

AUDIO APPARATUS

Background of the Invention

The present invention relates to an apparatus for playing audio signals to a user underwater, and in particular to an apparatus for playing audio signals using bone conduction of sound.

5 Description of the Prior Art

Reference in this specification to any prior publication (or information derived from it), or to any matter which is known, is not, and should not be taken as an acknowledgment or admission or any form of suggestion that the prior publication (or information derived from it) or known matter forms part of the common general knowledge in the field of endeavour to
10 which this specification relates.

The need for an improved and efficient underwater communication receiver is a prime concern for underwater users. In addition, the advent use of advanced/complex self-contained underwater breathing apparatus (SCUBA) in deep/technical diving has increased the exploration range of a diver to greater depths, which in turn increases the need for an
15 efficient communication system capable of withstanding extreme pressures.

Bone conduction is the transmission of sound waves or vibrations directly to the cochlea (or inner ear) through the bones of the skull, without travelling through air in the auditory canal (outer ear). It bypasses the ear drum (middle ear) since the outer and middle ear is unable to function efficiently underwater.

20 However, currently, there is no product that is able to operate in deep waters using the bone conduction technique, and instead most modern audio communication systems employ underwater headphones that do not use bone conduction for sound transmission to the ear. Instead, the sound is transmitted by air conduction to the ear canal where it is subsequently conducted through the ear-drum in the middle ear to the cochlea in the inner ear, and
25 eventually the sound vibrations are interpreted by the brain as sound. Such underwater headphones can only be used in fairly shallow waters, up to certain depths.

Using such conventional underwater headphones - which are placed on the ears - may cause the swimmer-diver to receive muffled noise. For example, at significant depths underwater, the external ambient pressure exerted on the outside face of the casing tends to force the casing inwardly, hence resulting in distorted and reduced audio output. Signal reception is poor and underwater sound clarity is affected. The sealing of the internal structure of the headphone housing is also affected by the harsh hydrostatic pressure, causing the ingress of water. These issues can greatly impair the swimmer-diver's sense of directional perception and localisation, particularly in deep waters, making the use of such system hazardous.

Summary of the Present Invention

In a first broad form the present invention seeks to provide apparatus for playing audio signals to a user underwater, the apparatus including:

- a) a transducer for generating vibration signals in accordance with audio signals received via an input; and,
- b) a housing defining a cavity containing the transducer, the housing being adapted to be positioned against a user to allow the vibration signals to be conducted via the housing and bones of the user, to an inner ear of the user, characterised in that at least part of the housing includes an acoustically transparent material.

Typically the acoustically transparent material is selected to minimise an acoustic impedance difference between air and sea water.

Typically the acoustically transparent material has an acoustic impedance of between 1.5 and 1.6.

Typically the acoustically transparent material has an acoustic impedance of approximately 1.56.

Typically the acoustically transparent material is polyoxymethylene.

Typically the housing includes:

- a) a casing defining the cavity and a cavity opening; and,
- b) a cover positioned in the cavity opening.

Typically the casing includes at least one step for receiving the cover.

Typically the casing includes first and second steps for receiving first and second steps of the cover.

Typically the cover is mounted within the cavity opening so that a rim of the casing extends beyond the cover to thereby define a gap between the cover and the rim.

- 5 Typically a sealant is provided in the gap to thereby seal the housing.

Typically the housing includes a sealant provided on at least an outer surface of the cover.

Typically the sealant includes a polyurethane layer.

Typically the sealant is bonded to the cover using an adhesive.

- 10 Typically the transducer is provided adjacent a wall of the housing, the wall of the housing being positioned against the user for conducting the vibration signals to the bone of the user, and being made of the acoustically transparent material.

Typically the entire housing is manufactured from an acoustically transparent material.

Typically transducer operates within the audio frequency band of 220 Hz to 20,000 Hz.

Typically input includes a cable extending through an aperture in the housing.

- 15 Typically the housing includes an aperture cavity provided adjacent the aperture, wherein the aperture cavity is filled with a sealant so that the cable is embedded within the sealant to thereby seal the aperture.

