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| [45] | Patented | Aug. 31, 1971 |
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| 3,220,505 | 11/1965 | Hargrave..... | 181/23 |

Primary Examiner—Stephen J. Tomskey
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- [54] CONFORMAL EAR ENCLOSURE**
9 Claims, 6 Drawing Figs.

- [52] **U.S. Cl.**..... 181/23
[51] **Int. Cl.**..... G02k 13/00,
H04r 25/00
[50] **Field of Search**..... 181/23;
2/209; 179/182, 156; 128/151, 152

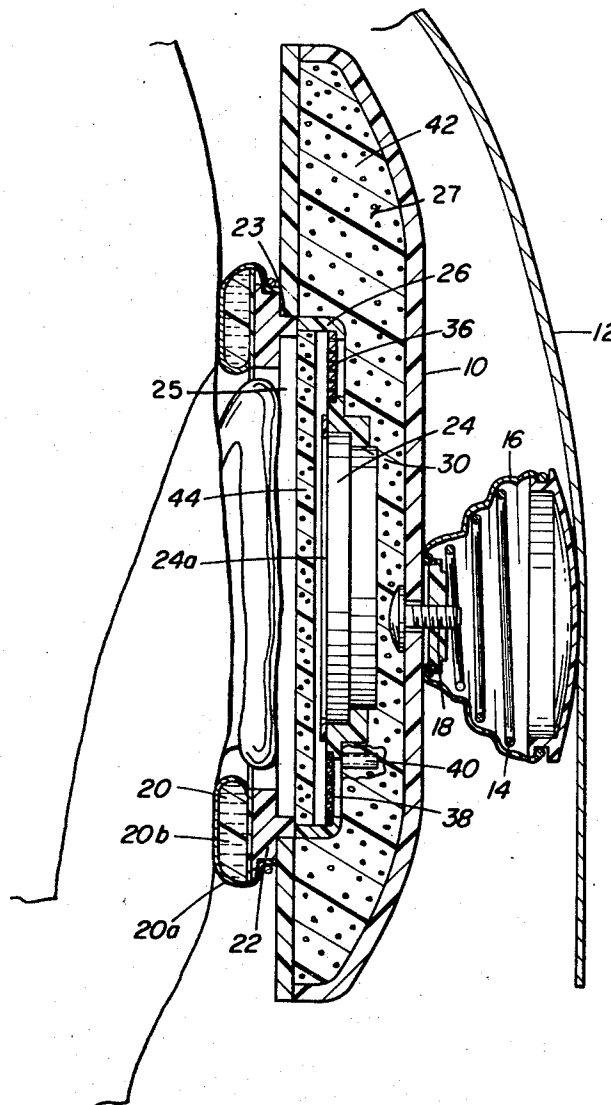
- | [56] | | References Cited |
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| 2,883,672 | 4/1959 | Hornickel et al. |
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ABSTRACT: A circumaural ear enclosure, including a rigid cup of reentrant shape and having a contour so as to be mounted within a protective helmet, for improving communication and safeguarding the hearing of personnel working in noisy environments. An air seal is obtained between the cup and the head of the user by a gel-filled cushion surrounding the ear, and attenuation of noise in a predetermined range of frequencies is maximized by dividing the cup into inner and outer cavities of unequal size with a partition on which the transducer is mounted and which includes means for providing frequency selective coupling between the cavities. This coupling is provided by a predominantly resistive element in parallel with a predominantly inductance element, these elements having values so as to assure maximum transducer response while maintaining high noise attenuation characteristics, with special emphasis to providing high noise attenuation at a particular frequency.



