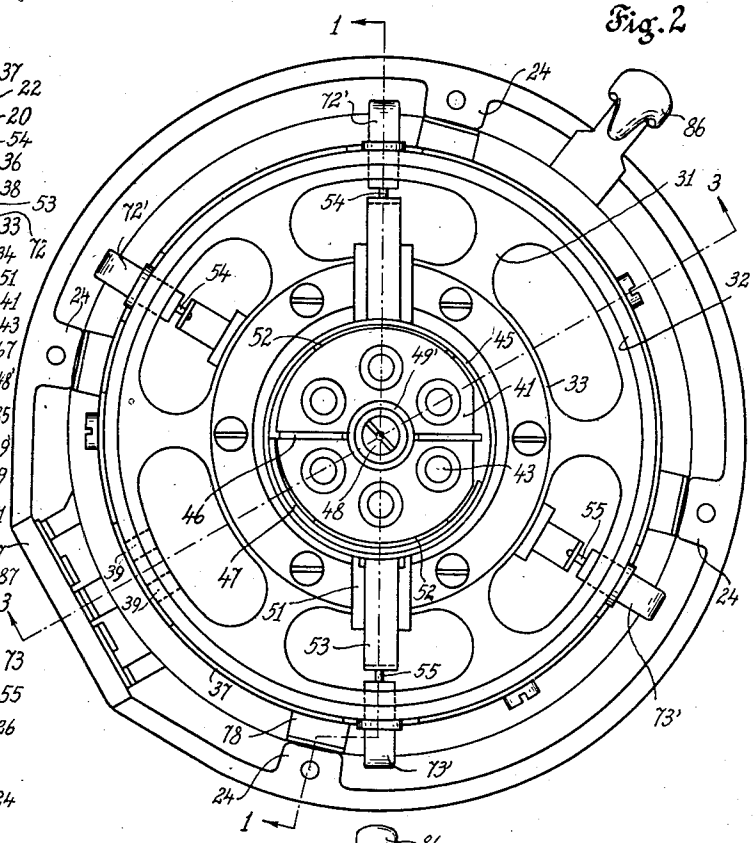
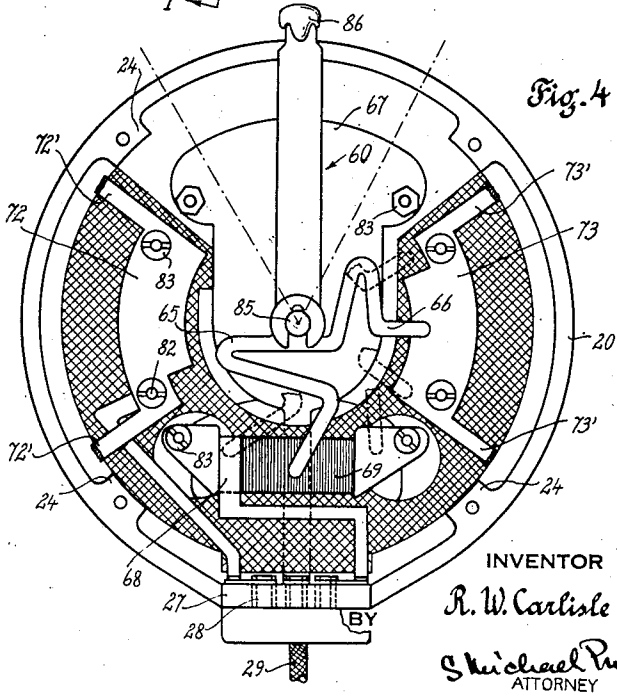


Fig. 3

Fig. 4



INVENTOR

R. W. Carlisle

BY

Michael Prindle

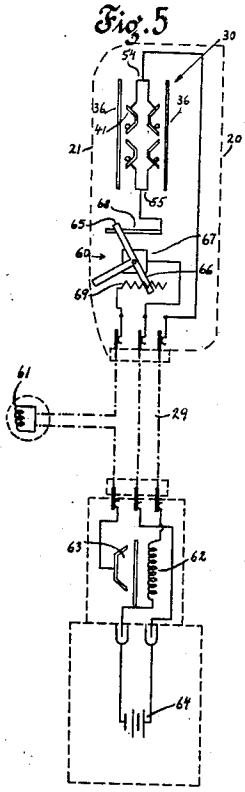
ATTORNEY

June 13, 1944. R. W. CARLISLE 2,351,400

MICROPHONE

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Fig. 5



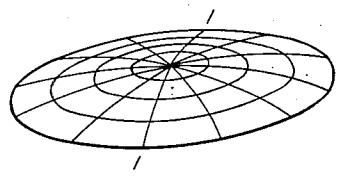


Fig. 6

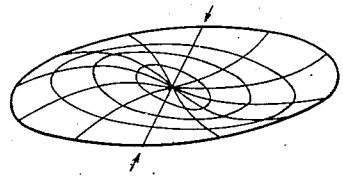


Fig. 7

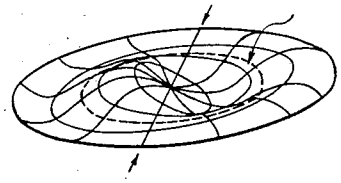
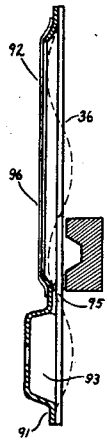


Fig. 8

Fig. 9



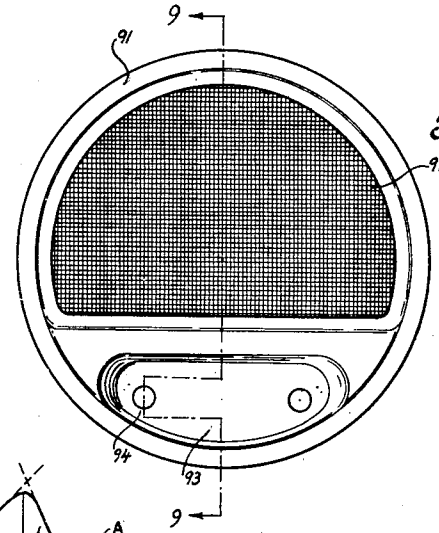
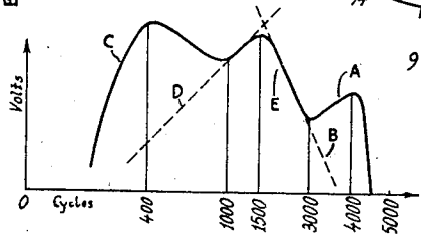


