March 28, 1961 G. J. THIESSEN ET AL 2,976,948

MECHANICAL DEVICE FOR DISTANCE DISCRIMINATION OF SOUNDS

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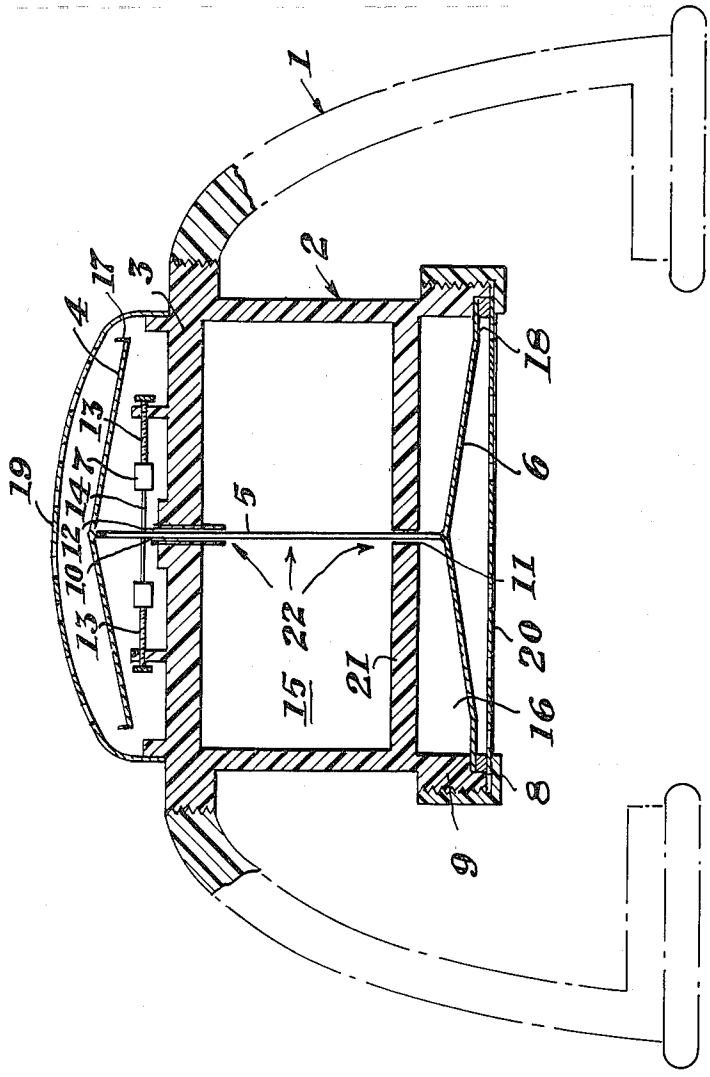


FIG. 1.

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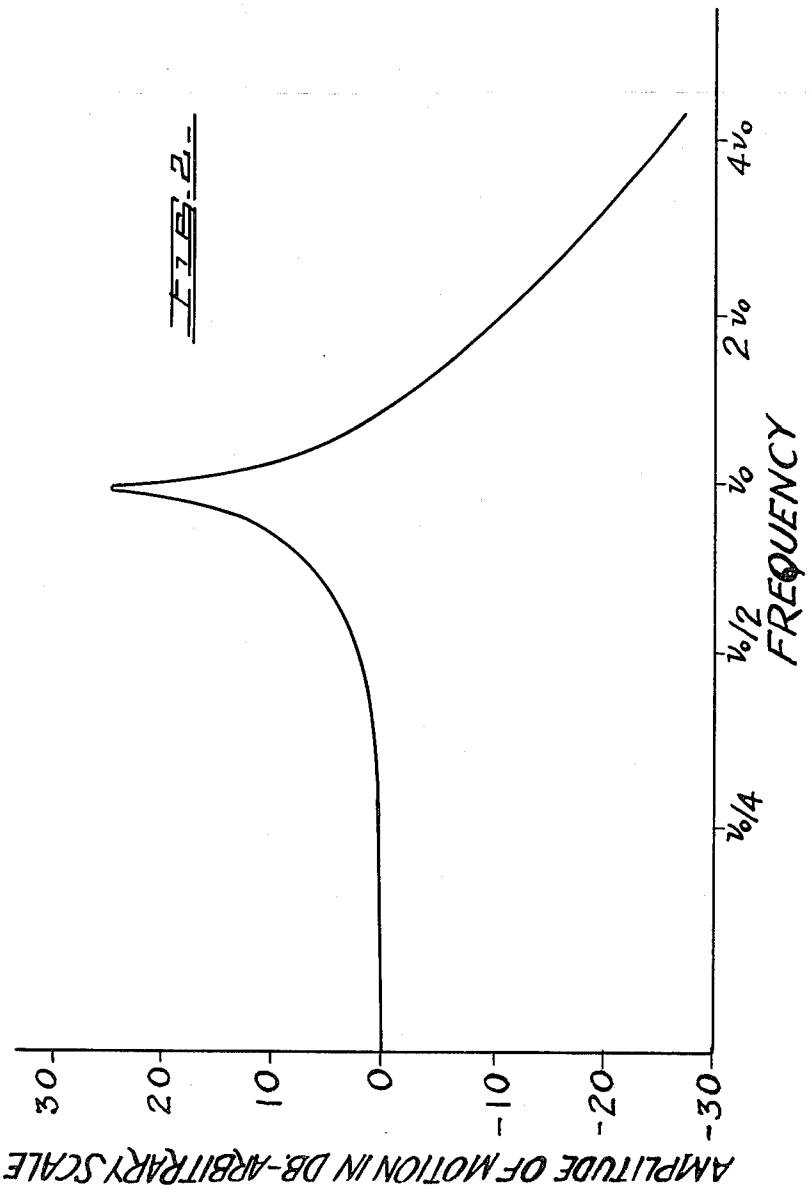
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MECHANICAL DEVICE FOR DISTANCE DISCRIMINATION OF SOUNDS

