Several hearing aid configurations for implantation within the middle ear cavity are disclosed. Each hearing aid is minute in size and is joined in operative relationship interiorly of the ear drum to the ossicle bone chain situated within the middle ear cavity. Each hearing aid is characterized by: (1) picking up or "reading" auditory signals off the ear drum, (2) subsequently amplifying and/or transmitting such signals directly to appropriate sound receiving mechanisms, natural or solid-state or both, located on the oval window, the round window, or the promontory leading into the inner ear, and (3) relying upon the automatic gain control (AGC) function performed by the tensors and flexors of the ossicle bone chain to prevent loud sounds from damaging the ear drum.
IMPLANTED HEARING AIDS

BACKGROUND OF THE INVENTION

1. Field of the Invention

The instant invention relates to surgically implantable hearing aids for stimulating the auditory system of the human body.

2. Description of the Prior Art

In recent years the medical arts have been, to a large extent, directed to surgical means for the correction of human bodily defects, i.e., those defects which occur in the human body due to injury, congenital malformation, or the like. Thus, for example, there have been disclosed in the medical arts a variety of elements capable of implantation within the human body. These elements in many instances comprise transplanted human organs. In many other instances, they comprise artificial members or prosthetic devices, such as, artificial hearts, heart valves, artificial kidneys, artificial limbs, and the like.

The population of the United States, as of the date of this invention, is approximately 210,000,000 people. Of such number, approximately 15 percent over 30,000,000 persons, have some form of inability to adequately perceive auditory information by means of their auditory sensory powers.

These forms of inability may be classified as follows: first, a conductive loss; secondly, a nerve loss; thirdly, a mixed type loss including body nerve and conductive losses; and fourthly, a psychogenic loss.

A conductive loss usually is attributable to excessive calcium or cartilaginous deposits on the joints on the ossicle bone chain of the middle ear. These deposits restrain movement of the conductive bone chain, and in most instances, also restrict movement of the oval window leading to the inner ear. Other conductive losses may be caused by damage to the ear drum or tympanum through subjection to concussion, extreme atmospheric pressure, or the like. Additionally, the ossicle bone chain may be eroded by chronic infection, congenital conditions, or the like.

Nerve loss is the most common type of hearing inability. Such loss may be attributable to deterioration of the auditory nerves through heredity, disease, noise damage or the like.

The third type of hearing inability, designated above as mixed nerve-conductive loss, includes those instances in which an individual has present in his auditory system a combination of the losses described above.

Referring again to condition one, the conductive loss, there are cases wherein the ear drum is eroded, ruptured, or otherwise impaired, and/or the bone movement is restricted through hardening and malfunction. Thus, in effect, the auditory signals received are reduced in intensity due to this loss of transmission effectiveness. Therefore, the necessary threshold level of desirable signals which must be transmitted to the brain by means of the auditory nerves is not achieved. Consequently, the signals perceived by the brain are inadequate to allow the brain to translate such signals into intelligible information.

Referring again to condition two, the nerve loss, it should be understood that such nerve damage may occur when fibers of the auditory nerves are damaged through disease or hereditary congenital defects. The cochlea within the inner ear functions as a receiving mechanism similar to a piano keyboard. When the cochlea or any other portion of the auditory nervous system is damaged, only a portion of the auditory energy which is received thereby is transmitted to the brain. These losses occur particularly in the upper end of the range of audible sounds, because of subjection to industrial noises, jet noises, explosions, atrophy age or the like.

Certain infectious conditions, such as scarlet fever, measles, sinusitis, or the like, are also known as common causes of the three above noted types of auditory losses.

A fourth type of loss, generally designated as psychogenic, usually occurs where there is a loss in energy transmission due to a mental blockage.

While the present invention is primarily directed to the correction of the first three hearing loss conditions described above, it will be understood that there may be instances in which the fourth condition may be corrected or alleviated by the insertion or implantation of the present devices.

Each of the above described conditions may be caused by congenital defects occurring within the human body, these defects usually being apparent within two and one-half decades from the birth of the individual, and at that time, generally perceivable by skilled examination.