Fig. 10

Fig. 11



INVENTOR

R. W. Carlisle

BY Shuchael Riele

ATTORNEY

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MICROPHONE

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Fig. 12



Fig. 12a

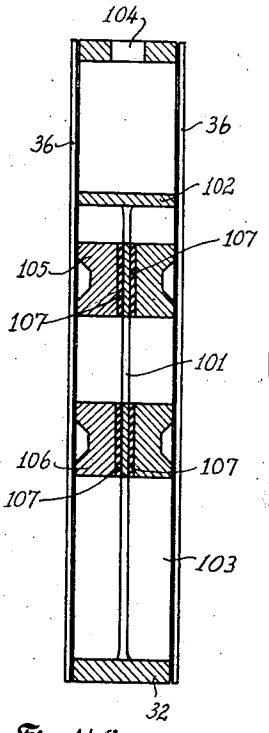


Fig. 13

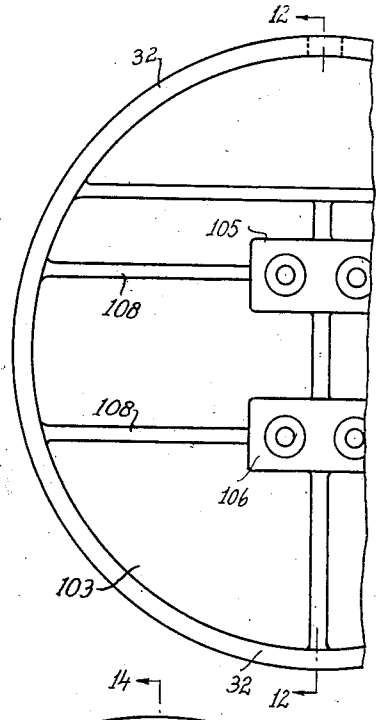


Fig. 14



Fig. 14a

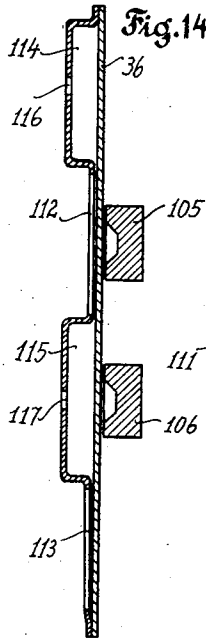
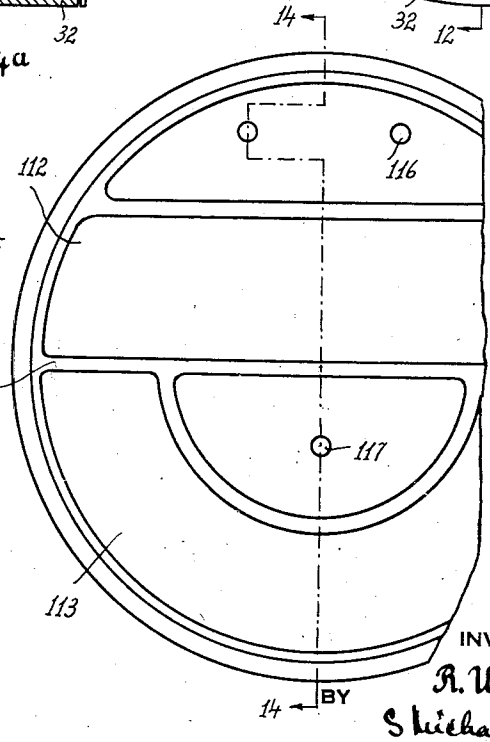


Fig. 15



INVENTOR

R. W. Carlisle

BY S. Michael Pucelo

ATTORNEY

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2,351,400

UNITED STATES PATENT OFFICE

2,351,400

MICROPHONE

Richard W. Carlisle, Elmsford, N. Y., assignor to Sonotone Corporation, Elmsford, N. Y., a corporation of New York

Application July 29, 1940, Serial No. 348,108

14 Claims. (Cl. 179—107)

This invention relates to microphones and more particularly to microphones of the type required for hearing aids and similar applications in which a small microphone structure of high sensitivity over the important part of the speech frequency range is required.

Among the objects of the invention is a microphone which, notwithstanding its great compactness essential for applications, such as hearing aids, has high sensitivity to speech frequency vibrations propagated over the air and has its acoustic elements so arranged inside a housing as to suppress the disturbing effects of cord and clothes rubbing vibrations imparted to the microphone and thus reduce the noise level of the microphone output.

The foregoing and other objects of the invention will be best understood from the following description of exemplifications thereof, reference being had to the accompanying drawings wherein

Fig. 1 is a cross-sectional view through a microphone of the invention along line 1—1 of Fig. 2;

Fig. 2 is a cross-sectional view along line 2—2 of Fig. 1;

Fig. 3 is a cross-sectional view along line 3—3 of Fig. 2;

Fig. 4 is an elevational view illustrating the interior of the rear shell of the microphone, some of the parts being broken off;

Fig. 5 is a diagrammatic view exemplifying the use of the microphone as a part of a hearing aid;

Figs. 6 to 8 illustrate different vibration modes of a circular diaphragm;

Fig. 9 is an enlarged cross-sectional view showing the coupling of the resonant cavity to the microphone diaphragm of Fig. 1;

Fig. 10 is a rear view of the cavity plate of Fig. 9;

Fig. 11 is a typical response curve of the microphone;

Fig. 12 is a curve illustrating the diaphragm vibration modes of the microphone unit shown in Figs. 12a and 13;

Figs. 12a and 13 are views similar to Figs. 9 and 10 illustrating another arrangement of the microphone unit of the invention;

Fig. 14 is a curve illustrating the diaphragm vibration modes of the microphone unit shown in Figs. 14a and 15; and

Figs. 14a and 15 are views similar to Figs. 9 and 10 illustrating a further arrangement of the microphone unit of the invention.

Deafened persons are very sensitive and seek to conceal their impairment. To be useful, a hearing aid device must be suitable for comfortable and inconspicuous wear on the body of the user. Only relatively small batteries are practical for such hearing aids. As a result, the microphone as well as all the other elements of the hearing aid must operate with a high sensitivity. In addition, the microphone and the other elements of a hearing aid device must not only be very small and light in weight to avoid being burdensome to the user, but they must be able to respond fairly uniformly at high efficiency to all important speech frequencies and they should operate satisfactorily under all conditions of use, without requiring special attention and frequent reconditioning.

Hearing aid microphones of the carbon type, utilizing the microphonic effect of carbon contacts for producing the electric output, present difficulties because they have to be operated in a variety of angular positions when tilted by the body of the user on which they are worn. In addition, since the microphone and the electric cords which connect it to the other elements of the hearing aid have to be worn more or less hidden under the clothing of the user, the microphone is subjected to vibrations caused by rubbing of the clothes against the microphone casing and the cord, thereby raising in a very disturbing way the noise level of the microphone.

Many difficulties have also been encountered with prior hearing aid microphones because of dust entering the microphone and causing damage to the control unit, such as the switch and rheostat mechanism usually associated with such hearing aid microphones.

