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Nunley et al.

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[54] **IMPLANTABLE HEARING AID AND METHOD OF IMPROVING HEARING**

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[52] **U.S. Cl.** ..... **179/107 E**

[51] **Int. Cl.** **H04r 25/02**

[58] **Field of Search** ..... 179/107 R, 1 E

[56] **References Cited**

UNITED STATES PATENTS

3,346,704	10/1967	Mahoney	179/107 R
3,712,962	1/1973	Epley	179/107 R
3,764,748	10/1973	Branch	179/107 E

OTHER PUBLICATIONS

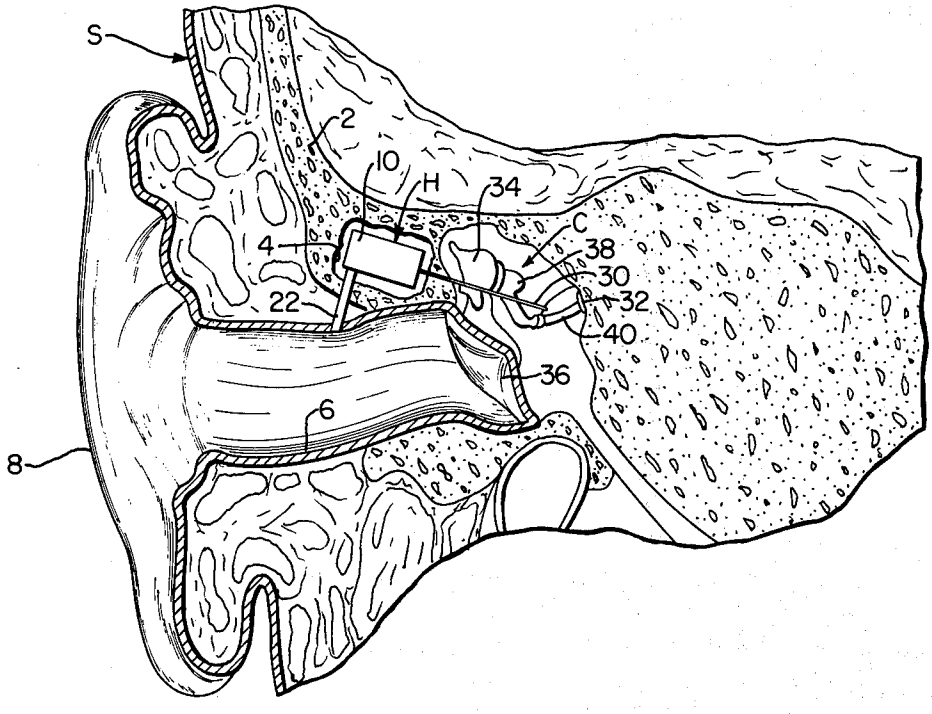
American Academy of Ophtalmology & Otolarynology, Course 319 Text, Oct. 1, 1966.

Primary Examiner—Ralph D. Blakeslee
Attorney, Agent, or Firm—Sheridan, Ross & Fields

[57] **ABSTRACT**

A self-contained hearing device made of components compatible with the human body is provided which is implanted in a hollowed-out portion of the skull adjacent the ear canal. A microphone port is connected with the ear canal for receiving sound that enters the ear and transforming it to energies which are transmitted by a direct connection to the ossicular chain or to other mechanical movable portions of the middle ear. A method of improving hearing is provided wherein a parallel hearing path is provided to augment the normal hearing path.