The prior art has disclosed various means for aiding in the correction of the above-identified and described auditory defects. These corrective devices have fallen into three basic categories. First, those devices which mechanically direct to the human ear, by means of filtration or the like, that portion of received auditory oscillations which contain intelligible information. Secondly, those devices which convey to the inner ear, via insertion within the outer ear and ear canal or via bone transmission, electrical and/or mechanical amplification of received auditory signals. Thirdly, corrective or prosthetic devices which are intended to be substituted for various elements of the human auditory system. Broadly speaking, the implanted transducer of the instant invention is a hybrid of the second and third categories of corrective devices.

The ear trumpet is deemed to be representative of the first category of corrective devices, for the trumpet merely funnels the sound received in the outer ear down the ear canal toward the ear drum without mechanically or electrically amplifying such auditory energy.

The majority of the hearing aids or corrective devices utilized today fall within the second category, for such hearing aids rely upon a sound amplifier-transmitter unit carried upon the person, with a wire connecting the transmitter to a receiver unit which is stuck into the outer ear and extends inwardly into the ear canal. With the advent of solid-state electronics, the sound amplifier-transmitter unit has been mounted in eyeglass frames, earrings, necklaces or the like, with a wire connection between the eyeglass frames, earring, necklace, etc., and the receiver unit inserted within the ear usually through the use of an earmold.

Many persons, however, despite their need for a corrective device to overcome their hearing loss, refuse to wear a hearing aid for esthetic or cosmetic reasons. Other persons cannot tolerate the distortions in tone caused by the transmission between the amplifier-transmitter unit and the receiver unit, in addition to the
distracting buzzing sound of the device itself. Furthermore, conventional hearing aids may not provide effective relief for certain persons since their hearing loss may be attributable to auditory problems in the middle ear and/or inner ear.

Consequently, an alternative type of corrective device of the second category has been evolved. This corrective device relies upon a surgically planted receiver that conducts auditory energy through the bones of the ossicular chain or the bones of the skull to the inner ear. The speech amplifier-transmitter, which supplies the power to the receiver via remote transmission without interconnecting wires, can be encased in a fountain pen shape, cigarette pack shape, standard hearing aid shape or similar object. Although the bone-conductive type of corrective device does overcome the widespread esthetic or cosmetic objection to the more conventional hearing aid, it has not met with complete acceptance for numerous reasons. United States Pat. Nos. 3,402,392 3,209,081 and 3,346,704, granted to Goldschmidt, Ducote et al., and Mahoney, respectively, disclose inoperative ear implants that rely upon bone conduction to achieve improved hearing.

As previously noted, there has been constantly increasing attention focused upon the utilization of artificial body members or prosthetic devices. Hence, prosthetic stapes of stainless steel, polyethylene, Tefton, platinum or other inert materials that are autoclavable, have been fabricated; for example, see U.S. Pat. Nos. 3,191,188 and 3,196,462, granted to Mercandino et al., and Robinson, respectively.

Such prosthetic devices, which fall within the third category of corrective devices as outlined above, enable the recipient of such implant to hear in the same fashion as a person with normal hearing ability. Thus, the recipient can distinguish sounds clearly over a wider range of frequencies and with greater fidelity than can be obtained by a hearing aid of the second category for the prosthetic device is operatively associated with the oval window leading into the inner ear.

One of the major drawbacks of such prosthetic stapes, however, is that the hearing loss may be attributable to defects in the malleus, the incus, or the stapes or the oval window area, or any combination of these elements. Accordingly, the implantation of the stapes may have limited success in alleviating hearing losses attributable to diseases of the middle ear. Furthermore, prior prosthetic stapes are merely substitutive in nature and cannot amplify the sound energy received at the inner ear.

More recently, attempts have been made to surgically implant a hearing aid within the body of the person suffering from a hearing loss. For example, U.S. Pat. No. 3,557,775 granted to Mahoney, discloses the implantation of a microphone tube, amplifier unit and a speaker tube in the antrum cell of the mastoid adjacent to the auricular appendage of the external ear. The unit is powered by a rechargeable battery, and the sound picked up by the microphone is fed into the speaker tube and thence to a point closely adjacent to the round window leading into the inner ear. The wave motion caused in the inner ear is transmitted to the cochlea, which initiates the electrical impulses to the brain which are translated into intelligible sound.