According to one phase of the invention, a microphone of high sensitivity and good overall response and very compact overall dimensions is provided by arranging a flat microphone unit having two outwardly facing diaphragms in a flat housing so as to form around the periphery of the microphone unit a peripheral acoustic chamber which is coupled to the exterior area through acoustic inlet vents distributed along the periphery of the housing, and to the two diaphragms through thin air spaces extending in front of each diaphragm, the acoustic spaces being so proportioned and designed as to cause the two microphone diaphragms to be excited in proper phase relation.

A phase of the invention resides in the mounting of a microphone unit in a housing formed of two parts separated by acoustic vents, one of the housing parts serving as the support for the

cord leading from the microphone, and the microphone unit being so supported in the housing that noise vibrations reaching the cord part of the housing are effectively prevented from being mechanically transmitted to the other part of the housing.

According to other phases of the invention, a microphone formed of a vibro-electric translating device including a vibratory diaphragm is combined with acoustic exciting means for causing the diaphragm to vibrate at one or more higher modes, and particularly dis-symmetrical modes, so as to modify the frequency response of the microphone, and specific arrangements are provided for exciting a microphone diaphragm to vibrate at one or more higher modes, and particularly dis-symmetrical modes, so as to modify its output response.

Other features of the invention involve a microphone unit enclosed in a flat casing so as to form around the periphery of the microphone unit an acoustic chamber which is coupled to the diaphragm through a thin air space extending in the front of the diaphragm having a thickness of the order of $\frac{3}{32}$ to $\frac{3}{64}$ of an inch, and the combination of such microphone with a switching and rheostat mechanism mounted in the thin air space and enclosed in a protective material that resists passage of dust but is highly pervious to sound so that the air space has substantially the same acoustic properties in the presence or absence of the protective layer.

A hearing aid microphone exemplifying the invention is shown in Figs. 1 to 4. It comprises a housing formed of a rear shell 20 and a front shell 21 enclosing a circular, substantially flat interior. The two housing shells 20, 21 are made by molding a synthetic resin material over formed sheets of strong material, such as duralumin, so as to keep the walls of the shells 20, 21 extremely thin and reduce to a minimum its overall bulk, without giving the exterior a metallic character, objectionable in a hearing aid microphone.

The rear shell 20 has, at four points spaced at an angle of about 45° against its vertical axis, indicated by a dash-dotted line, four anchoring posts 24 aligned opposite similar posts 25 extending from the front shell. The two housing shells 20, 21 are clamped to each other by screws 25' extending through the posts. The posts 25 of the front shell 21 have short pillar-like extensions about $\frac{1}{16}$ of an inch above the edge of the shell, so as to provide between the facing edges of the two shells a peripheral acoustic vent 26 from the exterior to the interior space of the housing.

As shown in Figs. 2 to 4, the bottom portion of the rear shell 20 has a forwardly projecting ledge portion 27 which serves as a support for three terminal bushings 28 designed to receive the plug terminals of a plug at the end of a cord 29 which connects the electrical elements of the microphone to the other elements of the hearing aid worn on the body of the user. The edge portion of the front shell facing the terminal ledge 27 is spaced therefrom by a gap, and the mechanical junction between the rear shell 20 and the front shell 21 is confined to the small areas of the four pillar projections located at a sufficient distance from the junction of the cord 29 to the ledge 27 so that vibrations, imparted by rubbing the clothes on the cord 29 and propagated along it to the rear shell 20, shall be kept away from the front shell. By confining the junction between the rear shell 20 and the front shell 21 to the small cross-sectional area of the four pillar posts 25, the disturbances of the microphone output by noises transmitted to the microphone housing, through propagation along the cord, are radically reduced.

This is probably due to the fact that in a microphone arranged in the general way described above, rubbing vibrations transmitted by the cord to the rear shell are propagated along the direction of its main plane in which it is very effective in attenuating such vibrations, whereas if such vibrations are propagated from the rear shell to the front shell, they are imparted thereto in a general direction perpendicular to its main surface in which direction it is more readily set into vibrations.

Inside the housing shells 20, 21 is mounted the microphone unit 30. The elements of the microphone unit are held in their operating positions by a spider member 31, formed, for instance, of a metal die-casting, having a circular rim 32 and a central supporting ring 33 spaced from the outer rim by the spider arms. The central ring 33 is slightly offset and has secured thereto a central supporting plate 34 which is aligned in the central plane of the rim 32.

The edges of the two similar circular vibratory diaphragms 36 are held against the opposite edges of the spider rim 32 by ferrules 37, suitably attached to the rim as by pins or screws, a spring washer 38, peripherally bent into wavy shape, keeping the edge of each diaphragm clamped to the rim 32.

The two diaphragms 36 are used to drive two vibro-electric energy translating units held on the opposite sides of the center plate of the spider 31, so as to produce by the combined action of both diaphragms 36 a relatively large electric output in response to sound propagated in the air surrounding the microphone housing 20, 21.

I have found that by arranging a flat microphone unit having two outwardly facing diaphragms in a flat housing so as to form around the periphery of the microphone unit a peripheral acoustic chamber, which is coupled to each diaphragm through thin air spaces extending in front of the diaphragm and to the exterior air through narrow acoustic inlet openings or vents distributed substantially uniformly around the periphery, the two microphone diaphragms will be excited in proper phase relation by sound propagated from the exterior air, and that they will operate with great sensitivity over the principal part of the speech frequency range important for a hearing aid, if the peripheral acoustic chamber, the thin diaphragm coupling spaces and the exterior inlet vents are designed to resonate in the principal part of the speech frequency range, and particularly over the range between about 1000 and 2500 cycles.

The provision of a peripheral acoustic chamber which is coupled to the exterior through relatively narrow slots and to two vibratorily excited microphone diaphragms by very narrow air spaces, it is possible to obtain a highly sensitive microphone that occupies a very narrow space.

The narrow air spaces extending in front of the diaphragms may be readily designed so that the rate of acoustic propagation through the air spaces is made equal to the rate of mechanical propagation through the diaphragms, and that the acoustic energy is transmitted from the air spaces to the diaphragms at not only the funda-

mental but at higher dis-symmetrical modes of the diaphragms.

In other words, by placing a microphone unit 30 having two outwardly facing acoustically excited diaphragms in a flat housing designed in accordance with the principles outlined above, so as to provide an acoustic cavity around the rim of the microphone unit which is coupled to the exterior through relatively narrow acoustic inlet vents and to the diaphragms through relatively narrow air spaces, the two diaphragms will be excited in proper phase relation so as to give an output much greater than that obtainable with a microphone having a single diaphragm and requiring a space of about the same order, as heretofore required for single diaphragm microphones.