10 Claims, 3 Drawing Figures



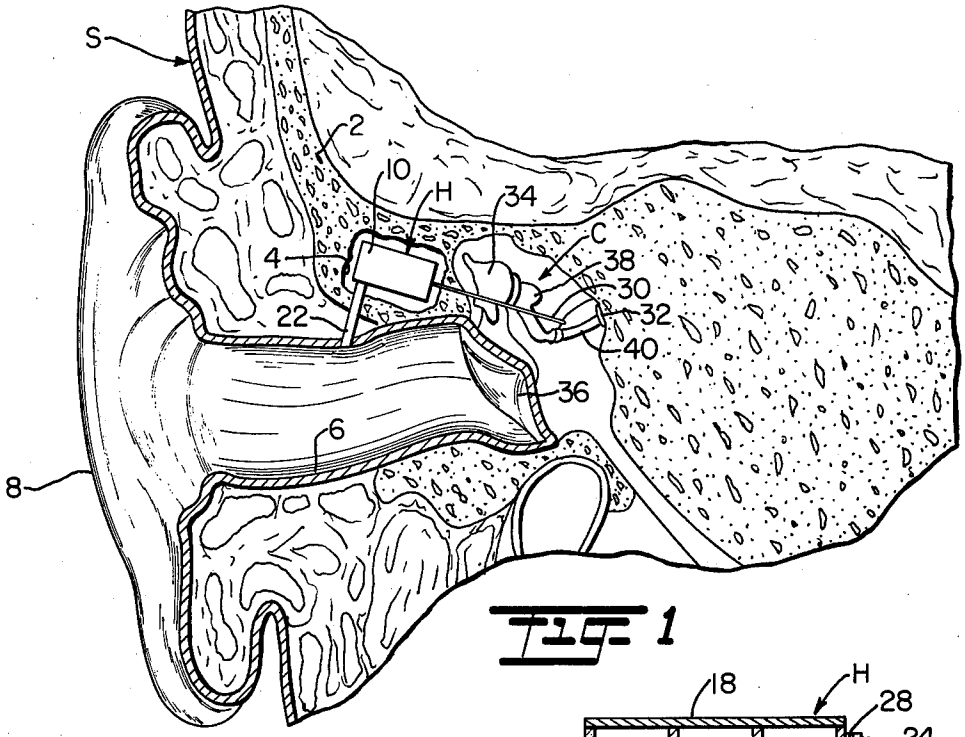


FIG. 1

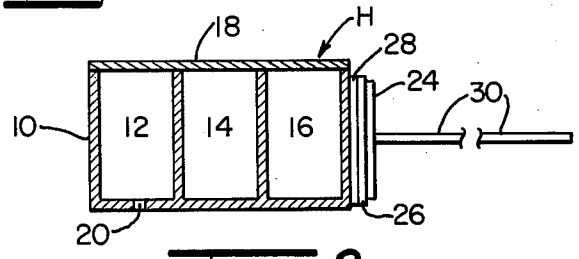


FIG. 2

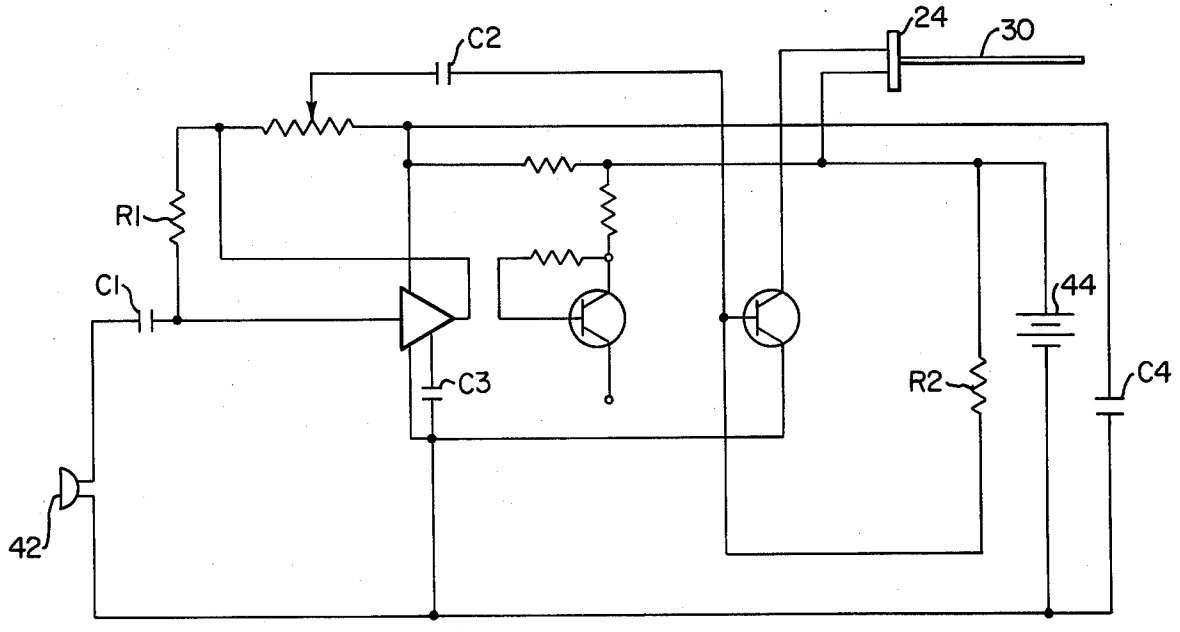


FIG. 3

IMPLANTABLE HEARING AID AND METHOD OF IMPROVING HEARING

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to a hearing device, and more particularly to a hearing device which is totally implantable in the skull of a human being. The device provides a parallel path for sound transmittal from the ear canal to the cochlea in addition to the normal hearing path to provide improved response at the oval window, to sound entering the ear canal.

2. Description of the Prior Art

Various attempts have been made to miniaturize and conceal hearing devices to make them aesthetically acceptable. In addition, attempts have been made to place hearing devices inside the ear or even implant them within the skull. U.S. Pat. No. 3,170,046 to Leale, discloses a hearing device which is entirely received within the ear canal. The difficulty with such a device is that it blocks out the normal passage of sound through the ear canal so that all sound must be transmitted through the device. Furthermore, it is still partially visible when looking at the ear from the side.

A device utilizing a piezo-electric element is disclosed in U.S. Pat. No. 3,712,962 to Epley, which includes an implanted receiver and a piezo-electric element connected to the ossicular chain. The receiver is responsive to an external transmitter worn on the body of the user. Obviously, this device has the disadvantage in that the entire device is not implanted in the ear and that many extraneous sounds may be transmitted to the receiver which distort the signal received by the ear.

A totally implantable hearing device and method for implanting the same is shown in U.S. Pat. Nos. 3,346,704 and 3,557,775, respectively, both to Mahoney. In these hearing devices, the microphone is located just under the skin behind the ear for receiving signals which are transmitted by means of a speaker tube to the middle ear where signals are transmitted by the round or oval window to the cochlea. With the microphone tube located just under the skin, there is a possibility of distortion of the sound and also, due to the position of the microphone behind the ear, all sound