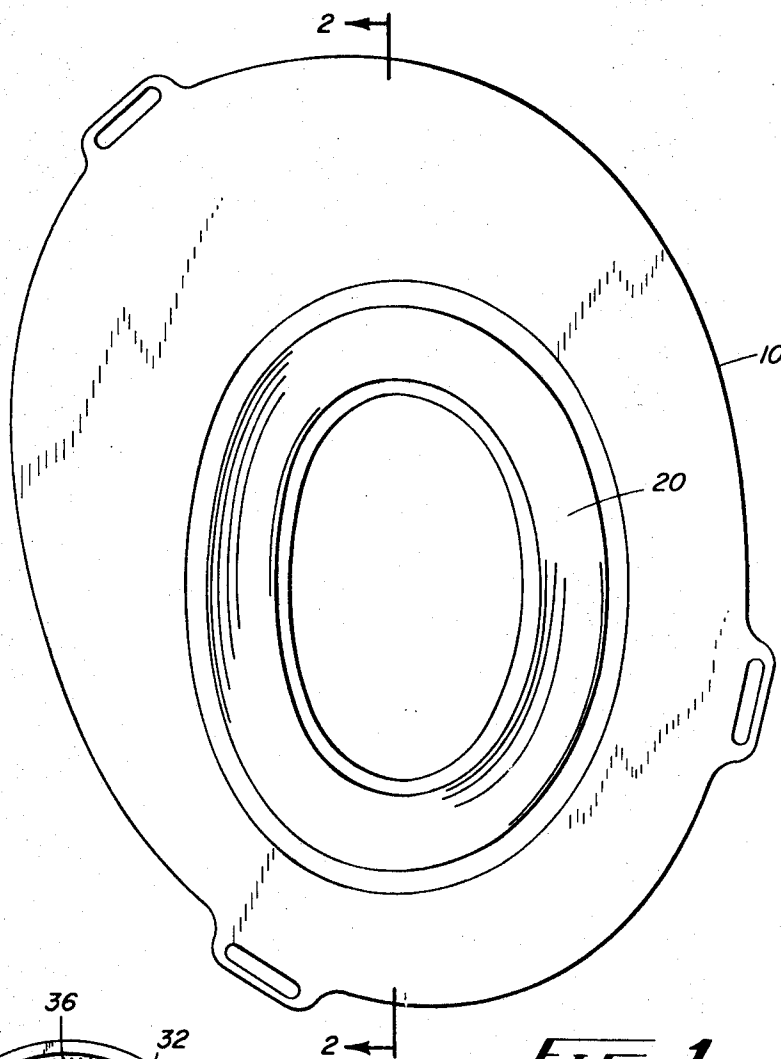


FIG. 1

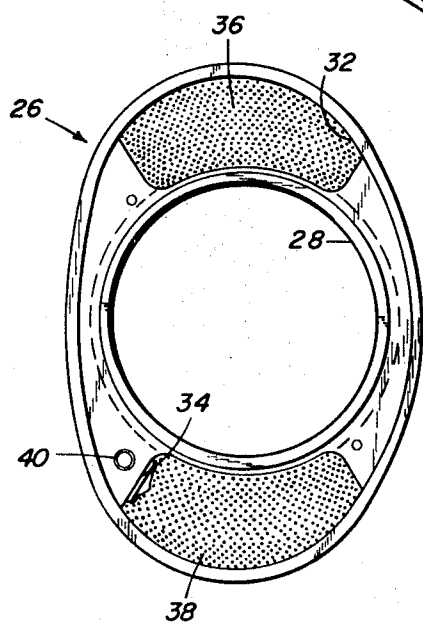


FIG. 3

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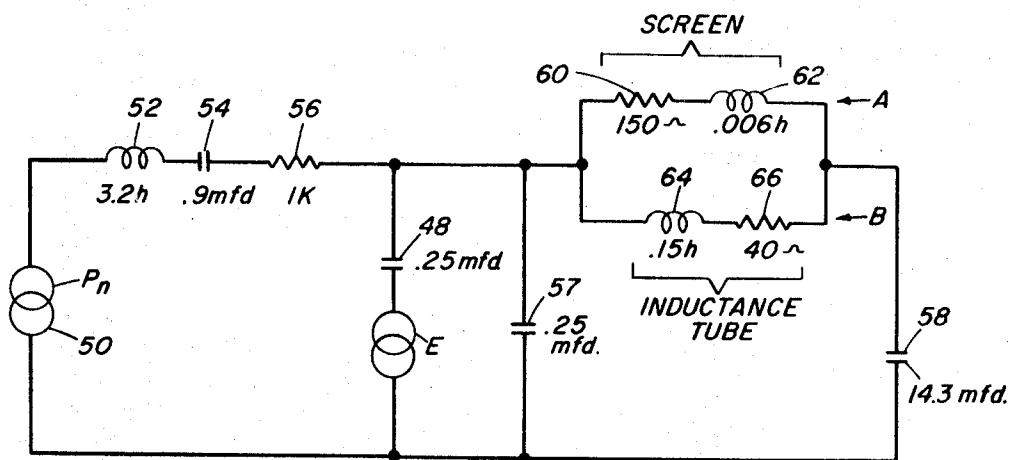