An exterior inlet vent slot of about $\frac{1}{16}$ to $\frac{3}{32}$ of an inch width and distributed substantially uniformly around the periphery is effective in securing efficient acoustic coupling of the peripheral chamber with the exterior.

Satisfactory propagation of sound from the peripheral chamber to the center of the diaphragms was found to occur if the flat walls of the microphone housing are spaced from the facing diaphragm by about $\frac{3}{64}$ to $\frac{3}{32}$ of an inch, the spacing depending on the hardness or stiffness of the vibratory diaphragms 36. Harder diaphragms operate better with a slightly wider spacing than softer diaphragms.

The peripheral air chamber is in general designed to distribute the acoustic impulses equally to the front and rear diaphragms and to be partially resonant with the acoustic inertance of the exterior inlet vent slots in the higher part of the principal speech frequency range between about 1500 and 2500 cycles.

In order to provide sufficient excitation of the diaphragms 36 at the lower part of the frequency range, the space between the diaphragms is connected to the peripheral cavity by internal vent holes 39 designed so as to resonate in the low frequency range, for instance, in the region of about 400 cycles.

Additional excitation of the diaphragms in dis-symmetrical modes may be secured by special acoustic resonators, as will be explained hereinafter.

Although the various features of the invention disclosed herein are applicable to Rochelle salt crystal, electromagnetic, condenser microphones, and the like, a specific exemplification of the invention as applied to a microphone of the carbon ball type, that is widely used in the hearing aid field, will here be described.

Each of the two diaphragms 36 is of carbon, and cooperates with a pair of carbon electrodes 41, each having a plurality of conical cavities 43, each containing a quantity of loose granules of microphonic material, such as carbon balls, resting between the conical cavity surface and the facing portion of the diaphragm so as to modulate a D. C. exciting current passing therebetween in response to sound reaching the diaphragm.

In the form shown, the cavity electrodes 41 are of semi-circular shape, and each pair of electrodes 41 facing a diaphragm 36 is assembled into a self-sustaining mechanical unit within a ring 45 of metal, for instance, being insulatingly spaced from each other and from the ring by radial insulating strips 46 and peripheral insulating strips 47. The two pairs of semi-circular cavity electrodes 41, each pair joined into a mechanical unit within the clamping ring 45, are clamped to the opposite sides of the central spider plate 34 by a single screw 48 and nut 48' which are insulated from the adjacent conducting elements by insulating collars 49, 49', the electrodes being insulated from the spider plate 34 by insulating sheet portions 51.

Against the periphery of each semi-circular electrode 41 is held clamped an arcuate contact strip 52 of metal having a tail portion 53 connected, as by soldering, to the inward tips of two pairs of terminal pins 54, 55 radially held within insulating sleeves seated in the spider rim 32, the pair of terminal pins 54 serving as terminals for one pair of oppositely facing microphone cavity electrodes 41, and the other pair of terminal pins 55 serving similarly as terminals for the other pair of oppositely facing microphone cavity electrodes.

When used as a part of a microphone amplifier hearing aid illustrated diagrammatically in Fig. 5, a microphone arrangement of the type described above will give very important operating advantages.

Such wearable hearing aid usually consists of a microphone 30' with a control unit 60, a hearing inducing receiver 61 and a microphone amplifier unit having an actuating winding 62 and an amplifier microphone 63 which are interconnected with a low voltage battery 64 through a cord 29. The control unit 60, which for convenience is mounted within the microphone casing, has a control arm operating a switch contact arm 65 and a rheostat contact arm 66 controlling the connections from a contact strip 67 leading to the battery 64 to a contact strip 68 leading to the microphone and a rheostat 69 leading to the receiver 61. When the control unit 60 is in the position shown, it connects the microphone 30' in series with the amplifier winding 62 to the battery for actuating the amplifier microphone 63 with modulated speech frequency input currents, and it connects the rheostat 69 in series with the receiver 61 and the amplifier microphone 63 to the battery for actuating the receiver 61 with amplified output currents.

To secure maximum sensitivity, such wearable hearing aids are usually equipped with carbon ball microphones having, as shown, a carbon diaphragm and a carbon block with a plurality of cone-shaped cavities, each cavity containing a quantity of carbon balls which form a heap resting in the space between the lower inclined wall of the cavity and the diaphragm and form a resistance path which varies the resistance between the carbon block and the diaphragm in accordance with the vibrations imparted to the diaphragm by sound waves propagated in the air for modulating the transmitter current passing between the transmitter electrodes and producing correspondingly modulated sound-frequency currents.

The carbon balls perform two functions. First, through the contacts with the diaphragm and the carbon block, the carbon balls provide resistance paths for the current that is modulated by the vibrations of the diaphragm. Second, the forces exerted by the weight of the balls supply the pressure for maintaining intact the ball contacts through which the modulated current flows between the diaphragm and the carbon block so that the current should not be broken when the diaphragm vibrates.

Since such hearing aid microphones are worn by the user, they are operated in a variety of

angular positions as they are tilted by the body of the user and the loose carbon balls in the cavities of a transmitter may assume in operation a variety of different formations, and if the microphone is tilted from the normal vertical to the horizontal position, a condition will be reached in which the contacts are broken. In addition, it is important to prevent the application of more than about 2½ volts to a diaphragm-cavity electrode pair of such a microphone.

In accordance with one feature of the invention, the tilting difficulties and the voltage limitations are overcome by using each diaphragm **36** itself as a series connection between the pair of cavity electrodes **41** with which it cooperates, and by connecting the two series connected microphone groups so formed in parallel between the outgoing microphone terminals **54**, **55**, so that the diaphragms **36** face outwardly, in the way shown diagrammatically in Fig. 5.

When such a microphone arrangement is tilted from the vertical to the horizontal position, the pressure on the balls facing the lower diaphragm will increase as the pressure on the balls on the upper side is decreased, with the result that the total direct current through the microphone remains substantially constant until the unit is nearly horizontal. This is extremely important for the stable operation of a microphone amplifier hearing aid because variations of the direct current flowing through the microphone upset the stability of the microphone amplifier.

At the same time, the voltage of the battery is at all times distributed over two series connected microphone electrode groups, so that no electrode group is subjected to a voltage higher than 2½ volts even if a 4½ volt battery is used.

In the arrangement shown in Figs. 1 to 4, the series parallel interconnections between the four microphone electrode groups of the microphone unit **30** formed by the two diaphragms **36** and the four cavity electrodes **41**, insulatingly mounted between the diaphragms, are completed by two segmental metallic connector strips **72**, **73** which are secured to the internal surface of the rear shell **20**, each connector strip **72**, **73** having a pair of long inwardly projecting arms **72'**, **73'** which have inwardly folded extremely flexible portions, the ends of which are connected, as by clamping, under the heads of the two pairs of cavity-electrode terminals pins **54**, **55**, respectively, so that each of the connector strips **72**, **73** connects one pair of oppositely facing cavity electrodes **51** in parallel and that each of the two diaphragms **36** which make contact with the carbon balls held in the cavity electrodes **51**, complete two series connections between each pair of cavity electrodes **51** facing it, in the way illustrated in Fig. 5.