U.S. Pat. No. 3,594,514, granted to Wingrove, also discloses an implantable hearing aid including a piezoelectric ceramic element. One end of the element is implanted in an area of the body that can provide a stable platform, such as the mastoid bone. The opposite end of the element is then placed adjacent one of the osseous bones in the middle ear or the oval window leading into the inner ear. The piezoelectric crystal bends or vibrates in response to a varying voltage signal delivered thereto over a receiving coil and a related to circuit responsive to varying sound waves. A microphone preferably located externally to the body, picks up sound waves and changes such waves into modulated RF signals through appropriate circuitry. The modulated RF signals are transmitted by a transmitting coil to the above noted receiving coil, and thence to the piezoelectric crystal.

Whereas Mahoney and Wingrove may suggest ways to resolve some of the problems previously encountered in designing hearing aids, both patents pick up sound at a point exterior of the middle ear cavity. Additionally, both patents attempt to substitute electronic components for the sound receiving function normally performed with great accuracy by the ear drum and for the sound transmitting function performed by the ossicle bone chain. Accordingly, whatever sound receiving and transmitting capability still resides in one's auditory system may work at cross purposes to the electronic implant suggested by Mahoney and Wingrove. The naturally received sound energy may clash with the electronically received and transmitted sound energy to produce distortion, and the automatic gain control provided by the sensors and flexors of the ossicle bone chain is totally overlooked.

**SUMMARY**

In light of the magnitude of the problem of hearing losses and in view of the limited success of prior devices in correcting this problem, the instant invention contemplates numerous configurations of implanted transducers that combine the most desirable features of the second and third category of corrective devices. More particularly, the instant invention contemplates a transducer implanted within the middle ear cavity so that it can pick up the sound energy striking the ear drum and can amplify such energy without distortion by causing the ossicle bone chain to mechanically vibrate and transmit such energy to the oval window, round window or promontory leading to the inner ear. Alternatively, in those instances where the ossicle bone chain is damaged, the instant invention contemplates numerous simple methods for reading the vibrations of the ear drum and translating such vibrations into electrical signals for application to the oval window, round window or promontory leading to the inner ear. Furthermore, the instant invention relies upon the natural automatic gain control of the sensors and flexors of the ossicle bone chain to prevent loud sounds from injuring the wearer to the implant, and also utilizes the natural distortion-free transmission of sound through the ossicle bone chain whenever possible.

Furthermore, the instant invention contemplates surgically drilling through the mastoid bone to position the transducer in operative relationship to the bones of the ossicle chain and/or the oval window, round window or promontory leading into the inner ear while minimizing the irritation to the ear drum.

Additionally, the implanted transducer constitutes an "all-in-the-ear" device and does not require an external, visible interconnection between the amplifier-
transmitter and receiver units, thus overcoming the current widespread objection to existing unsightly corrective devices because of cosmetic or esthetic reasons. Furthermore, the implanted hearing aids minimize, if not eliminate, the distortion and buzzing and may be used to treat other diseases of the ear, such as tinnitus. Also the transducer can be fabricated in sundry shapes and from diverse materials that are pre-selected in accordance with the dimension of the bones within the inner ear of the recipient. Ear molds with appropriate tuning and recharging circuits can be utilized to periodically externally re-tune the implanted hearing aid without resorting to a second operation or surgical procedure. Hearing aids utilizing means for converting audio impulses into light are also envisioned. Yet, additional significant advantages of the implanted transducer, and the surgical techniques employed therewith, will become apparent in light of the following description of the invention when construed in conjunction with the accompanying sheets of drawings.

DESCRIPTION OF THE DRAWINGS

FIG. 1 is a cross-sectional view of the basic human auditory system;

FIG. 1A is a front elevational view of the osseous labyrinth of the human auditory system;

FIG. 1B is a horizontal cross-sectional view of a fragment of the labyrinth, such view being taken along line 1B—1B in FIG. 1A in the direction indicated;

FIG. 2 shows a preferred embodiment of the hearing aid implanted in operative relationship to the ossicle bone chain within the middle ear cavity, such hearing aid being sound powered and constructed in accordance with the principles of the instant invention;

FIG. 3 shows, on an enlarged scale, details of the hearing aid of FIG. 2;

FIGS. 4, 5, 6, 7 and 8 show five alternative embodiments of the sound powered hearing aid;