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FIG. 2.



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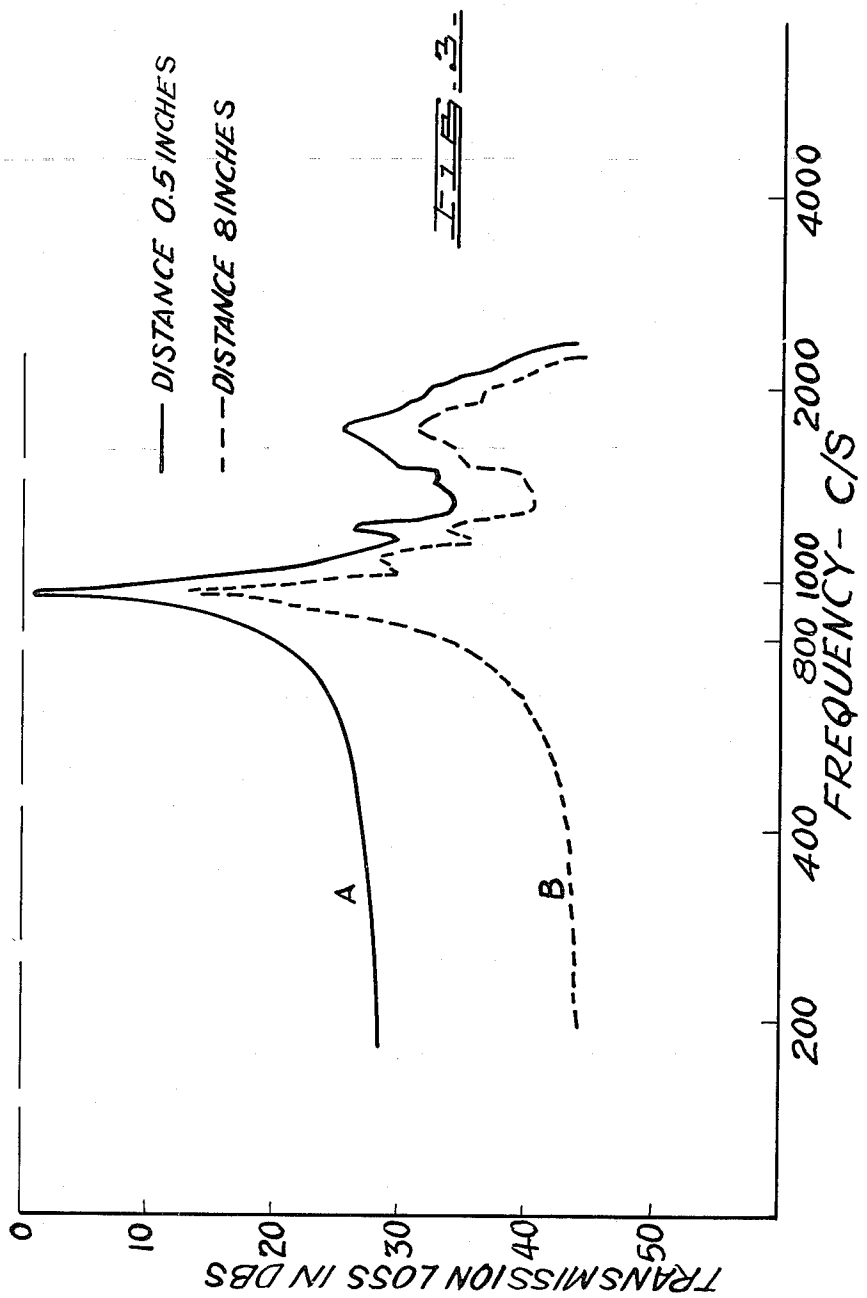
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MECHANICAL DEVICE FOR DISTANCE DISCRIMINATION OF SOUNDS