FIG. 4

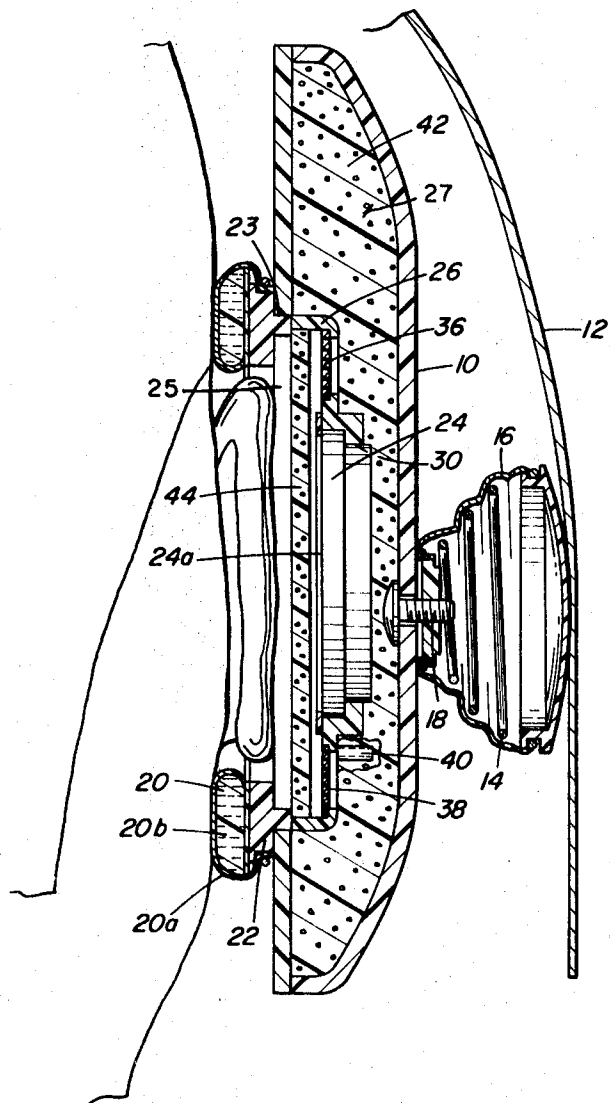


FIG. 2

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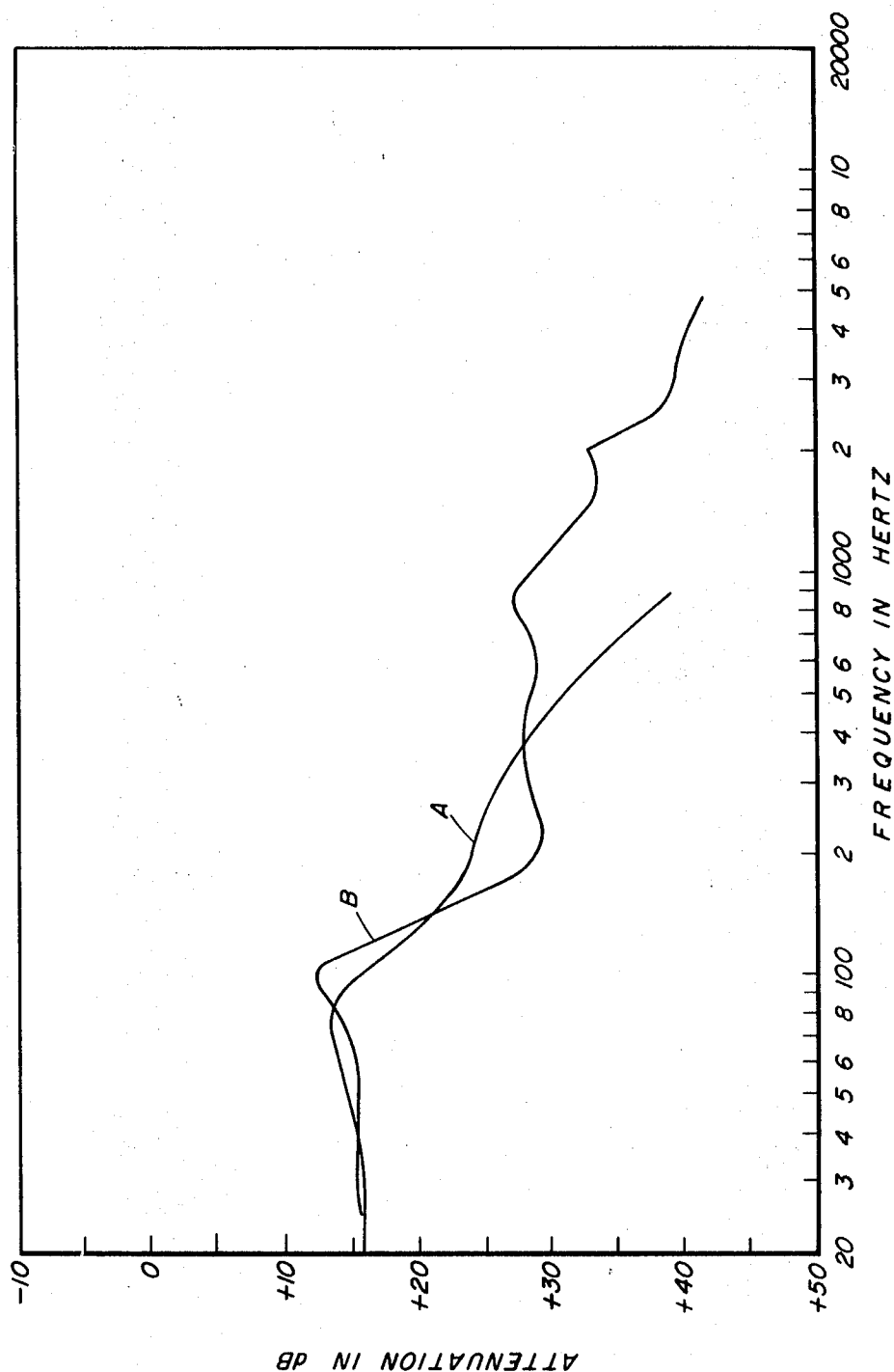