The flexible suspension arms **72'**, **73'** which serve as connectors to the microphone unit **30**, serve also to locate it in its position within the microphone housing. In order to assure that noise vibrations reaching the rear shell are not propagated through the suspension arms **72'**, **73'** to the microphone unit **30** and that they thus insulate it against the communication of noise vibrations, the flexible suspension arms are made as thin as consistent with the requirement that they should resist corrosion. In the practical construction of such microphone, the suspension arms are about .002 to .003 inch thick.

In order to hold the microphone unit **30** in its proper operating position within the housing and maintain its two diaphragms **36** spaced by the required gap from the facing surfaces of the housing shells **20**, **21**, small sponge rubber pads **78** are cemented to the surfaces of the four pairs of posts **24**, **25** facing the rim **32** of the microphone unit, the sponge rubber pads being proportioned to have sufficient thickness to assist the flexible suspension arms **72'**, **73'** in keeping the microphone unit in its properly spaced position, while at the same time having sufficient vibration absorbing capacity to effectively suppress propagation of noise vibrations from the shell to the microphone unit **30** and to reduce the effect of rubbing noises on the microphone output to a negligible value.

The metallic connector strips **72**, **73** are insulated from the underlying metallic reinforcing plate **22** of the housing shell **20** by a thin sheet or layer of insulating material **81** extending over and united to substantially the entire inwardly facing surfaces of the reinforcing plate.

The metallic connector strips **72**, **73**, as well as the other metallic operating elements located on the interior surface of the housing shell **20** described hereinafter are insulatingly held thereon in their proper operating position by threaded studs **82** and flat nuts **83**, the studs **82** having heads molded in the insulating body of the shell **20** and insulatingly projecting through holes in its reinforcing plate **22** so as to be completely insulated. All elements held in position by screw studs, such as studs **82**, are so arranged and located that their flat nuts **83** face the area of the overlying microphone diaphragm **36**, and the thickness of the nuts **83** is substantially equal to the height of the clamping ferrule overlying the edge of the diaphragm **36** so that the screws and nuts do not increase the overall thickness of the microphone assembly.

By following the principles of the design outlined above, it was possible to compress within a unit having an overall diameter of not more than 3⅛ of an inch and an overall thickness of not more than .83 of an inch, a hearing aid microphone that has all the desirable features of the best heretofore available hearing aid microphones, and that at the same time was operating with two driving diaphragms and was able to give a greater output at a much lower noise level.

In addition, a way was also found for mounting in the cramped acoustic cavity space of the extremely flat housing of such microphone the elements of the switching and rheostat mechanism, required when such microphone is used as a part of a wearable microphone amplifier hearing aid, without impairing the acoustic effect of the cavities and propagation spaces upon which its high sensitivity and good frequency response depends.

As shown in Figs. 1 to 4, a unitary three-armed control member **60** is made from thin high strength elastic non-corrosible metal, such as Z-nickel, and is pivoted at its hub on a pivot stud **85** held in the rear shell, so that by operating its control arm which extends through the upper acoustic slot **26** and has an exterior operating knob **86**, its other two arms **65**, **66** will slide on a flat thin contact strip **68** and a flat rheostat **69** held clamped by insulated screw studs **82** and nuts **83** extending from the rear shell **20**. Although the distance from the pivot **85** of the control member **60** to the contact strip **68** and the rheostat **69** is very short, its two sliding contact arms **65**, **66** are given the resiliency essential for obtaining reliable wiping contact engagement by forming them with looped undulations aligned in

the same plane so that notwithstanding their thinness, they have the required high stiffness in the direction of their sliding motion and the required resiliency in the direction of the contact pressure. To avoid vibrations when the control member 60 is moved, the looped undulations of the contact arms 65, 66 are so biased, as by bending, that the undulation elbows of the arms ride firmly on the surface of the rear shell 20 rather than move without support.

A contact plate 67 of thin sheet metal having low friction resistance, such as nickel silver, is disposed between the reinforcing plate 22 of Duralumin and the lever 60, because the high friction resistance of aluminum would result in scraping. If a low friction metal is used for the shell reinforcing plate 22, the contact plate 67 may be eliminated.

As shown in Fig. 3, a thin connector strip extending from the contact plate 67 of the control member 60 is connected to the center terminal bushing of the microphone shell 20, the two outer terminal bushings being connected by similar contact strips to the microphone electrode connector strip 54 and one end of the rheostat 69, the other microphone electrode connector strip 55 being connected by a similar thin connector strip to the switch contact strip 68.

Great difficulties have been encountered in the past with rheostats built into the microphone of the hearing aids because the cavity of the microphone casing must have acoustic inlets and the dust which invariably reaches the contact surface of the rheostat through the acoustic inlets is ground in by the moving contact into the rheostat surface. As shown in Figs. 1 to 4, in the arrangement of the invention, the rheostat 69 is formed of an extremely thin wire-wound bobbin which is sunk into a recess in the rear shell 20 and projects only slightly more than $\frac{1}{32}$ inch above its surface.

A thin closely-woven sheet 87 of fabric is placed over the elements of the control mechanism 60 to the periphery of the rear shell 20 so as to permit free operation of the control member 60, while at the same time impeding the entrance of dust or lint into the neighborhood of the rheostat. Such arrangement was found very effective in practical construction.

This effective protection of the rheostat against dust is secured without any additional space by using for the protective sheet 87 a fabric which is air-pervious, but dust impervious. Fine cotton fabric, such as cotton lawn, was found satisfactory in actual use.

By designing the control mechanism in accordance with the principles described above, it may be combined with a compact hearing aid microphone of the invention without occupying any space required for giving the acoustic chambers in the microphone housing the characteristics essential for the satisfactory operation of the microphone.

It has been long known that plain diaphragms vibrate not only with a fundamental mode, but also with higher modes. Morse, "Vibrations and Sound," 1936, pp. 133–181, deals with such vibrations. Figs. 6 to 8 of the drawings illustrate the different vibration modes of a circular diaphragm, Fig. 6 showing the fundamental mode, Fig. 7 a first dis-symmetrical mode and Fig. 8 a second dis-symmetrical mode.

Similar modes occur in rectangular diaphragms. In general, a membrane may be defined as a thin elongated member, such as a sheet of rubber, capable of sustaining tension, but not compression, and a plate may be defined as a thin solid body which can sustain tension as well as compression.