Typically the sealant is polyurethane.

Typically the housing is capable of withstanding:

- 20 a) at least 40 meters of water pressure; and,
b) at least 100 meters of water pressure.

Typically the housing includes a wall that provides a substantially circular, flat, non-slip surface, to reduce slipping of the housing relative to the user's cheek in use.

Typically the housing is adapted to be held in position against a cheek of a user using a strap and sliding mounting.

In a second broad form the present invention seeks to provide a method of constructing apparatus for playing audio signals to a user underwater, the method including:

- 5 a) providing a housing defining a cavity, the housing being adapted to be positioned against a user to allow vibration signals to be conducted through the housing and bones to an inner ear of the user, characterised in that at least part of the housing includes an acoustically transparent material;
- b) providing a transducer; and,
- 10 c) coupling the transducer to an input thereby allowing the transducer to generate vibration signals in accordance with audio signals received via the input.

Typically the housing includes a casing defining the cavity and a cavity opening and wherein the method includes:

- a) mounting the transducer in the cavity; and,
- 15 b) providing a cover in the cavity opening.

Typically the casing includes a step, and wherein the method includes positioning the cover on the step.

Typically the casing includes first and second casing steps, and wherein the method includes positioning the cover by aligning first and second cover steps of the cover with the first and
20 second casing steps.

Typically the cover is mounted within the cavity opening so that a rim of the casing extends beyond the cover to define a gap between the cover and a rim of the casing, and wherein the method includes providing a sealant in the gap to thereby seal the housing.

Typically the sealant includes a polyurethane layer.

25 Typically the method includes applying an adhesive to the cover to thereby bond the sealant to the cover.

Typically the method includes:

- a) inserting the cable through an aperture in the housing; and,

- b) electrically connecting the cable to the transducer.

Typically the housing includes an aperture cavity provided adjacent the aperture, wherein the method includes filling the aperture cavity with a sealant so that the cable is embedded in the sealant to thereby seal the aperture.

- 5 Apparatus for playing audio signals to a user underwater, the apparatus being substantially as hereinbefore described with reference to the accompanying drawings.

A method of constructing apparatus for playing audio signals to a user underwater, the method being substantially as hereinbefore described with reference to the accompanying drawings.

10 **Brief Description of the Drawings**

An example of the present invention will now be described with reference to the accompanying drawings, in which: -

Figure 1 is a schematic diagram illustrating the components of an example of apparatus for playing audio signals to a user underwater;

- 15 Figure 2A is a schematic exploded perspective view of the apparatus of Figure 1;

Figure 2B is a schematic perspective view of the apparatus of Figure 1;

Figures 3A to 3C are schematic plan, cross sectional and side views of the apparatus of Figure 1;

Figures 4A and 4B are schematic views of the apparatus of Figure 1 as worn by a user;

- 20 Figure 5A is a schematic cross-sectional view of a rear cover of an alternative example of apparatus for playing audio signals to a user underwater;

Figure 5B is a schematic cross-sectional view of the casing of the alternative example of apparatus for playing audio signals to a user underwater; and,

Figure 5C is a schematic plan view of the casing of Figure 5B.

25 **Detailed Description of the Preferred Embodiments**

An example of apparatus for playing audio signals to a user underwater will now be described with reference to Figures 1 to 4.

In this example, the audio playback apparatus 100 includes a housing 110 defining a cavity 111. The cavity 111 contains a transducer 120, for generating vibration signals in accordance with audio signals received from an input 130. The transducer 120 can be of any appropriate form, and in one example, is a passive device which utilises a driving audio signal to cause a diaphragm on the transducer 120 to vibrate at an audio frequency, thereby generating a corresponding vibration signal within the audio frequency band of 220 Hz to 20,000 Hz.