FIG. 5

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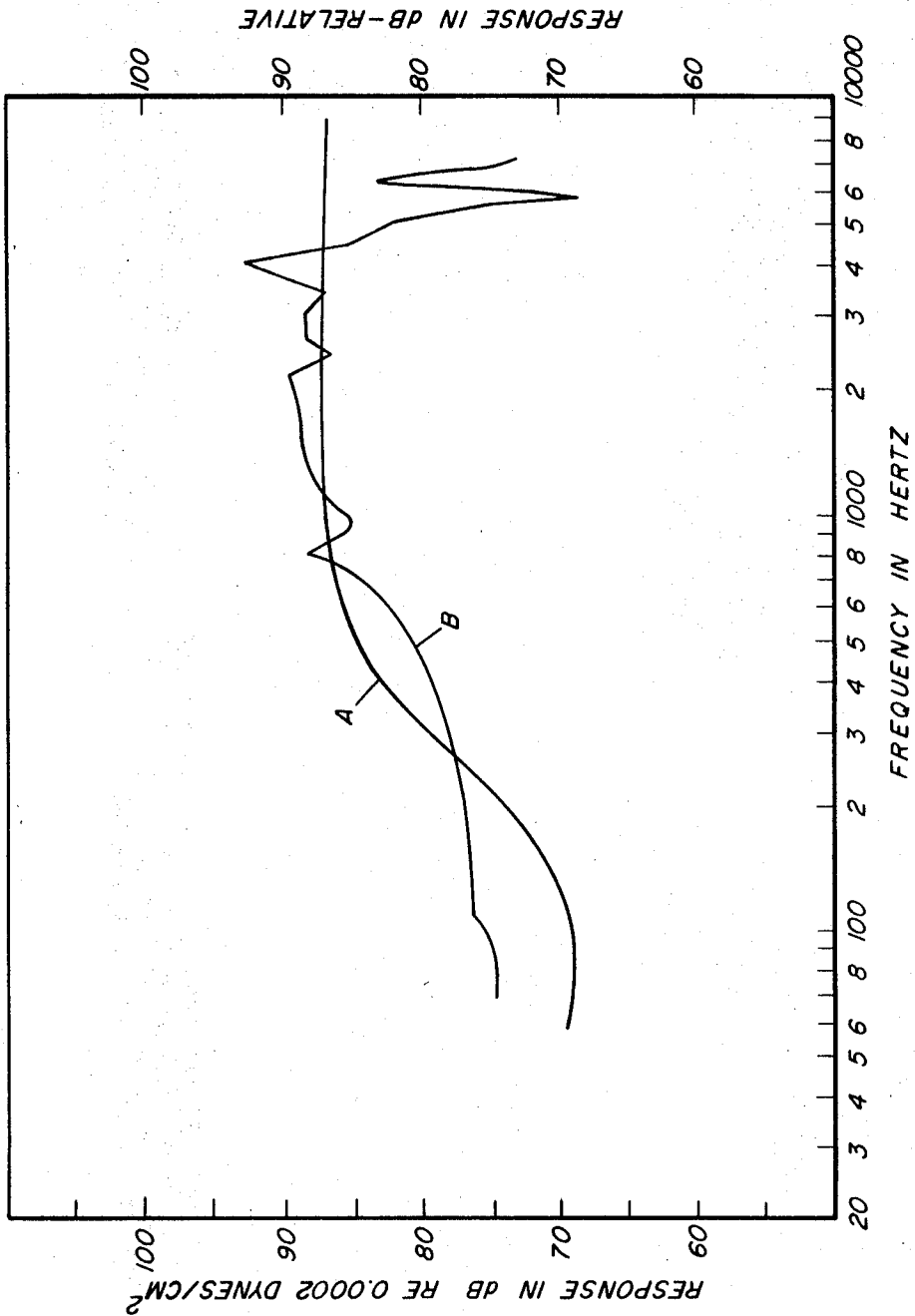