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FIG. 3.



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MECHANICAL DEVICE FOR DISTANCE DISCRIMINATION OF SOUNDS

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The present invention relates to an acoustic device adapted to discriminate between a desired signal and unwanted background noise. The device is especially suitable for incorporation in ear defenders but can be used in other applications when it is desired to effect discrimination of this type.

In places where a high intensity of background noise exists, speech communication between individuals, even when in close proximity to each other, is always difficult and sometimes impossible. Under such circumstances (as for example in the machine room of a paper mill) it is common practice to resort to slower or more limited means of communication such as hand signals, lip reading, writing, etc.

If spoken communication is necessary any aid thereto should be capable of use in conjunction with ear covers or plugs because of the high ambient noise level. The use of ear covers or plugs alone improves the intelligibility of speech by a small amount when noise levels are high, the improvement being due to a reduction of the amount of non-linear distortion in the ear when the sound level at the ear is reduced. The improvement in intelligibility achieved by shouting on the part of the speaker (in an attempt to increase the ratio of speech signal to noise) is limited by the maximum energy output of which the human voice is capable, and this output is also subject to non-linear distortion at the highest energy levels with consequent reduction in its intelligibility.

The difficulties of securing adequate speech transmission in environments having high intensity background noise cannot be overcome by receiving the speech with a pressure sensitive microphone since this also, of course, receives the background noise with the same sensitivity. In whatever way the signals may then be processed by normal linear sytsems before they reach the ear of the listener the ratio of the required speech signal to the unwanted noise remains unaltered. Substantial improvement in intelligibility can not be achieved without increasing the signal-to-noise ratio. To this end first and higher order pressure gradient sensitive microphones (known also as close talking microphones) have been developed.

Whereas the traditional microphone is sensitive to the pressure generated by the sound wave, a pressure gradient microphone is, as its name indicates, sensitive to the pressure gradient at its diaphragm. As the point source of a sound wave field is approached, the amplitude of the pressure gradient of the sound field increases at a greater rate than the amplitude of the sound pressure itself increases. If now the microphone is near to the point source of the desired sound feld and far from the source of the unwanted noise, the signal-to-noise ratio will be greater if a pressure gradient responsive microphone is used than if a pressure responsive microphone is used. It can be shown that the higher the derivative of the pressure to which the microphone responds the greater is the increase obtainable in the signal-to-noise ratio.

A first order pressure gradient microphone consists, in

one of its manifestations, of two identical pressure microphones whose electrical outputs are opposed. The resultant electrical signal is then proportional to the difference between the two sound pressures, or, if the two microphones are close together, to the pressure gradient at the position of the microphone. In another form of pressure gradient microphone the two pressures may be opposed mechanically by allowing the sound field to have access to both sides of a single diaphragm, the resultant motion of the diaphragm is then converted into an electrical signal which again is proportional to the first order pressure gradient of the sound field.

All first order pressure gradient devices have a bi-directional response, i.e., their response to incoming sound waves is weighted by the cosine of the angle between the direction of the incoming signal and the line joining the centers of the two pressure sensitive elements. If the source of the desired signal then lies in a direction to which the device is most sensitive this bi-directional property of the pressure gradient microphone gives a further increase in the signal-to-noise ratio unless the background noise also originates entirely from sources lying in the two directions of greatest sensitivity.