may not reach it. In addition, the sounds received would not necessarily be the same as those passing through the ear canal causing distortion and confusion of sound transmitted both through the ear canal and through the hearing device to the cochlea, resulting in a garbled and possibly highly unintelligible sound sensed by the user. Furthermore, the device depends upon the transformation of sound waves to mechanical movements which may or may not be in phase with sounds coming into the ear canal.

SUMMARY OF THE INVENTION

In this invention, a novel method and apparatus for improving defective hearing has been provided wherein a self-contained miniature hearing device having a transducer, such as a microphone with a microphone port positionable in the ear canal, an amplifier and a transmitter which provides a mechanical response to the sound received by the microphone, is implanted in the skull just behind the ear with the microphone port positioned in the ear canal and the mechanical response means connected between the transmitter and mechanical drive structure within the ear. Thus, some

hearing can be obtained in the normal manner, if a total hearing loss is not present, and this can be supplemented by a parallel path provided by the implanted unit wherein sound is received in the ear canal and amplified by the hearing aid device and converted to a mechanical response which is connected to a mechanical drive structure in the ear. As used throughout the specification and claims herein, the term "mechanical drive structure within the ear" includes all movable elements of the ear, including the ear drum, all parts of the ossicular chain, and the oval window; and the term "parallel path" refers to a path providing an alternate route for sound to travel along at least a portion of the normal route of sound travel from the ear canal to the oval window and is not limited to a geometrically parallel arrangement.

In a preferred embodiment of the invention, the transmitter includes a piezo-electric crystal connected to one end of a rod which is moved by the piezo-electric crystal in response to sound waves picked up by the receiver, with the other end of the rod being connected to the ossicular chain, preferably to the stapes. This attachment can be made in any medically suitable manner.