In this example, the input 130 is in the form of a cable for connecting the apparatus 100 to external electronic equipment for generating the audio signals. Whilst the input is shown as a cable in this example, it will be appreciated that this is not essential, and alternative inputs may be used to provide audio signals, such as a wireless communication system. However, the use of a cable 130 can be advantageous as this allows the audio signals to be used to power the passive transducer 120 without requiring the apparatus 100 to incorporate an additional power supply, thereby minimising the need for electronic components within the housing 110, making the housing needed smaller.

It will be appreciated that the audio signals can be generated by any suitable electronic equipment, such as an underwater communication system, audio player, audio guidance system, or the like.

In use, the housing 110 is adapted to be positioned against a part of the user's head, and typically the cheek, to allow the vibration signals to be conducted through the housing 110 and bones to the inner ear of the user.

In one example, the audio playback apparatus 100 can be mounted to the user's head *H* using a strap 150, as shown for example in Figures 4A and 4B. In this arrangement, the strap 150 is coupled to a sliding mounting 151 attached to the housing 110, thereby allowing the audio playback apparatus 100 to be slid along the strap 150 until a desired position is reached, and then held in place against the user's cheek. In one specific example, the transducer 120 is mounted within the cavity 111 adjacent a wall 110.1 of the housing 110 which is in turn positioned against the cheek of the user's head *H*, thereby allowing the vibration signals to propagate through the cheek bone and directly to the user's inner ear for interpretation. This enables the audio playback apparatus 100 to produce undistorted audio signals, even at extreme depths.

To maximise the transmission of sound, at least part of the housing 110, and more typically all of the housing 110, includes an acoustically transparent material (ATM). An ATM is a “matching” material that has an acoustic impedance (Z) that is similar to that of sea water. The acoustic impedance of a material is governed by the equation:

$$Z = \rho \cdot c$$

where: ρ is the material density

c is the velocity of sound in the material

The acoustic impedance of sea water is approximately 1.56 and accordingly, at least part of, and more typically all of the housing 110 is fabricated from an ATM whose acoustic impedance is within the range 1.5 to 1.6, and more typically is approximately 1.56. An example of a suitable ATM includes a polyoxymethylene, such as DelrinTM (also commonly referred to as POM and also known as acetal, polyacetal or polyformaldehyde). Polyoxymethylene is an engineering thermoplastic demonstrating high stiffness, low friction and excellent dimensional stability, thereby making the mechanical properties suitable for use in manufacture of the housing 110, which needs to be sufficiently resilient to withstand the high pressures associated with submersion in deep water.

By using an ATM whose acoustic impedance is approximately equal to that of sea water, this minimises the acoustic impedance difference between air and water, which in turn allows essentially 100 % transmission of sounds through the material. In such circumstances, the user will have the ability to detect sounds in their surroundings concurrently while the audio signals are being supplied from their electronic system through the audio playback apparatus. Furthermore, by using an ATM whose acoustic impedance is matched to the acoustic impedance of sea water, signals are transmitted from the source (or transducer) to the target (or cochlea) with minimal reflection and attenuation.

Whilst the entire housing may be constructed from an ATM, this is not essential, and in one example at least the wall 110.1 is manufactured from the ATM, thereby ensuring good conduction of vibration signals to the inner ear of the user.

In one specific example, the housing 110 includes a casing 112, defining the cavity 111 and a cavity opening 113, and a cover 114 positioned in the cavity opening 113. The housing 110 can include a step 116 provided in the cavity opening 113 to assist in positioning of the cover

114 and to prevent the cover 114 entering the cavity 111 upon the application of external pressure, for example when the apparatus 100 is immersed in sea water.

Additionally, the step 116 can be used to position the cover 114 within the cavity opening 113 so that a rim 117 of the casing 112 extends beyond the cover 114. This defines a gap 118 between the cover 114 and the rim 117 of the casing 112, allowing a sealant to be provided in the gap to thereby further seal the housing. Whilst any suitable sealant may be used, in one example the sealant includes a polyurethane layer, which can be bonded to the cover 114 using an adhesive promoter, or other similar material.