Known devices for discriminating between a signal and background noise all involve the production of an electrical signal. This signal must then be transmitted to the person receiving it by either wire or radio. Communication by wire requires that each person be wired to the system. It often occurs, however, that persons in a high noise level environment cannot be stationary but must be individually mobile, for example machine operators or maintenance men, and it is impractical for such persons to have their freedom of movement restricted by wires. Additionally, loose wires, and restrictions of movement generally, are dangerous when in the vicinity of machinery having moving parts and may be precluded by safety requirements. A radio system obviates persons being tethered to the remainder of the system but they are still hampered to some extent by having to support the weight of transmitters and receivers and there will still be dangling wires which again are likely to be precluded by safety requirements. Furthermore, use of radio requires expensive electronic equipment.

It is an object of this invention to aid the human voice in a noisy environment by purely mechanical means.

This and other objects, which will be evident from the description, are fulfilled by the provision of a device comprising an acoustically insulating wall having an aperture therein which provides an air column extending through the wall. A microphone located on one side of the wall has a pressure gradient sensitive characteristic. A receiver diaphragm is located on the other side of the wall and a rigid link means provides mechanical connection between the microphone and the diaphragm, the rigid link means being so arranged that it passes through and is surrounded by the air column provided by the aperture. Finally, filter means are associated with the aperture for attenuating sound transmitted by the air column. In a preferred embodiment of the invention the acoustically insulating wall is a cup-shaped member of design similar to conventional ear cover. The microphone comprises a single diaphragm (conveniently referred to hereafter as the "detector diaphragm") and the rigid link is in the form of a pin joining the center points of the two diaphragms.

The microphone whose pressure gradient sensitivity is preferably of the first order discriminates against background noise and transmits to the receiver diaphragm, by way of the link member, vibrations in which the signal-to-noise ratio is considerably increased. The link member must not be impeded by friction which would be caused by rubbing contact with the sides of the aperture,

and the aperture itself can be suitably dimensioned so as to form an effective part of the filter.

The invention will be described by way of reference to the accompanying drawings in which:

Figure 1 is a cross-sectional view of a preferred embodiment of the invention, illustrating its use in conjunction with an ear defender,

Figure 2 is a graph showing the theoretical response of a typical device of the kind shown in Figure 1, and

Figure 3 is a graph showing the experimental transmission loss exhibited at different frequencies by the device of Figure 1.

The device of Figure 1 is of the ear cover type and comprises a rigid cup shaped ear cover 1 of acoustically insulating material. A generally cylindrical hollow chamber member 2 is mounted in the wall of the ear cover 1, the outside end 3 of this chamber 2 conveniently being arranged to form part of the outside surface of the cover 1. In this embodiment the pressure gradient sensitive microphone comprises a first order pressure gradient sensitive detector diaphragm 4 exterior of the ear cover 1 which is supported at only its center point by means of a pin 5 to one end of which it is rigidly attached. The other end of the pin 5 is attached to the center of the receiver or second diaphragm 6 inside the ear cover 1. The diaphragm 6 is supported at all points around its periphery, being held firmly in place outside the chamber 2, but inside cover 1, by means of an annular screw cap 8 engaging a thread provided on a flange 9 depending from the chamber member 2.

In this particular embodiment the cylindrical hollow chamber member 2 provides an aperture, generally represented at 22, through which the pin 5 extends in passing through the wall of the ear cover between the inside and outside thereof. In the embodiment shown the aperture comprises three parts: a narrow cylindrical passage 10 located in the outside end of member 2, a section of much greater cross-sectional area which comprises the cavity 15 of member 2, and another narrow cylindrical passage 11 located in the inside end 21 of member 2, but either or both of passages 10 and 11 may be tubes or holes. To ensure proper performance it is necessary that the pin 5 extend freely through the passages 10 and 11. This requires that the diameter of the passages be somewhat greater than the diameter of the pin 5 and that the pin be aligned as closely as possible in the center of the passages. The position of the end of the pin 5 inside the ear cover 1 is maintained by its connection to the diaphragm 6. The position of the other end of pin 5 may be adjusted by means of screws 13 each of which bears on a ring 7 concentric with the pin 5 and attached thereto by means of light flexible wires or threads 14.

The chamber 2 encloses a cavity 15 and also forms, in combination with the diaphragm 6, a second cavity 16. A screen 19 may be provided to protect the diaphragm 4 from damage, and a screen 20 to protect the diaphragm 6.