A distinct advantage of this invention is that the rod can be connected to different portions along the mechanical drive structure of the ear, depending upon the particular hearing defect of the person on which it is to be used. While the stapes is believed to be the most practical place to connect the wire, it could be connected to other portions of the chain, or, if the ossicular chain is entirely defective, it can be attached directly to the oval window.

Additional advantages of this invention will become apparent from the description which follows, taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a fragmentary section through a portion of a human skull adjacent the ear showing the location of the implantable hearing aid of this invention within the skull;

FIG. **2** is an enlarged longitudinal section through the implantable hearing aid of FIG. **1** showing further details of construction; and

FIG. **3** is a circuit diagram which can be used in the hearing aid of FIGS. **1** and **2.**

DESCRIPTION OF THE PREFERRED EMBODIMENT

In accordance with this invention, an implantable hearing device H is implanted in the skull **2** in a recess **4** formed adjacent an ear canal **6.** To accomplish this, the ear **8** is bent forward and an incision (not shown) made therebehind to expose the skull **2** whereupon it is hollowed-out to form the recess **4** and receive hearing device H which is made of a material which is compatible with the human body as is well understood in the art. Conveniently, the hearing device H includes a housing **10** which contains a transducer, such as a microphone, an amplifier and a transmitter. As best seen in FIG. **2,** housing **10** includes three compartments **12,** 14 and **16,** as shown. Conveniently, a microphone can be placed in compartment **12,** an amplifier circuit in compartment **14** and a source of power, such as a battery, in compartment **16,** after which housing **10** can be closed by lid **18** sealed thereto by suitable means. Con-

veniently, compartment **12** has a microphone port **20** which, as shown in FIG. **1,** is connected to ear canal **6** by means of a tube **22** so that the hearing device H receives all audio signals as they enter the ear.

As described more fully below, the audio signal entering through tube **22** and port **20** is transmitted by a microphone in compartment **12** to an amplifier circuit in compartment **14** where the signal is amplified and used to power a piezo-electric crystal **24** which conveniently is mounted on a metal disc **26** connected to the end of housing **10,** as by a silicon rubber mounting **28.** Thus, the signal causes movements of crystal **24** in response to the audio signal received by the microphone causing longitudinal movement of an elongated rigid element such as a metal wire or rod **30** which moves in response to the signal and has an outer end connected to a portion of the mechanical drive structure within the ear, such as the ossicular chain C. By this means, the ossicular chain will be caused to move or vibrate in response to movement of the piezo-electric crystal and rod **30** and, therefore, transmit this response to the oval window **32** to provide suitable responses in the cochlea. Other configurations can be used and certain modifications may be desirable for specific applications.

As is well known in the art, the ossicular chain C comprises a malleus **34,** which normally moves in response to the tympanic membrane or ear drum **36.** The malleus is in turn connected to the incus **38** which is connected to the stapes **40** which causes movement of the oval window **32.** At present, it is believed that the device will operate more satisfactorily if wire **30** extends to the stapes **40,** but it should be understood that the wire could be connected to any other portion of the ossicular chain C, or to the ear drum **36** or the oval window **32,** depending upon the particular condition and problem causing deficiency in the hearing of the user.

From the arrangement shown, it is apparent that by inserting hearing device H in the position shown, a parallel path of sound transmittal is provided in addition to the normal hearing path. Thus, the hearing device does not interfere with normal hearing, but can be used to supplement and amplify the response so that the response perceived by the user is as nearly normal as is possible.

A typical circuit for hearing device H is shown in FIG. **3,** but it will be understood that various other circuits can be used and certain modifications may be desirable for particular applications. In the present circuit, a low current gain microphone **42** having a resistance of 1K to 5K ohms can be used. Conveniently, capacitor C1 and C2 are of 1 mf having a low frequency response. C3 is a 0.01 mf type with a high frequency roll off, and C4 is a 20 mf decoupling capacitor. R1 is a 470K ohm feed-back resistor, whereas R2 is a 100K ohm idle current set resistor. R3 is a 5K ohm resistor for volume control purposes. Conveniently, battery **44** is used as the power source. In some applications this battery may be a 1.5 volt mercury battery. Periodically it may be necessary to make an incision behind ear **8** and remove the hearing device H to replace power source **44** in compartment **16.** After replacement, of course, the hearing device can be remounted in recess **4** as shown in FIG. **1.** Some replacements may be avoided by use of rechargeable power sources.