FIG. 9 shows a hearing aid comprising a transmitting unit and a receiving unit for delivering an electrical stimulus to the inner ear to assist the natural hearing function;

FIG. 10 shows, in schematic fashion, the remotely situated control circuitry utilized in conjunction with the various embodiments of the hearing aid;

FIG. 11 shows a lightly embodiment of the hearing aid utilizing sensing means positioned within the middle ear to read or pick-up the vibrations of the ear drum when sound strikes such member;

FIG. 12 shows a second embodiment of a hearing aid utilizing magnetically responsive means to read the vibrations of the ear drum;

FIG. 12A is a detailed view of that portion of the embodiment of FIG. 12 that is located within the viewing circle;

FIGS. 13—15 diagrammatically show three alternative sensing circuits that are responsive to the variations in magnetic field transmitted by a magnet affixed to the ear drum in the manner shown in FIG. 12;

FIG. 16 shows a first, or preferred, embodiment, of a hearing aid utilizing light emitting means; and

FIG. 17 shows, in schematic fashion, the control circuitry for the hearing aid of FIG. 16;

FIG. 18 shows an insertable hearing aid unit that may be used to treat tinnitus; and

FIG. 19 shows an ear mold for tuning the controls circuits of FIG. 10.

DESCRIPTION OF THE INVENTION

Referring now in detail to the drawings in which similar reference numerals refer to similar parts, FIG. 1 depicts the basic structure of the human auditory system, such system being indicated generally by reference numeral 10. It is understood that the following description includes only those basic components of the human auditory system which are essential to hearing. For further reference to the exact details of the human auditory system, reference may be made to any standard text, such as "The Physics of the Ear" by T.S. Little, published in 1965 by Pergamon Press, Ltd., of London, England; see particularly pages 1—14.

The human auditory system comprises the outer ear, indicated generally by reference numeral 10, and including an auricle 11, an auditory canal 15 extending inwardly toward an ear drum or tympanum 16; a middle ear 12 including therein a malleus 17, an incus 18, and a stapes 19 and an inner ear 13. The bones of the middle ear collectively comprise the energy transmitting bone chain or ossicle chain 20. These bones are sometimes, respectively, referred to as the hammer 17, the anvil 18, and the stirrup 19. The stirrup is connected to, in vibratory relation, the ovular window or fenestra 30 of a fluid filled sac 40, known as the labyrinth. The ovular window 30, which is a membrane, separates the middle ear 12 from the inner ear 13.

Referring particularly to FIG. 1A, it will be appreciated that ovular window 30 forms the entry to the inner ear 11, which is enclosed within the labyrinth. The labyrinth 40 consists of two parts, the membranous labyrinth and the osseous labyrinth. The membranous labyrinth is a system of interconnected canals and pouches within the osseous labyrinth, or protective casing. Consequently, FIG. 1A depicts the configuration of the osseous labyrinth, whereas FIG. 1B illustrates a portion of the membranous labyrinth. The space between the membranous labyrinth and the osseous labyrinth is filled with a water-like fluid known as perilymph. The membranous labyrinth contains another fluid known as endolymph.

Furthermore, as indicated by the appropriate reference numerals in FIG. 1A, the osseous labyrinth is divided into three parts; the vestibule 35, the cochlea 43, and the semi-circular canals 45. These are three semi-circular canals disposed at right angles to another and filled with fluid. These canals regulate the individual's sense of balance and are not directly involved in the hearing process.

The vestibule 35 is the central part of the osseous labyrinth and the cochlea 43 is that portion of the labyrinth concerned specifically with hearing. The cochlea 43 is snail-shaped and lies horizontally in front of the vestibule 35. Such spatial relationships can be best understood by realizing that FIG. 1A is a front elevational view of the osseous labyrinth taken on a plane substantially parallel to the plane of ear drum 16 in FIG. 1.

As shown by the cut-away section of the cochlea illustrated in FIG. 1B, the membranous cochlea is divided throughout the greater portion of its spiral length into two passages by the basilar membrane 44. The upper passage of the membranous cochlea terminates at ovular window 30 while the lower passage terminates at round window 42, which is a membrane similar to ovular window 30. The windows are separated from each other by promontory 41. The basilar member 44
has a large number of specialized hair cells 44A disposed thereon; these cells collectively form the organ of Corti. These hair cells respond to the sound waves passing through the fluid in the cochlea and transmit such sound waves by way of acoustic nerves 46 to the brain.