FIG. 6

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CONFORMAL EAR ENCLOSURE

BACKGROUND OF THE INVENTION

This invention relates to circumaural type earphones, and more particularly to an earphone enclosure adapted for mounting inside a helmet, and having improved sensitivity and a high degree of extraneous noise attenuation.

A variety of forms of earphone enclosures have been designed, all of which have the general object of coupling an earphone to the ear of the user in such a manner that the electroacoustic sensitivity is as high as possible and reasonably uniform throughout the range of frequencies encountered, while at the same time protecting the ears as much as possible from ambient noise. Typically, such earphone enclosures are used in industrial establishments having noisy environments, and a particular example is that of communication with and between flight deck personnel on aircraft carriers and crew members of aircraft. In the latter case, and in other military applications, such as for communication between crew members of a tank, the earphone enclosures are necessarily mounted within a head protecting helmet. An additional significant constraint on the design of such enclosures is the fact that transducers available for transforming the electrical energy in the communication system into sound waves have a limited power output which must be reckoned with in reaching a compromise between acceptable communication and safeguarding the hearing of personnel.

In general, earphone enclosures of the type here under consideration broadly comprise a cup which surrounds the ear and in which the earphone is supported. The cup defines a cavity which is effectively coupled to the ear, and through which the sound pressure, whether due to the transducer or external noise, is dispersed. The vibrating part of the earphone establishes sound waves in the cavity which effect changes in cavity volume which, in turn, manifest themselves in pressure waves to which the ear is sensitive. Similarly, external noise which causes vibration of the earphone unit as a whole causes changes in the cavity volume which also set up pressure waves detected by the ear. In the case of air leakages due to imperfect seals with the region of the head surrounding the ear, the noise is introduced into the cavity by means of pressure waves in the air leakage columns which, in turn, set up pressure waves inside the cavity.

It is known that the greater the volume of the cavity the lower will be the amplitude of the pressure waves set up in it for a given level of sound energy. Accordingly, for a predetermined noise or signal input, a larger effective earphone coupling volume will result in correspondingly less sound pressure applied to the ear. Conversely, when the effective coupling volume is made quite small, the sound waves are confined to a smaller space and greater sound pressure is applied to the ear. However, because the enclosure must be mounted within an existing helmet of predetermined contour, increasing the cavity volume is not a straightforward design change, and even if the volume is increased, if an earphone having limited power output is mounted on the wall of the cup the sound pressure level would be too low for adequate or effective communication.

Some of the foregoing requirements are met by the earphone enclosure in Shaw and Thiessen Pat No. 3,112,005, this being the most pertinent art of which applicant is aware. The earphone disclosed therein includes a rigid, nonporous cup adapted to enclose the ear and define an acoustic cavity therearound. A liquid filled cushion member is mounted on the edge of the cup so as to effect a substantially airtight seal with the region of the head surrounding the ear. An enclosed transducer is rigidly attached to the cup and, in a specific embodiment, is mounted on a partition disposed in the cup so as to divide the cavity into inner and outer sections of unequal volume. The partition has a relatively large number of small holes therein having predominantly resistive effects whereby at low frequencies the inner section makes a substantial con-

tribution to the effective earphone coupling volume, while at higher frequencies the inner section becomes progressively less important.

As disclosed, the enclosure is of hemispherical shape and thus not readily mountable within a helmet, and the cushion comprises a flexible tube partially filled with a nongaseous fluid material, making it subject to leakage if punctured.