From the foregoing, the advantages of this invention are readily apparent. A hearing device has been provided which is completely self-contained and can be implanted in the skull of the user so that there are no cosmetic drawbacks, as the device will be completely hidden. In addition, a novel method of improving hearing is provided wherein only the sound that enters the ear is picked up and converted to a mechanical signal which is transmitted along a parallel path to aid the impaired hearing of the user so that the user may perceive the signal as nearly normal as is possible.

The invention has been described in detail with particular reference to a preferred embodiment thereof, but it will be understood that variations and modifications can be effected within the spirit and scope of this invention.

What is claimed is:

1. A self-contained implantable hearing device for positioning in a hollowed-out portion of the skull adjacent to the ear canal to provide a sound path parallel to the normal sound path to improve hearing, said unit comprising:

transducer means positionable adjacent the ear canal for receiving audio signals entering the ear canal and converting them to electrical signals;

means for connecting said transducer means with the ear canal for transmission of the audio signal from the ear canal to said transducer means for transmission along a path parallel to the ear canal;

amplifier means coupled to said transducer means adjacent the ear canal for amplifying the electrical signal produced by said transducer means along said parallel path;

transmitter means coupled to said amplifier means adjacent the ear canal for converting the electrical signal to a mechanical response; and

mechanical response means coupled to said transmitter means adjacent the ear canal and connectable to a mechanical drive structure within the ear to complete said parallel path and to provide a mechanical movement of the structure in response to an acoustical signal received by said transducer, which augments and supports any signal produced by the transmission of sounds through the normal sound path of the ear to provide improved hearing.

2. An implantable hearing device unit, as claimed in claim **1,** wherein said mechanical response means includes:

an elongated rigid element.

3. An implantable hearing device unit, as claimed in claim **1,** wherein said transmitter means is:

a piezo-electric crystal.

4. An implantable hearing device unit, as claimed in claim **1,** wherein:

said mechanical response means is connected to the ossicular chain.

5. An implantable hearing device unit, as claimed in claim **1,** wherein:

said mechanical response means is connected to the stapes.

6. An implantable hearing device unit, as claimed in claim **1,** wherein:

said mechanical response means is connected to the oval window.

7. A self-contained implantable hearing device for positioning in a hollowed-out portion of the skull adjacent to the ear canal to provide a sound path parallel to the normal sound path to improve hearing, said unit comprising:

transducer means positionable adjacent the ear canal for receiving audio signals entering the ear canal and converting them to electrical signals;

means for connecting said transducer means with the ear canal for transmission of the audio signal from the ear canal to said transducer means for transmission along a path parallel to the ear canal;

amplifier means coupled to said transducer means adjacent the ear canal for amplifying the electrical signal produced by said transducer means along said parallel path;

a piezo-electric crystal connected to said amplifier means adjacent the ear canal and providing a mechanical response proportional to the electrical signal from said amplifier means; and

an elongated rigid element having one end connected to said piezo-electrical crystal adjacent the ear canal and the other end connectable to the ossicular chain to complete said parallel path and to provide a mechanical movement of the structure in response to an acoustical signal received by said transducer means, which augments and supports any signal produced by the transmission of sound through normal sound path of the ear to provide improved hearing.

8. A method of improving hearing by providing a sound path parallel to the normal sound path for reproducing sound and augmenting the sound entering an ear canal, including the steps of:

implanting a hearing device in the skull bone adjacent the ear canal, wherein said hearing device includes in series a microphone, an amplifier circuit, and a mechanical output responsive to an audio signal received by the microphone;

connecting the microphone in audio communication with the ear canal; and

connecting the mechanical output of the hearing device to a mechanical drive structure within the ear so that sound entering the ear can pass along a parallel path through said hearing device to augment sound passing along the normal path.

9. The method as claimed in claim **8,** wherein the connecting of the mechanical output is made to the ossicular chain.

10. A method as claimed in claim **8,** wherein the connection of the mechanical output is to the stapes.

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