The outer ear or auricle 11 serves as a horn for directing sound vibrations into the auditory canal 15, thus impressing these sound vibrations on the tympanum or ear drum 16. This member converts such vibrations to mechanically transmittable energy via the ossicle bone chain 20 thereby transmitting through the middle ear cavity impulses capable of subsequent translation by the brain. As previously noted, that portion of the human auditory apparatus positioned anteriorly, i.e., towards the source of external auditory energy from the tympanum 16, is generally designated as the outer ear 11. The middle ear 12 is operatively connected to the outer ear 11 through the auditory canal 15 and the tympanum 16. The tympanum serves as the dividing line between the outer ear 11 and the middle ear 12.

As explained above, the middle ear 12 includes a cavity which contains therein the above described ossicle bone chain 20. The bone chain forms a linkage for transmitting sound vibrations from the tympanum 16 to cause mechanical movement for pulsating or vibrating the oval window 30. The stapes is hinged at its upper end at 19a so that the foot plate is pivoted or rocked against window 30. In turn, window 30 pulses the fluids in the inner ear 13 to stimulate the organ of Corti and transmit impulses to the brain via acoustic nerves 46.

Thus, the hearing process can be characterized as a chain reaction involving the following four steps. First, sound vibrations are caught by the external ear 11 and passed through auditory canal 15 to the tympanum or ear drum 16. Second, the vibrations of tympanum 16 are conducted by ossicle bone chain 20 to oval window 30. Third, movement of window 30 disturbs the perilymph between the membranous labyrinth and the osseous labyrinth, which in turn, disturbs the endolymph within the membranous labyrinth. Lastly, the organ of Corti translates these liquid vibrations into electrical impulses that are transmitted by acoustic nerves 46 to the brain.

Referring now to FIGS. 2–8, it will be appreciated that the instant invention comprises diverse transducers adapted to be implanted or inserted within the human auditory system in operative relationship to the middle ear structure. Obviously, the present invention is intended to be so implanted by simple surgical procedures.

Keeping in mind the above description of the basic components of the human auditory system, as shown in FIGS. 1, 1A and 1B, reference is now made to the geometrical configurations, materials and methods for surgical implantation of the transducers constructed in accordance with the instant invention.

As explained above, the ear consists of an outer ear portion 10, a middle ear portion 12, and an inner portion 13. Contained within the middle ear portion 12, whose boundaries are roughly defined by the tympanum 16 and the oval window 30, there is the ossicle bone chain consisting of the hammer 17, anvil 18, and stirrup 19. The stirrup, in the normal human auditory system, is in operative mechanical vibratory relationship to the oval window 30. All of these elements are contained within the middle ear cavity and operate in the manner described above to coat with the other above-described members of the human auditory system. Tensor muscles 16b are disposed within the cavity to maintain the tympanum 16 properly tensioned, as shown in FIGS. 2, 4 and 5–8, and the chorda tympanum 16a maintains the bone chain 20 in proper orientation. Flexors 16c are also shown in FIGS. 2, 4 and 5–8; the tensors and flexors work in concert with each other to prevent loud noises from damaging the ear drum 16 and the other members of the auditory system.

Referring now to FIGS. 2 and 3, a preferred embodiment of the hearing aid is implanted in the middle ear cavity and is identified generally by reference numeral 60. The stapes has been removed from the ossicle bone chain, either through a simple surgical procedure or through deterioration attributable to diseases of the auditory system.

Hearing aid 60 includes a stylus 62 with an annular upper end 64 with a slot 66 passing therethrough; the slot enables stylus 62 to be slipped onto, and retained in position upon, anvil 18 by applying a crimping pressure to end 64. The point of the stylus bears against the base of a pressure sensitive device 68. A suitable pressure sensitive device is the Pitan piezoelectric transducer produced by Stow Laboratories, Inc. of Hudson, Massachusetts; such transducer assumes the form of a planar NPN transistor in which the emitter-base junction is responsive to the application of a pressure or a point force to produce a linear, amplified voltage. Numerous other pressure sensitive devices could be utilized in place of the Pitran piezoelectric transducer; such devices include piezoelectric crystals, diodes, strain gage transducers or electrically conductive wires.