The explanations given by Morse for vibrating plates which are rigidly clamped at the edges apply in a general way also to diaphragms which are not clamped at the edges, the frequency ratios of the successive modes of a diaphragm varying somewhat from those of a plate, but the general shape of a diaphragm vibrating with different modes is substantially the same as that of a plate.

As far as I am aware, no attempt was ever made to devise a microphone using a higher dis-symmetrical vibration mode of a diaphragm as a part of its operating system. I have found that dis-symmetrical modes of a diaphragm may be used with great advantage in microphone vibrating systems and that various arrangements may be used for driving the diaphragm in such dis-symmetrical modes.

According to the invention, acoustic means are combined with a diaphragm forming part of a microphone so as to drive the diaphragm at one or more dis-symmetrical modes; or such a diaphragm is combined with a plurality of acoustic driving means to simultaneously actuate it in a number of symmetrical modes, the modes being used to operate a microphone transducer element.

As acoustic means for driving a diaphragm of a microphone at one or more dis-symmetrical modes, acoustic chambers may be used. According to the invention, the acoustic means for driving a diaphragm at a desired mode are formed of acoustic chambers having a volume and small vent apertures to the exterior so proportioned and arranged as to resonate substantially at the same frequency as the desired mode of a given microphone diaphragm.

According to the invention, such a modal-resonance acoustic chamber of the desired characteristics is acoustically coupled to a moving part of the diaphragm so as to drive it acoustically. The acoustic coupling may consist of a narrow slit 95 formed between the diaphragm and an extension on the edge of the acoustic chamber enclosure, the width and the depth of the coupling slit being so proportioned as to have considerable inertance which keeps the air to a certain extent from circulating through it except at frequencies below those at which the chamber is to be effective in exciting the diaphragm at the desired mode.

According to the invention, a number of chambers are coupled to the diaphragm and used at high frequencies without interfering with the action of others used at lower frequencies by properly proportioning the slit by which the high frequency chambers are coupled to the diaphragm, so that they may be uncoupled from the diaphragm at low frequencies.

In practical designs, a narrow slit about 1 to 5 millimeters wide and about ¼ to ½ millimeter deep formed between the diaphragm and an extension of the chamber enclosure is effective for exciting diaphragms to operate at its higher modes and particularly at dis-symmetrical modes.

In designing such coupling slit, consideration should be given to the fact that narrow slits offer little acoustic impedance at low frequencies while they offer high impedance at high frequencies.

The vibration modes of a diaphragm may be analyzed and determined by measuring the current passing between the vibrating diaphragm

and a single carbon ball interposed between the diaphragm and an exploring electrode. In case of a circular diaphragm of carbon .020 inch thick and 2⅜ of an inch diameter, the fundamental mode is at about 800 cycles, a dis-symmetrical harmonic occurs near 2700 cycles, and another dis-symmetrical harmonic occurs between 4000 and 5000 cycles.

Figs. 9 and 10 illustrate one practical way for acoustically coupling to a circular carbon diaphragm 36 of a microphone, such as shown in Figs. 1 to 4, a modal resonant chamber so as to excite the diaphragm at higher mode and thereby broaden and improve the microphone response.

To the outer edges of a circular carbon diaphragm 36 of the microphone is clamped a circular chamber plate 91 having a large opening 92 exposing the major part of the diaphragm area, and an offset plate portion 93 forming adjacent a segmental region of the diaphragm an acoustic cavity having a volume and small outlet vents 94 proportioned so that the cavity 93 has the desired resonant characteristics. As seen from a comparison with the similar diaphragm of Fig. 8, the cavity 93 extends over a region of the diaphragm which is bounded by nodes of the dis-symmetrical mode shown in Fig. 8, except that instead of extending the resonant cavity 93 over the entire half of the diaphragm periphery on which the dis-symmetrical mode occurs, it is made somewhat shorter in arcuate length, leaving out the end regions in which the velocity of the diaphragm is negligible at the modal frequency.

The large opening 92 of the chamber plate 91 exposes the major part of the diaphragm 36 to the sound waves reaching the microphone. The vent holes 94 of the acoustic chamber 93 are so proportioned as to cause the chamber 93 to resonate at the frequency of the particular mode at which the microphone diaphragm is to vibrate.

In designing such acoustic resonant chambers 93 for exciting the diaphragm to vibrate at its higher modes, the manner in which the chamber is coupled to the diaphragm is of importance. In the case shown in Figs. 9 and 10, the chamber plate portion 95 which forms the boundary between the chamber acoustic cavity 93 and the large segment of the diaphragm 36 which is exposed through hole 92, is placed sufficiently close to the diaphragm 36 as to form a slit 95 which keeps air from circulating through it except at the frequencies at which the chamber is to resonate. In the specific embodiment of the invention shown, the radial length of the slit 95 is ⅛ to ¼ of an inch and the thickness of the slit is about .010 to .020 inch.

In order to prevent dust from reaching the slit 95 and become jammed therein against the diaphragm, a close-grained screen 96 of silk or similar sound-pervious, but dust-impervious, fabric is secured, as by cementing, to the outwardly bent flange portions of the chamber plate which border the opening 92 through which the diaphragm is exposed.

When using such modal excitation chamber for the diaphragm of the microphone unit 30 shown in Figs. 1 to 4, the outer shell 21 has, as shown, formed therein holes 99 in front of the openings 94 of the modal excitation chamber in order to assure its effectiveness.

The full-line curve A of Fig. 11 illustrates a typical response curve of a practical microphone of the invention, such as shown in Figs. 1 to 4, using a modal resonant cavity 93, such as shown in Figs. 9 and 10. The same microphone, without the resonant chamber 93, but with a flatter front shell 21 spaced from the front diaphragm 36 by the same gap as the rear shell 20, will have very little response above 3000 cycles, as indicated by the curve portion B. The inner vent holes 39 in the rim of the microphone unit 30 raise the response in the low frequency region down to below 400 cycles, as indicated at C. By closing the inner vent holes 39, the low frequency response may be lowered, as indicated at D, to fit the needs of a deafened individual having good hearing at low frequencies. The resonance effect of the peripheral acoustic chamber of the microphone housing and its exterior inlet vents, and the resonance effect of the narrow diaphragm coupling spaces raise the response in the region between 1000 and 2500 cycles, as indicated at E.

Figs. 12, 12a and 13 show another arrangement for exciting a microphone diaphragm to vibrate at a higher as well as its fundamental mode. To the opposite sides of the rim of a spider 101 are clamped two diaphragms 36, as in Figs. 1 to 4. The spider 101 has a transverse partition 102, so as to form between the inwardly facing segmental regions of the two diaphragms an acoustic cavity 103 having a volume and vent openings 104 through the spider rim proportioned so that the cavity 103 is resonant in the frequency range of the desired higher mode, as in the arrangement of Figs. 9 and 10.