The sound field has access to the underside, as well as the upper side of the detector diaphragm 4 with the result that the pressure of the sound field applies no net force on the detector diaphragm. The pressure gradient however results in a difference in pressure on the two sides of the diaphragm 4 and this net force causes the diaphragm to move in a direction perpendicular to its own plane. To make sure that the sound field does not excite unwanted flexural modes of vibration in the diaphragm 4, it is constructed in the form of a cone having a semi angle of, say, 80° to 85°. A narrow ring 17 around the periphery of the diaphragm is bent through approximately a right angle to give the diaphragm further rigidity by a "girder like" action.

The pin 5 is sufficiently rigid that its bending modes are either not appreciably excited or lie at higher frequencies than are of interest in speech communication.

Only one side of the diaphragm 6 is exposed to the ear of the listener and hence movement of this diaphragm results in pressure changes in the region of the ear. To ensure that a given displacement of the pin 5 gives rise to a larger volume movement of the diaphragm 6, and hence a larger pressure change, the diaphragm 6 is constructed as a relatively rigid cone within a flat peripheral ring 18, within which ring by far the greater part of the diaphragm bending takes place.

Associated with aperture 22 is a filter system designed to attenuate unwanted sounds which would otherwise leak through the aperture to the inside of ear cover 1. In the embodiment shown, the passages or holes 10 and 11, the cavity 15 and the cavity 16 together form a low-pass filter system. In the absence of such a system, the air columns at 10 and 11 around the pin 5 could allow background noise to have access to the cavity 16, the diaphragm 6, and thence to the ear, thereby nullifying some of the benefits yielded by the pressure gradient sensitive transmission system. To avoid this effect the acoustic variables of the constituents of the low-pass filter system referred to above are so arranged that sounds reaching the diaphragm 6 from the outside of the ear cover 1 via the air columns at 10 and 11 are attenuated by the low pass filter system to the same or even greater extent than sounds which are transmitted by other paths. The variables of the filter system are the effective length and area of the air columns provided by the passages 10 and 11, the volume of the cavity 15 and the volume of the cavity 16 modified to take account of the non-rigidity of the diaphragm 6.

The device as described above displays some degree of resonance effects—i.e., it does not have a linear response as a function of frequency. If the amplitude of the pressure gradient is maintained constant as its frequency is varied the amplitude of the pressure signal produced in the region of the ear will vary. The nature of such variation is shown in Figure 2. The mass of the moving system, and the stiffness acting on it, determine the resonant frequency, V_0. The mass of the system comprises the mass of the diaphragm 4, the mass of the pin 5 and the modified mass of the diaphragm 6 (modified to take account of the fact that not all of this diaphragm moves with the same amplitude as the remainder of the moving system). The stiffness acting on the moving system is provided mainly by the stiffness of the flat peripheral ring 18 of the diaphragm 6. There will also be a contribution to the stiffness provided by the finite volume of the cavity on which the diaphragm 6 acts but in general this latter contribution will be small. The resonant frequency of the moving system is chosen to lie in that range of frequencies which it is desired to transmit, in this case those which contribute most to the intelligibility of speech. The resonance of the moving system in effect gives a further increase in the signal-to-noise ratio by rejecting both the signal and background noise in other less important ranges of frequency. In particular, this property eliminates the high frequency range in which all pressure gradient microphones cease to give any effective discrimination against distant sources.

In Figure 3, curve A shows the actual response of one model of the device illustrated in Figure 1 for a source 0.5 inch away. The ordinate is a measure of the level of sound intensity which the system introduces into the inner cavity of the ear defender. The reference level indicated as 0 decibels shows the sound intensity which would exist in the earphone cavity if it were open to the air. The difference between these levels thus represents the loss of intensity attributable to the transmission system. It will be noted that at the resonant point (about 1000 cycles per second) sufficient intensity is transmitted into the cavity by the system that it is almost equivalent to the situation which would exist if the cavity were entirely open to the air. On the other hand, the response at lower and higher frequencies falls off relatively rapidly, and to the extent that signal sound as opposed to noise

has important components of frequencies of the order of 1000 cycles per second, it can be seen that the signal-to-noise ratio has been increased by utilization of this resonant system, apart altogether from discriminatory response provided by the pressure gradient characteristic of the detector diaphragm. Curve B shows the response for a source at a distance of 8 inches. If the source at 0.5 inch is considered the signal, and the source at 8 inches the noise, the difference between the curves gives some indication of the extent to which the device can increase the signal-to-noise ratio. If the noise source is situated at a distance greater than 8 inches then the discrimination may be even greater than that shown by Figure 3.