The variable voltage generated by the variable pressure upon device 68 is conducted by appropriate lead 70 to remotely situated tuning circuit 72. Circuit 72, which is encased in a suitable housing, is implanted in the mastoid bone near auricle or outer ear 11. A representative circuit 72 may include a high gain FET circuit with automatic gain control to provide external volume tuning for implant 60. The variable amplified voltage signal is conducted over lead 74 to one side of a pair of piezoelectric crystals retained between the bottom face of pressure sensitive device 68 and oval window 30. The crystals may be oriented either horizontally, as shown in FIG. 3, or vertically, as shown in FIG. 4. The signals are impressed upon the crystals, which may be benders, stretchers, twisties, or combinations thereof, and the crystals vibrate against or in proximity to the oval window 30 or cochlea 43.

Although the pressure of the stylus upon the pressure sensitive device 68 may produce sufficient voltage to effectively vibrate the crystals against oval window 30, an auxiliary power source may be utilized to insure sufficient voltage for efficiently vibrating the crystals for a prolonged period of time. The auxiliary power source, which is designated by reference numeral 80, may assume the form of a minute rechargeable nickel-cadmium battery or other suitable rechargeable miniature power supply; power source 80 may also be implanted in the mastoid bone at a location remote from the middle ear cavity. A charging circuit 82 is operated with power supply 80 and could be encased in the same housing implanted in the mastoid bone. Power supply 80 and charging circuit 82 are operationally associated with transducer 68 and crystals 76,
The voltage from power supply 80 is impressed upon the crystals via lead 86, and tuning circuit 72 adjusts the frequency at which the crystals will deform or vibrate. The term sound powered indicates that the ear drum is intact and that the vibrations from the sound striking same are transmitted mechanically through the ossicle bone chain toward the inner ear. It will be noted that the hearing aids shown in FIGS. 2, 4, 5, 6, 7 and 8 fall within the broad category of sound powered devices.

In the embodiment of FIGS. 2 and 3 the piezoelectric crystals are horizontally oriented whereas in the embodiment of FIG. 4, identical crystals are vertically oriented in operative relationship to oval window 30; the stapes or stirrup 19 has not been removed from the ossicle bone chain, and no external control circuits are utilized. The crystals are situated in operative relationship to the footplate of stapes 19 and the vibrations of the crystals assist the footplate in rocking the stapes about hinge point 19. By virtue of leaving the ossicle bone chain intact, the auditory energy striking the ear drum and passing through the bone chain is distortion-free and hearing aid 88 need only supply minimal assistance to the hearing process. Aid 88 is well suited for overcoming mild hearing losses. Alternatively, the stapes 19 can be removed and the aid 88 placed in its place where conditions permit; consequently, stapes 19 is shown in dotted outline in FIG. 4.

FIG. 5 shows a second alternative sound powered hearing aid 92 that is located within the middle ear cavity in operative relationship to the ossicle bone chain. As in the embodiment of FIGS. 2 and 3, the stapes is removed from the ossicle bone chain, thus allowing the end of incus 18 to be free hanging. Hearing aid 92 includes an elongated piezoelectric crystal bar 94 that is clipped onto the free end of incus 18 by means of crimpable rings 96, 98. A pin or stylius 100 is secured to the lower end of bar 94 and extends inwardly into contact with pressure sensitive device 102 situated in proximity to a crystalline device 103 situated on promontory 41, adjacent to, or near, oval window 30. Pressure sensitive device 102, which may be a Pitran piezoelectric transducer, a piezoelectric crystal, a pressure sensitive diode, a strain gage transducer or the like produces a voltage that stimulates the oval window 30, and/or the cochlea 43, thus raising the threshold of hearing. Crystalline device 103 may be a bucker, bender, or twister crystal, or combinations thereof.

In addition to serving as a part of the mechanical linkage that produces a significant mechanical advantage in transmitting forces from ear drum 16 to oval window 30, the stresses placed upon pressure sensitive device 102 produce a variable voltage which is conducted by lead 101 to a remotely situated, high gain amplifying circuit 104. The frequency of the voltage is adjusted to the desired rate by circuit 104 and is then returned over lead 105 to crystalline device 103 to cause same to vibrate or deform at the selected frequency.