The housing 110 can also include an aperture cavity 119 provided adjacent the aperture 115 through which the cable 130 is inserted. The aperture cavity 119 is open, allowing the aperture cavity 119 to be filled with sealant when the sealant is provided in the gap 118. This ensures the cable 130 is embedded within the sealant, thereby sealing the aperture 115.

With this arrangement, the audio playback apparatus can be simply constructed by positioning the transducer 120 in the cavity 111, inserting the cable 130 through the aperture 115, and electrically connecting the cable 130 to the transducer 120. Following this, the cover 114 is positioned on the step 116 so that the rim 117 of the casing 112 extends beyond the cover 114 to define the gap 118. The adhesive promoter is applied to the cover 114, before sealant is provided in the gap 118 and aperture cavity 119, thereby hermetically sealing the housing 110.

The above described construction therefore ensures that the cavity 111 is hermetically sealed, thereby preventing the ingress of water into the housing 110 under extreme pressure, and protecting the transducer 120 within. In this regard, the housing 110 is typically shaped so that the transducer 120 fits snugly within the cavity 111, thereby equalising the hydrostatic pressure on all surfaces thereby reducing the likelihood of housing failure.

In one example, the housing 110 includes a wall 110.1 that provides a substantially circular, flat, non-slip surface, to reduce slipping of the housing 110 relative to the user's cheek in use, for example when the user is diving at extreme depths.

In an alternative example, the step 116 is replaced with a dual step arrangement, as will now be described with reference to Figures 5A to 5C.

In this example, the audio playback apparatus includes a rear cover 114, having first and second cover steps 514.1, 514.2, and a casing 112, having first and second casing steps 516.1, 516.2. Otherwise, the configuration of the audio playback apparatus is substantially as per the audio playback apparatus 100 described above and remaining features will not therefore be described in any further detail.

The dual step arrangement can provide a number of benefits. For example, the arrangement can assist in ensuring that the rear cover 114 sits perfectly within the cavity opening 113 by having the first and second cover steps 514.1, 514.2 of the cover 114 align with the first and second casing steps 516.1, 516.2 of the casing 112. Secondly, the provision of the double step configuration provides a firm foothold to support the rear cover 114 against compression/deformation (if any) in harsh underwater pressure conditions.

Furthermore, the configuration can prevent further seepage of water/moisture into the cavity 111. In this regard, the second casing step 516.2 acts as an additional (third) barrier to water incursion, after the barriers provided by the sealant and the first casing step 516.1. This therefore helps further prevent water seepage into the transducer 120 under extreme underwater hydrostatic pressure at great depths. Thus, even in the event that the sealant fails, the two-stepped configuration will significantly reduce the flow of water into the cavity by trapping water along surface 516.3.

A further benefit of the dual step configuration is that it can increase the thickness of housing 110, thereby providing a more robust structure.

Accordingly, both of the above described audio playback apparatus arrangements provide a robust casing fabricated with an ATM of an appropriate thickness thereby allowing the playback of high fidelity sound underwater at depths. In this regard, it will be appreciated that the thickness of the housing 110, including the casing 112 and the rear cover 114 are selected depending on the intended use of the audio playback apparatus 100, and in particular the intended operating depth. In particular, the thickness is selected to be proportional to the pressure underwater and they are designed such that no water seeps into the interval cavity of the structure at the required depth. This allows the audio playback apparatus to withstand the harsh ambient hydrostatic pressure in deep waters, thereby allowing clear playback of audio signals to users at depth of up to at least 40 meters, which is the limit of recreational diving

without requiring any decompression procedures. However, as the thickness of the housing 110 can be made proportional to the hydrostatic pressure to be encountered underwater, the thickness of the housing 110 can be increased proportionally based on the depth of intended use, thereby allowing the audio playback apparatus 100 to be used at depths of greater than 100 meters, for deep, decompression diving, assuming a suitable thickness of housing 110 is used.

In one example, the audio playback apparatus is duplicated, and worn by the user on each cheek, as shown in Figures 4A and 4B, allowing a dual channel arrangement to be provided, for example to allow the playback of binaural (stereophonic) signals. This can be used for example, to enhance the directional perception of the user by providing different signals to the user's left and right ears depending on the user's orientation.