SUMMARY OF THE INVENTION

Having in mind the above-outlined constraints, the present invention relates to improvements in circumaural earphones of the general type exemplified by Shaw and Thiessen, and particularly to an enclosure having good sensitivity and a high degree of extraneous noise attenuation yet having a low profile so as to be mounted within a combat or similar helmet. In common with the prior art, the enclosure includes a rigid cup having a cushion on its edge to effect a substantially airtight seal with the region of the head surrounding the ear. However, the volume enclosed by the cup is larger than that of prior art enclosures, and to achieve the increased volume while still permitting mounting within available helmets, the cup is of reentrant shape to give a low profile. The volume enclosed by the whole cup—less the space occupied by the transducer mounted inside the cup—constitutes the total cavity volume, but, as will be explained in more detail hereinbelow, in order to position the limited output transducer sufficiently close to the ear, and to modify the performance of the enclosure so that at certain frequencies not all parts of the total cavity volume are used to couple the transducer to the ear, the transducer is mounted on a partition which divides the cup into two cavities, an inner cavity immediately surrounding the ear and a relatively larger outer cavity. The partition has one or more openings therethrough covered by a resistance screen formed of fine mesh of perforated metal and additionally has a small diameter tube projecting therethrough and providing coupling between the two cavities. The combination of the resistive effect of the mesh metal effectively in parallel with the inertance effect of the tube provides an equivalent parallel RL filter that couples the two cavities at frequencies below about 200 Hertz so that the entire volume of the cup is available to provide enhanced noise attenuation at this frequency. It should be noted that the enhanced attenuation frequency can be altered to accommodate the particular external noise which one desires to exclude. At frequencies above 200 Hertz (where noise exclusion is generally adequate) the outer cavity is effectively decoupled so that the earphone is required to drive the inner cavity volume only. It is known that very little speech energy exists below about 200 Hertz; thus, there will be little or no degradation of speech quality as a result of this filter action.

In accordance with another feature of the invention, porous sound absorbing material is disposed within the outer cavity, between the partition and the outer wall of the cup, for further establishing the desired acoustical properties of the overall enclosure. A further feature is that the cushion is filled with a soft gel which conforms to irregularities in head shape in a manner comparable to a liquid filling, yet will not leak if the cushion is punctured.

DESCRIPTION OF THE DRAWINGS

For a better understanding of the present invention, reference may be made to the accompanying drawings in which:

FIG. 1 is a full-size plan view of the inner surface of the ear enclosure according to the invention;

FIG. 2 is a sectional view of the enclosure taken along line 2—2 of FIG. 1, and shown in position on the head of the user;

FIG. 3 is a plan view of the partition which divides the cup into inner and outer cavities, and illustrates the features which gives it its frequency selective coupling characteristics;

FIG. 4 is a diagram of the electrical equivalent circuit of the enclosure and associated transducer;

FIG. 5 is a graph showing the noise attenuation of the enclosure as a function of frequency both theoretical and actual; and

FIG. 6 is a graph showing the frequency response, both theoretical and actual, of a limited power output transducer mounted in the enclosure.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring now to FIGS. 1 and 2, the circumaural ear enclosure according to the invention includes a rigid, nonporous cup member 10, preferably formed of plastic, of generally elliptical shape in plan, as shown in FIG. 1, and of reentrant shape in the height dimension as shown in FIG. 2. The reentrant shape provides a larger total cavity volume than a cup of hemispherical shape, for example, while permitting the enclosure to be mounted within a protective helmet 12, a portion of which is shown in cross section. A compressible spring 14, enclosed in a suitable "boot" 16, is secured to the outer wall of the cup, as by a screw 18, the spring having a modulus such that when compressed (as shown in FIG. 2) between the helmet and the enclosure it applies the correct pressure to the circumaural region of the head of the user and occupies a minimum of transverse space.

Although the reentrant shape of the cup appears to present a larger surface area to pressure waves created by external noise than would a cup of hemispherical shape and having a circumaural cushion of the same diameter, and thus might be expected to increase the deleterious effect of such noise, because the cup reentrant in shape the ambient pressure waves also impinge on the area of the cup facing the head of the user to thereby cancel part of the effect of the increased area. Thus, only those external sound waves impinging on the area of the cup subtended by the cushion 20 surrounding the circumaural region can affect the generation of pressure waves within the cup.

The cup member is sealed to the region of the head around the ear by means of a cushion 20 which is soft and yielding so as to provide a good air seal against the head but which, when in place develops a high spring constant and thus provides a high acoustical impedance for effective attenuation of external noise. These properties are achieved by a cushion comprising a covering 20a of pliable or flexible but substantially nonelastic material, such as a suitable polymeric sheet plastic, wherein forms a chamber around the ear-enclosing periphery of the rigid cup, the covering being substantially completely filled with a gel 20b. A suitable gel for the purpose is a dielectric gel sold by Dow Corning under the trademark "Sylgard 51," which has the advantageous property of not leaking out even if the covering is punctured. The cushion is secured to a ring 22, also formed of a rigid material, preferably plastic, by a suitable adhesive, the ring, in turn, being secured in an opening 23 in the inner face of the cup.