Two pairs of carbon blocks 105, 106 having carbon-ball-holding outwardly-facing cavities are insulatingly held adjacent the diaphragms 36 by spider arms 108 between the two inwardly facing regions of the diaphragms 36, which are excited to vibrate with the fundamental and higher dis-symmetrical vibration modes of the diaphragm for producing, in response to sound reaching the microphone unit, an electric output having a correspondingly broadened frequency response.

Figs. 14, 14a and 15 illustrate another microphone arrangement having diaphragms excited at fundamental and higher dis-symmetrical modes. To the rims 32 of a mounting spider is clamped a diaphragm 36 and an overlying chamber plate 111, as in Figs. 1 to 4. The chamber plate 111 has two large openings 112, 113 through which the diaphragm 36 is exposed, and two offset plate portions forming, in front of the facing portions of the diaphragm, two modal-resonant cavities 114, 115 with vent holes 116, 117, respectively. The volume and the vent holes of the two cavities 114, 115 are proportioned so that the cavities are resonant at the frequency of the desired higher mode. Two carbon block electrodes 105, 106 with ball cavities are suitably supported opposite the other side of the diaphragm 36, so that the carbon balls held in the block cavities are actuated by the fundamental and higher dis-symmetrical modes of the diaphragm 36, as in Figs. 1 to 4, 9, 10 and 12, 13.

The principles of the invention explained in connection with specific exemplifications thereof will suggest to those skilled in the art many other applications and modifications of the same. It is accordingly desired that the appended claims be construed broadly, and that they shall not be limited to the specific details shown and described in connection with exemplifications thereof.

I claim:

1. In a microphone having a vibratory mechano-electric energy translating element: a diaphragm one side of which is exposed to an ad-

joining air space in which sound is propagated; said diaphragm having a fundamental resonant frequency in the speech frequency range and having a modal region of a higher modal-frequency mode; means including a wall portion overlying a portion of the modal region and forming with it an acoustic enclosure having vent opening portions to said adjoining space; said enclosure and said vent opening portions being arranged and proportioned so as to resonate at said higher modal frequency and to cause said diaphragm to be effectively excited at its fundamental and modal frequencies; said vibratory element being actuated by a portion of the diaphragm which is set into vibration through excitation by the sound waves in said enclosure and by sound waves acting directly on the part of the diaphragm directly exposed to said exterior space.

2. In a microphone having a vibratory mechano-electric energy translating element: a diaphragm one side of which is exposed to an adjoining air space in which sound is propagated; said diaphragm having a fundamental resonant frequency in the speech frequency range and having a segmental modal region of a higher modal-frequency mode; means including a wall portion overlying a portion of the modal region and forming with it a segmental acoustic enclosure having vent opening portions to said adjoining space; said enclosure and said vent opening portions being arranged and proportioned so as to resonate at said higher modal frequency and to cause said diaphragm to be effectively excited at its fundamental and modal frequencies; said vibratory element being actuated by a portion of the diaphragm which is set into vibration through excitation by the sound waves in said enclosure and by sound waves acting directly on the part of the diaphragm directly exposed to said exterior space.

3. In a microphone having a vibratory mechano-electric energy translating element: a flat diaphragm one side of which is exposed to an adjoining air space in which sound is propagated; said diaphragm having a fundamental resonant frequency in the speech frequency range and having a modal region of a higher modal-frequency mode; means including a wall portion overlying a portion of the modal region and forming with it an acoustic enclosure having vent opening portions to said adjoining space; said enclosure and said vent opening portions being arranged and proportioned so as to resonate at said higher modal frequency and to cause said diaphragm to be effectively excited at its fundamental and modal frequencies; said vibratory element being actuated by a portion of the diaphragm which is set into vibration through excitation by the sound waves in said enclosure and by sound waves acting directly on the part of the diaphragm directly exposed to said exterior space.

4. In a microphone having a vibratory mechano-electric energy translating element: a flat diaphragm one side of which is exposed to an adjoining air space in which sound is propagated; means for supporting said diaphragm along its periphery; said diaphragm having a fundamental resonant frequency in the speech frequency range and having a modal region of a higher modal-frequency mode; means including a wall portion overlying a portion of the modal region and forming with it an acoustic enclosure having vent opening portions to said adjoining space; said enclosure and said vent opening portions being arranged and proportioned so as to resonate at said higher modal frequency and to cause said diaphragm to be effectively excited at its fundamental and modal frequencies; said vibratory element being actuated by a portion of the diaphragm which is set into vibration through excitation by the sound waves in said enclosure and by sound waves acting directly on the part of the diaphragm directly exposed to said exterior space.

5. In a microphone having a vibratory mechano-electric energy translating element: a flat, circular diaphragm one side of which is exposed to an adjoining air space in which sound is propagated; means for supporting said diaphragm along its periphery; said diaphragm having a fundamental resonant frequency in the speech frequency range and having a modal region of a higher modal-frequency mode; means including a wall portion overlying a portion of the modal region and forming with it an acoustic enclosure having vent opening portions to said adjoining space; said enclosure and said vent opening portions being arranged and proportioned so as to resonate at said higher modal frequency and to cause said diaphragm to be effectively excited at its fundamental and modal frequencies; said vibratory element being actuated by a portion of the diaphragm which is set into vibration through excitation by the sound waves in said enclosure and by sound waves acting directly on the part of the diaphragm directly exposed to said exterior space.

6. In a microphone having a vibratory mechano-electric energy translating element: a diaphragm one side of which is exposed to an adjoining air space in which sound is propagated; said diaphragm having a fundamental resonant frequency in the speech frequency range and having a segmental modal region of a higher modal-frequency mode; means including a wall portion overlying a portion of the modal region and forming with it a segmental acoustic enclosure having vent opening portions to said adjoining space; said enclosure and said vent opening portions being arranged and proportioned so as to resonate at said higher modal frequency and to cause said diaphragm to be effectively excited at its fundamental and modal frequencies; said vibratory element being actuated by a portion of the diaphragm which is set into vibration through excitation by the sound waves in said enclosure and by sound waves acting directly on the part of the diaphragm directly exposed to said exterior space; said wall portion having a border portion acoustically sealed to an inner portion of said diaphragm by a narrow slit space proportioned to constitute an effective acoustic inertance over frequency regions substantially outside the frequency region of the modal region.

7. In a microphone having a vibratory mechano-electric energy translating element: a diaphragm one side of which is exposed to an adjoining air space in which sound is propagated; said diaphragm having a fundamental resonant frequency in the speech frequency range and having a segmental modal region of a higher modal-frequency mode; means including a wall portion overlying a portion of the modal region and forming with it a segmental acoustic enclosure having vent opening portions to said adjoining space; said enclosure and said vent opening portions being arranged and proportioned so as to resonate at said higher modal frequency and to

cause said diaphragm to be effectively excited at its fundamental and modal frequencies; said vibratory element being actuated by a portion of the diaphragm which is set into vibration through excitation by the sound waves in said enclosure and by sound waves acting directly on the part of the diaphragm directly exposed to said exterior space; said wall portion having a substantially straight border portion acoustically sealed to an inner portion of said diaphragm by a narrow slit space proportioned to constitute an effective acoustic inertance over frequency regions substantially outside the frequency region of the modal region.