Although the pressure upon the pressure sensitive device 102 may produce sufficient voltage to effectively vibrate crystalline device 103 against oval window 30, an auxiliary power supply 106 may be connected over leads 107, 109 to opposite faces of crystalline device 103. Furthermore, a charging circuit (not shown), similar to charging circuit 82 of FIG. 3, could be implanted in the mastoid bone in operative relationship to auxiliary power supply 106. Since bar 94 is a piezoelectric crystal, a variable voltage is also produced at opposite faces thereof when it is mechanically stressed by the ossicle bone chain. Such voltage may be added to the voltage produced by the pressure sensitive device 102 and the auxiliary power supply 106, and the sum of the voltages may be applied to crystalline device 103 for more efficient operation.

A diode could be utilized in lieu of the crystalline device situated in proximity to oval window 30 in the hearing aid embodiments of FIGS. 2-5. Such diode would receive the voltage produced by pressure sensitive device 68 and rectify same into pulsating D.C. voltage that could be applied directly to the oval window, thus providing electrical stimulus to the auditory nerve. Alternatively, the diode and the crystalline device could be omitted, and the voltage from pressure sensitive device 68 could be led over electrically conductive wires directly to the oval window to shock same.

FIG. 6 shows a third alternative embodiment of the sound powered hearing aid, such embodiment being indicated generally by reference numeral 108. The ossicle bone chain is intact, and hearing aid 108 assumes the form of a pressure sensitive device of substantially rectangular shape with a small stylus bearing thereagainst. One corner of the pressure sensitive device is secured to the footplate of stapes 19 to assist the stapes in rocking or pivoting against window 30 about hinge 19c. The pressure transmitted through the ossicle bone chain press against the stylus of device 108 with sufficient intensity to generate a voltage on leads 109 that stimulate the area of oval window 30. If need be, additional voltage may be supplied to pressure sensitive device 102 from a remote power supply situated in the mastoid bone near auricle 11.

FIG. 7 shows a fourth alternative embodiment of the sound powered hearing aid, such embodiment being indicated generally be reference numeral 110. The stapes has been removed from the ossicle bone chain, so that the inwardly extending, free end of anvil 18 can be utilized to transmit vibrations from the ear drum to hearing aid 110. A collar 112 on hearing aid 110 is slipped over the free end of anvil 18, so that the movement of the anvil causes movement of stylus 114 situated on the underside of collar 112. The stylus bears upon a pressure sensitive device 116, such as the Pitran transducer described above, and produces a voltage proportional to the force pressing thereagainst. The voltage is led over appropriate leads 118 to a remotely situated tuning circuit 119 and/or an auxiliary power source 121. The voltage after appropriate tuning and/or amplification, is returned via leads 120 to opposite faces of a crystalline device 122, such as a piezoelectric crystal. The crystal rests atop a fluid filled sack 124 that is secured to oval window 30 by a layer 126 of plastic jelly-like foam known commercially as Jel-Foam.

Consequently, sound striking the ear drum and passing through the hammer to the free end of the anvil, produces a variable pressure bearing against pressure sensitive device 116. Device 116, in turn, generates a voltage proportional to the pressure applied thereto; the voltage is led over leads 118 to the remote tuning and/or amplification circuits 119 and 121, respectively, and then returned over leads 120 for application to the opposite faces of crystal 122. The crystal, which may be a bender, twister, or bucker, or any combination thereof, flexes and such movement is transmitted.
through the fluid medium in sack 124 to oval window 30.

If desired, sack 124 may be designed as a truncated cone with the broader surface providing increased support for crystalline device 122. The parallel, narrower surface would be affixed to oval window 30. The cone shape of the sack might well enhance the effectiveness of the vibrations transmitted therethrough. Additionally, the voltage produced by pressure sensitive device 116 may be amplified, tuned, clipped, etc., by conventional circuits before being applied to crystal 122.

FIG. 8 shows a fifth alternative embodiment of the sound powered hearing aid, such embodiment being indicated generally by reference numeral 125. Hearing aid 125 is similar to the hearing aid 110 of FIG. 7 and includes a collar 126, a stylus 128, a pressure responsive device 130, leads 132 and 134, control circuits 136 and 138, crystalline device 140, and a fluid filled sack 142 positioned atop oval window 30. While hearing aid 110 in FIG. 7 requires the removal of stapes 19, hearing aid 125 takes full advantage of the ossicle bone chain and leaves same intact.