Thus, the above described audio playback apparatus can provide audio sound directly to the inner ear (cochlea) by having it worn on the cheeks (in front of both ears) of the swimmer-diver. The invention also "frees" the swimmer-diver's ears by wearing it on the cheeks instead of on the ears. No additional head gear or equipment is required by the swimmer-diver, hence saving the swimmer-diver the hassle of having to adjust the head gear and equipment during the dive. Therefore, the invention minimises encumbrances to the diving experience.

The audio playback apparatus can be used in all categories of underwater swimming/diving, such as commercial, military, search and rescue, and recreational.

Persons skilled in the art will appreciate that numerous variations and modifications will become apparent. All such variations and modifications which become apparent to persons skilled in the art should be considered to fall within the spirit and scope of the invention broadly appearing and described in more detail herein.

It is to be appreciated that reference to "one example" or "an example" of the invention is not made in an exclusive sense. Accordingly, one example may exemplify certain aspects of the invention, whilst other aspects are exemplified in a different example. These examples are intended to assist the skilled person in performing the invention and are not intended to limit the overall scope of the invention in any way unless the context clearly indicates otherwise.

Features that are common to the art are not explained in any detail as they are deemed to be easily understood by the skilled person. Similarly, throughout this specification, the term "comprising" and its grammatical equivalents shall be taken to have an inclusive meaning, unless the context of use clearly indicates otherwise.

THE CLAIMS DEFINING THE INVENTION ARE AS FOLLOWS:

- 1) Apparatus for playing audio signals to a user underwater, the apparatus including:
 - a) a transducer (120) for generating vibration signals in accordance with audio signals received via an input (130); and,
 - 5 b) a housing (110) defining a cavity (111) containing the transducer (120), the housing (110) being adapted to be positioned against a user to allow the vibration signals to be conducted via the housing (110) and bones of the user, to an inner ear of the user, characterised in that at least part of the housing (110) includes an acoustically transparent material.
- 10 2) Apparatus according to claim 1, wherein the acoustically transparent material is selected to minimise an acoustic impedance difference between air and sea water.
- 3) Apparatus according to claim 1 or claim 2, wherein the acoustically transparent material has an acoustic impedance of between 1.5 and 1.6.
- 4) Apparatus according to any one of the claims 1 to 3, wherein the acoustically transparent
15 material has an acoustic impedance of approximately 1.56.
- 5) Apparatus according to any one of the claims 1 to 4, wherein the acoustically transparent material is polyoxymethylene.
- 6) Apparatus according to any one of the claims 1 to 5, wherein the housing (110) includes:
 - a) a casing (112) defining the cavity (111) and a cavity opening (113); and,
 - 20 b) a cover (114) positioned in the cavity opening (113).
- 7) Apparatus according to claim 6, wherein the casing (112) includes at least one step (116) for receiving the cover (114).
- 8) Apparatus according to claim 7, wherein the casing (112) includes first and second steps (516.1, 516.2) for receiving first and second steps (514.1, 514.2) of the cover (114).
- 25 9) Apparatus according to any one of the claims 6 to 8, wherein the cover (114) is mounted within the cavity opening (113) so that a rim (117) of the casing (112) extends beyond the cover (114) to thereby define a gap (118) between the cover (114) and the rim (117).
- 10) Apparatus according to claim 9, wherein a sealant is provided in the gap (118) to thereby seal the housing (110).
- 30 11) Apparatus according to any one of the claims 6 to 10, wherein the housing (110) includes a sealant provided on at least an outer surface of the cover (114).