A transducer, such as the earphone 24, is supported inside the cup 10 on a partition 26 with its front surface 24a (the surface through which the sound is emitted) spaced from but facing the ear. Electrical leads for the transducer (not shown) are brought through the cup wall at some convenient point.

The partition 26, which is rigidly secured to the cup 10 along the periphery of flange 22, divides the cup into two sections, an inner cavity 25 surrounding the ear and an outer cavity 27 of substantially larger volume. Shown in plan in FIG. 3, the partition is formed of a suitable rigid plastic, and has a central circular opening 28 in which the transducer is received. The partition presents considerable resistance to aid flow between the inner and outer cavities by means of two openings 32 and 34 in the partition respectively covered by perforated inserts 36 and 38 which may be formed of thin metal or sheet plastic, each having a large number of small holes therein. For clarity, the inserts are shown with exaggerated thickness. In an embodiment which has been successfully operated, perforated metal of a thickness of 0.050 in. having 0.043 in. diameter holes in a 19×19 hole array per

inch, or 361 openings per square inch, was used. The total area of the two perforated metal covered openings in the illustrated embodiment is approximately two square inches. Although omitted from the drawing for clarity, the perforated inserts 36 and 38 are covered with a fine mesh cloth for keeping dust out of the outer cavity and, more importantly, to further increase the resistance to air flow between the two cavities. A fabric having a specific flow resistance of 20 cgs. ohms/cm.² was used in combination with the above-described perforated metal inserts.

While the primarily resistive barriers would by themselves provide frequency selective coupling between the two cavities, a significant aspect of the present invention is the provision of inertance in parallel with this resistance to provide the acoustical equivalent of a parallel connected resistance-inductance filter circuit. Suitable inertance in parallel with the resistance afforded by the perforated metal screens so as to maximize coupling between the cavities at frequencies below about 200 Hertz while effectively decoupling the cavities at frequencies above about 200 Hertz, is provided by a tube 40 having an internal diameter of 0.1141 inch and a length of 0.472 inch pressed into the wall of the partition and extending into the outer cavity. At low frequencies the acoustic resistance and inertance presented by the perforated partition and tube allows the two sections of the cup to behave as essentially one volume, but at higher frequencies they together provide a parallel resistance-inductance filter system which prevents any substantial penetration of high frequency speech sound into the larger outer cavity. The result is that the enclosure provides the degree of attenuation of extraneous low frequency sounds obtainable with large cavity volumes (which is of particular importance in low frequency noise environments such as on the flight deck of an aircraft carrier or in a tank), while at the same time providing high earphone sensitivity in the 200 to 3,000 Hertz region, which is important for high speech intelligibility.

In order to obtain more uniform medium and high frequency response it is advantageous to fill the outer cavity with a porous sound absorbing material 42, such as foamed plastic. This filling of sound absorbing material eliminates large fluctuations in performance by damping resonances that exist within the enclosure. It is also desirable to position an acoustical pad 44, which may also be formed of foamed plastic, within the inner cavity between the transducer and the ear of the user. This pad is relatively thin and serves more to prevent the ear contacting the front face of the transducer than in affecting the acoustical properties of the enclosure.

FIG. 4 is a diagram of the electroacoustic analog of the enclosure and associated transducer. In this equivalent circuit, E represents a constant transducer force and the 0.25 mfd. capacitor 48 in series therewith represents the compliance of the transducer. The generator 50 represents a source of external noise, the 3.2 henry inductance represents the mass of the ear cup, and the 0.9 mfd. capacitor and 1 K resistor represent the compliance and dissipation, respectively, of the ear cushion 20 in combination with circumaural flesh. The volume of the inner cavity is represented by the 0.25 mfd. capacitor 57 and the larger outer cavity is represented by the 14.3 mfd. capacitor 58.

The parallel RL filter coupling the two cavities is simulated by the parallel-connected circuit consisting of a 150 ohm resistor 60 representing the resistance of the perforated inserts 36 and 38, and a 0.15 henry inductor 64 representing the inertance of tube 40. The 0.006 henry inductor 62 in series with resistor 50 in branch A and the 40 ohm resistor in series with inductor 64 in branch B represent undesired inherent inertance and resistance associated with the acoustical implementation of the resistance screen and inertance tube, respectively, but which do not contribute substantially to the filter properties.