What we claim as our invention is:

1. A device for discriminating between a desired signal and unwanted background noise, comprising: an acoustically insulating wall comprising a rigid cup member adapted to enclose the ear; an aperture in said wall, said aperture providing an air column extending through said wall; a detector diaphragm on one side of said wall, said detector diaphragm having a pressure gradient sensitive characteristic; a second diaphragm on the other side of said wall; and link means connecting said detector diaphragm to said second diaphragm, said link means passing freely through said aperture; and filter means associated with said aperture for attenuating sound transmitted by the air column.

2. A device for discriminating between a desired signal and unwanted background noise comprising: an acoustically insulating wall; an aperture in said wall, said aperture providing an air column extending through said wall; a detector diaphragm on one side of said wall, said detector diaphragm having a pressure gradient sensitive characteristic; a second diaphragm on the other side of said wall; rigid link means connecting said diaphragms, said rigid link means passing through and surrounded by the air column provided by said aperture; and low-pass filter means associated with said aperture for attenuating sound transmitted by the air column, said low-pass filter means comprising a hollow chamber situated between said detector diaphragm and said second diaphragm, said hollow chamber being continuous with and forming part of the air column in said aperture.

3. The device as claimed in claim 2 wherein the detector diaphragm has a first order pressure gradient sensitive characteristic.

4. A device for discriminating between a desired signal and unwanted background noise, comprising: a rigid cup shaped member adapted to enclose the ear; an aperture in said cup shaped member, said aperture providing an air column extending through said cup shaped member; a cone-shaped detector diaphragm on the exterior side of said cup shaped member, said detector diaphragm having a first order pressure gradient sensitive characteristic; a second diaphragm on the inside of said cup shaped member, said second diaphragm comprising a cone-shaped central portion surrounded by an annular base; means rigidly connecting the periphery of the annular base to the cup shaped member; pin means connected between the apices of the cone shaped diaphragms, said pin means passing through and surrounded by the air column provided by said aperture; and filter means associated with said apertures for attenuating sound transmitted by the air column.

5. The device as claimed in claim 4 wherein said filter means associated with said aperture comprises relatively narrow passages at each end of the aperture, and a hollow chamber portion of greater cross-sectional area intermediate the ends of the aperture.

6. A device for discriminating between a desired signal and unwanted background noise, comprising: a rigid cup shaped member adapted to enclose the ear; a hollow chamber member rigidly mounted in and extending through the base of the cup shaped member whereby a first end of said hollow chamber member is positioned on the outside of the cup and a second end is positioned on the inside of the cup; narrow passages having air columns therein extending through said first and second ends of said hollow chamber member; a detector diaphragm disposed adjacent said first end of said hollow chamber member, said detector diaphragm having a first order pressure gradient sensitive characteristic; a second diaphragm disposed adjacent said second end of said hollow chamber member; link means connecting said diaphragms, said link means passing through and surrounded by the air column provided by said passages in said first and second ends of said hollow chamber member.

7. A device for discriminating between a desired signal and unwanted background noise, comprising: a rigid cup shaped member adapted to enclose the ear; a circular opening in the base of said cup shaped member; a cylindrical hollow chamber member having first and second ends mounted in said circular opening, said first end being positioned on the outside of said cup shaped member and said second end being positioned inside said cup shaped member; a circular passage having air columns therein extending through each of said ends of said hollow chamber member, said circular passages and said hollow chamber being aligned in concentric relation; a cone shaped detector diaphragm disposed outside said cup shaped member with the base of the cone adjacent said first end of said hollow chamber member, said detector diaphragm having a first order pressure gradient sensitive characteristic; a second diaphragm inside said cup shaped member adjacent said second end of said hollow chamber member, said second diaphragm comprising a cone shaped central part surrounded by an annular base, the apex of the cone being adjacent said second end of said hollow chamber member; clamping means engaging the periphery of said annular base; a pin joining the apices of said cone shaped diaphragms, said pin passing through and being concentric with the cylindrical air columns provided by said passages.

8. A device as claimed in claim 7 in which a flange projects from the second end of said hollow chamber member and the periphery of the annular base is clamped to said flange.

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