- 12) Apparatus according to claim 10 or claim 11, wherein the sealant includes a polyurethane layer.
- 13) Apparatus according to any one of the claims 10 to 12, wherein the sealant is bonded to the cover (114) using an adhesive.
- 5 14) Apparatus according to any one of the claims 1 to 13, wherein the transducer (120) is provided adjacent a wall of the housing, the wall of the housing being positioned against the user for conducting the vibration signals to the bone of the user, and being made of the acoustically transparent material.
- 15) Apparatus according to any one of the claims 1 to 14, wherein the entire housing (110) is
10 manufactured from an acoustically transparent material.
- 16) Apparatus according to any one of the claims 1 to 15, wherein transducer (120) operates within the audio frequency band of 220 Hz to 20,000 Hz.
- 17) Apparatus according to any one of the claims 1 to 16, wherein input (130) includes a cable extending through an aperture (115) in the housing (110).
- 15 18) Apparatus according to claim 17, wherein the housing (110) includes an aperture cavity (119) provided adjacent the aperture (115), wherein the aperture cavity (119) is filled with a sealant so that the cable (130) is embedded within the sealant to thereby seal the aperture (115).
- 19) Apparatus according to claim 18, wherein the sealant is polyurethane.
- 20 20) Apparatus according to any one of the claims 1 to 19, wherein the housing (110) is capable of withstanding:
- a) at least 40 meters of water pressure; and,
- b) at least 100 meters of water pressure.
- 21) Apparatus according to any one of the claims 1 to 20, wherein the housing (110) includes
25 a wall (110.1) that provides a substantially circular, flat, non-slip surface, to reduce slipping of the housing (110) relative to the user's cheek in use.
- 22) Apparatus according to any one of the claims 1 to 21, wherein the housing (110) is adapted to be held in position against a cheek of a user using a strap (150) and sliding mounting (151).
- 30 23) A method of constructing apparatus for playing audio signals to a user underwater, the method including:

- a) providing a housing (110) defining a cavity (111), the housing (110) being adapted to be positioned against a user to allow vibration signals to be conducted through the housing (110) and bones to an inner ear of the user, characterised in that at least part of the housing (110) includes an acoustically transparent material;
 - 5 b) providing a transducer (120); and,
 - c) coupling the transducer (120) to an input (130) thereby allowing the transducer (120) to generate vibration signals in accordance with audio signals received via the input (130).
- 24) A method according to claim 23, wherein the housing (110) includes a casing (112) defining the cavity (111) and a cavity opening (113) and wherein the method includes:
- 10 a) mounting the transducer (120) in the cavity (111); and,
 - b) providing a cover (114) in the cavity opening (113).
- 25) A method according to claim 23 or claim 24, wherein the casing (112) includes a step (116), and wherein the method includes positioning the cover (114) on the step (116).
- 15 26) A method according to claim 25, wherein the casing (112) includes first and second casing steps (516.1, 516.2), and wherein the method includes positioning the cover (114) by aligning first and second cover steps (514.1, 514.2) of the cover (114) with the first and second casing steps (516.1, 516.2).
- 27) A method according to any one of the claims 23 to 26, wherein the cover (114) is
- 20 mounted within the cavity opening (113) so that a rim (117) of the casing (112) extends beyond the cover (114) to define a gap between the cover (114) and a rim (117) of the casing (112), and wherein the method includes providing a sealant in the gap to thereby seal the housing (110).
- 28) A method according to claim 27, wherein the sealant includes a polyurethane layer.
- 25 29) A method according to claim 27 or claim 28, wherein the method includes applying an adhesive to the cover (114) to thereby bond the sealant to the cover (114).
- 30) A method according to any one of the claims 23 to 29, wherein the input includes a cable (130), and wherein the method includes:
- a) inserting the cable (130) through an aperture (115) in the housing (110); and,
 - 30 b) electrically connecting the cable (130) to the transducer (120).
- 31) A method according to claim 30, wherein the housing (110) includes an aperture cavity (119) provided adjacent the aperture (115), wherein the method includes filling the

aperture cavity (119) with a sealant so that the cable (130) is embedded in the sealant to thereby seal the aperture (115).

32) Apparatus for playing audio signals to a user underwater, the apparatus being substantially as hereinbefore described with reference to the accompanying drawings.

5 33) A method of constructing apparatus for playing audio signals to a user underwater, the method being substantially as hereinbefore described with reference to the accompanying drawings.