8. In a microphone having a vibratory mechano-electric energy translating element: a diaphragm one side of which is exposed to an adjoining air space in which sound is propagated; said diaphragm having a fundamental resonant frequency in the speech frequency range and having a segmental modal region of a higher modal-frequency mode; means including a wall portion overlying a portion of the modal region and forming with it a segmental acoustic enclosure having vent opening portions to said adjoining space; said enclosure and said vent opening portions being arranged and proportioned so as to resonate at said higher modal frequency and to cause said diaphragm to be effectively excited at its fundamental and modal frequencies; said vibratory element being actuated by a portion of the diaphragm which is set into vibration through excitation by the sound waves in said enclosure and by sound waves acting directly on the part of the diaphragm directly exposed to said exterior space; said wall portion being shaped substantially as a segment of a circle having a substantially straight border portion acoustically sealed to an inner portion of said diaphragm by a narrow slit space proportioned to constitute an effective acoustic inertance over frequency regions substantially outside the frequency region of the modal region.

9. In a microphone having a vibratory mechano-electric energy translating element: a diaphragm one side of which is exposed to an adjoining air space in which sound is propagated; said diaphragm having a fundamental resonant frequency in the speech frequency range and having a segmental modal region of a higher modal-frequency mode; means including a wall portion overlying a portion of the modal region and forming with it a segmental acoustic enclosure having vent opening portions to said adjoining space; said enclosure and said vent opening portions being arranged and proportioned so as to resonate at said higher modal frequency and to cause said diaphragm to be effectively excited at its fundamental and modal frequencies; said vibratory element being actuated by a portion of the diaphragm which is set into vibration through excitation by the sound waves in said enclosure and by sound waves acting directly on the part of the diaphragm directly exposed to said exterior space; said wall portion having a border portion acoustically sealed to an inner portion of said diaphragm by a narrow slit space proportioned to constitute an effective acoustic inertance over frequency regions substantially outside the frequency region of the modal region; the inner portion of said diaphragm at said acoustic seal constituting a substantially nodal region with respect to said higher mode.

10. In a microphone having a vibratory mechano-electric energy translating element: a diaphragm one side of which is exposed to an adjoining air space in which sound is propagated; said diaphragm having a fundamental resonant frequency in the speech frequency range and having a segmental modal region of a higher modal-frequency mode; means including a wall portion overlying a portion of the modal region and forming with it a segmental acoustic enclosure having vent opening portions to said adjoining space; said enclosure and said vent opening portions being arranged and proportioned so as to resonate at said higher modal frequency and to cause said diaphragm to be effectively excited at its fundamental and modal frequencies; said vibratory element being actuated by a portion of the diaphragm which is set into vibration through excitation by the sound waves in said enclosure and by sound waves acting directly on the part of the diaphragm directly exposed to said exterior space; said wall portion having a substantially straight border portion acoustically sealed to an inner portion of said diaphragm by a narrow slit space proportioned to constitute an effective acoustic inertance over frequency regions substantially outside the frequency region of the modal region; the inner portion of said diaphragm at said acoustic seal constituting a substantially nodal region with respect to said higher mode.

11. In a microphone having a vibratory mechano-electric energy translating element: a diaphragm one side of which is exposed to an adjoining air space in which sound is propagated; said diaphragm having a fundamental resonant frequency in the speech frequency range and having a segmental modal region of a higher modal-frequency mode; means including a wall portion overlying a portion of the modal region and forming with it a segmental acoustic enclosure having vent opening portions to said adjoining space; said enclosure and said vent opening portions being arranged and proportioned so as to resonate at said higher modal frequency and to cause said diaphragm to be effectively excited at its fundamental and modal frequencies; said vibratory element being actuated by a portion of the diaphragm which is set into vibration through excitation by the sound waves in said enclosure and by sound waves acting directly on the part of the diaphragm directly exposed to said exterior space; said wall portion being shaped substantially as a segment of a circle having a substantially straight border portion acoustically sealed to an inner portion of said diaphragm by a narrow slit space proportioned to constitute an effective acoustic inertance over frequency regions substantially outside the frequency region of the modal region; the inner portion of said diaphragm at said acoustic seal constituting a substantially nodal region with respect to said higher mode.

12. In a microphone forming part of a hearing aid small enough for inconspicuous wear on the body of the user: a microphone unit comprising two outwardly facing vibratory diaphragms mounted on opposite sides of said unit and vibro-electric translating means located between said diaphragms and actuated thereby for supplying an electric output corresponding to sound vibrations imparted to said diaphragms; a casing enclosing said microphone unit having a peripheral wall region confining a peripheral acoustical space extending along the peripheries of said two diaphragms and two side walls located in

front of said two diaphragms and arranged to confine in front of said two diaphragms two narrow acoustic air spaces constituting an acoustic coupling between the peripheral air space and said diaphragms; said casing having vent opening portions from its peripheral space to the exterior air space; said exterior vent opening portions of said peripheral acoustic space and said narrow acoustic spaces being designed and proportioned to constitute an acoustic system resonant in the range between about 1000 and 2500 cycles.

13. In a hearing aid designed to be small enough for inconspicuous wear on the body of the user: a microphone unit; a casing forming an acoustic enclosure around said microphone unit and having an exterior surface subjected to mechanical vibrations caused by rubbing contact with a garment portion of the user or the like; connector elements held by a portion of said casing and providing circuit interconnections between said microphone unit and the other elements of said hearing aid; and supporting means including sheet elements of flexible metallic material carrying said microphone in a relatively movable position within said casing so as to effectively impede the propagation of mechanical vibrations from said casing to said microphone while maintaining said microphone unit in its operative position within said casing; said sheet elements forming electric circuit connections between said connector elements and said microphone.

14. In a microphone designed for inconspicuous wear on the body of the user, such as a hearing aid microphone, a microphonic unit, a casing having two facing casing shells forming an acoustic enclosure around said microphonic unit, one of said shells having an anchoring element for an electrical connecting cord, said shells having facing edge portions and junction elements at a plurality of spaced points along said edge portions for joining said shells into a self-supporting structure, said junction portions being so arranged and placed at sufficient distances from said anchoring element as to substantially impede vibrations reaching the shell having said anchoring element and substantially suppress the transmission of said vibrations from the shell having said anchoring element to the other shell.

RICHARD W. CARLISLE.