When this circuit simulating the enclosure of FIG. 2 was run on a computer the attenuation to external noise as a function of frequency (plotted on a logarithmic scale) was as shown in

curve A of FIG. 5, and the earphone response, plotted in decibels, relative, was as shown in curve A of FIG. 6. The actual noise attenuation and frequency response, objectively measured using an artificial head, were as shown in curves B of FIGS. 5 and 6, respectively, with the frequency response in FIG. 6 plotted in decibels relative to 0.0002 dynes per square centimeter.

It will be noted that the measured curves generally correspond to the theoretical, and that the attenuation to external noise is maximized in the frequency range from 20 to 100 Hertz, drops approximately 15 db. between 100 and 200 Hertz and then is relatively uniform over the range from 200 to 1,000 Hertz. Thus, the enclosure gives maximum protection in low frequency noise environments with an ear enclosure volume small enough to fit within a practical helmet. The response of the transducer (measured with a constant power available input of 1 milliwatt from a 15 ohm source) was relatively constant up to about 200 Hertz, increased gradually to about 800 Hertz and was substantially uniform to about 4,500 Hertz.

From the foregoing it is apparent that the objective of providing an ear enclosure which gives maximum protection against low frequency noise—below about 200 Hertz—yet having a profile so as to be received within a practical helmet, has been satisfied. Contributing heavily to this desirable result is the parallel RL filter provided by an inertance element and a resistive element in parallel coupling the two cavities at frequencies below about 200 Hertz and essentially decoupling them at frequencies above 200 Hertz. It is to be understood that although this parallel filter arrangement has been described as embodied in, and has particular utility in, a partitioned cup of reentrant shape, the principle can be applied in partitioned cups of hemispherical or other shapes.

I claim:

1. A circumaural ear enclosure comprising a rigid, non-porous cup adapted to enclose the ear and define an acoustic cavity therearound,

a cushion member mounted around the edge of the cup and adapted to effect a substantially airtight seal with the region of the head surrounding the ear,

a partition dividing said cup into an inner cavity adapted to receive the ear and an outer cavity, and

a transducer positioned within said cup,

said partition including a passage defining predominantly an acoustic resistance and inertance operative in parallel to provide frequency dependent coupling between said inner and outer cavities.

2. An ear enclosure as claimed in claim 1 wherein said acoustic resistance comprises at least one opening in said partition covered with thin perforated sheet material and wherein

said inertance comprises a tube extending through said partition.

3. An ear enclosure as claimed in claim 2 wherein the values of said acoustic resistance and inertance are so related to the volumes of said inner and outer cavities as to substantially completely couple said inner and outer cavities at frequencies below approximately 200 Hertz, and to substantially decouple said cavities at frequencies above approximately 200 Hertz.

4. An ear enclosure as claimed in claim 2 wherein the values of said acoustic resistance and inertance are so related to the volumes of said inner and outer cavities as to substantially completely couple said inner and outer cavities at frequencies below approximately 200 Hertz, to substantially decouple said cavities at frequencies above approximately 200 Hertz, and to enhance the sound absorption capability within said inner cavity at a frequency of approximately 200 Hertz.

5. An ear enclosure as claimed in claim 3 wherein said tube is longer than the thickness of said partition and projects into said outer cavity.

6. An ear enclosure as claimed in claim 1 wherein said cup is of reentrant shape, said cushion and said inner cavity having a first diameter and said outer cavity having a diameter substantially larger than said first diameter and a height substantially smaller than its radius.

7. An ear enclosure as claimed in claim 1 wherein said cup and said partition are formed of rigid plastic material, and wherein at least part of said outer cavity is filled with a porous sound absorbing material.

8. A circumaural ear enclosure comprising:

a rigid, nonporous cup adapted to enclose the ear and define an acoustic cavity therearound,

a cushion member mounted around the edge of said cup and adapted to effect a substantially airtight seal with the region of the head surrounding the ear,

a rigid partition dividing said cup into an inner cavity adapted to receive the ear and an outer cavity,

a transducer mounted in cooperative relationship with said enclosure with its sound emitting surface operative into said inner cavity,

said partition having at least one opening therein covered with thin perforated sheet material defining predominantly an acoustic resistance, and

an additional opening extending through said partition defining predominantly an acoustic inertance,

said openings being in a parallel arrangement and operative to provide frequency dependent coupling between said inner and outer cavities.

9. An ear enclosure as claimed in claim 8 wherein said additional opening is in the form of a tube which is longer than the thickness of said partition and projects into said outer cavity.

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