Pressure sensitive device 130, which is a minute element, is slipped between anvil 18 and stirrup 19 at their juncture, and sack 142 is positioned between the footplate of stirrup 19 and oval window 30. The movement of the inner end of anvil 18, in response to sound striking the ear drum, thus presses stylus 128 against pressure responsive device 128 to produce a variable voltage output across leads 132, 134. The variable voltage is tuned by control circuit 136, and the variable voltage is amplified by control circuit 138. The voltage is then applied across the opposite faces of crystalline device 140, and the resultant movement of device 140 is transmitted by sack 142 to oval window 30. The sack may be adhered to the oval window by a suitable surgically acceptable jelly, or the depth of the oval window with respect to promontory 41 may be such that the sack is retained in place, without adhesive, by the surrounding walls of the promontory. The sack and the pressure sensitive device are designated to take up any slack in the ossicle bone chain, and thus maximize the effectiveness of the sound conduction through the ossicle bone chain.

Variants of hearing aid 125 are equally feasible. For example, sack 142 may be omitted and crystalline device 140 may be positioned against oval window 30. Alternatively, crystalline device 140 may be implanted in the mastoid bone surrounding the middle ear cavity and rely upon bone conduction techniques to send sound into the inner ear. Additionally, the pressure sensitive device may be slipped under the footplate of stapes 19 to take advantage of the rocking motion of the stapes. As yet another variant, a first pressure sensitive device may be slipped between teh anvil 18 and the stirrup 19, and a second device may be slipped beneath the footplate. In all instances, such hearing aids 125 are particularly effective in overcoming hearing deficiencies attributable to conductive losses.

Although the operation of hearing aids 60, 88, 92, 108, 110, and 125 has already been described in detail above, it is believed to be expedient to briefly reiterate the salient features of such hearing aids at this juncture. In all embodiments, sound passing down ear canal 15 and striking ear drum 16, is, in normal sequence, amplified twenty-two times by the fulcrum action of the ossicle bone chain before reaching oval window 30. The stylus or the pin function in the same capacity as the stapes without any reduction in the mechanical amplification. Furthermore, the tensors and flexors function as a natural automatic gain control circuit to cushion the impact of loud sounds upon the auditory system.

Additionally, in all the above described sound-powered embodiments, either the stapes 19 or the stylus that cooperates with the pressure sensitive device, converts the movement of the ear drum and the ossicle bones to movement of the pressure sensitive device positioned over, or in operative relationship, to oval window 30. The varied pressure of the sound striking the ear drum thus produces a varied output voltage that may be fed directly to oval window 30 for electrical stimulus, or may be amplified and then impressed upon a crystalline device, such as a piezoelectric crystal, adjacent to, or atop, the oval window. External tuning and volume control circuits may also be utilized. In summary, the ear drum and the ossicle bone chain replace the microphone in the receiving unit of conventional hearing aids, for the sound from the ear drum is mechanically amplified through the natural functions of the ossicle bone chain; such variations in the bone chain are pressed upon a pressure sensitive device to produce a correspondingly varied electrical output that is sent to a high gain amplifying circuit and then to a crystalline device operatively associated with the oval window. Alternatively, the high gain amplifying circuit may be omitted. The above described hearing aids are considered to be sound powered devices, and will probably correct one-half of the mild hearing losses. Approximately, 75 per cent of those persons suffering from hearing losses fall within this extremely broad category.

In all of the embodiments of the instant hearing aid, the crystalline devices, diodes and conductive wires (see FIG. 9) are described and illustrated for the sake of clarity as if they were in direct contact with oval window 30 or promontory area 41. However, the actual implantation of the hearing aids has shown that an alternative method of fixation is more desirable. Such method relies upon a pliable substance, such as a Jel Foam, to be packed about the innermost end of the device to be coupled to oval window 30. The pliable substance dissolves partially and leaves a protective sac of minute dimension, the sac functioning in much the same manner as a balloon loosely filled with water. This resilience helps to adjust the linkage differential in the bone displacement of the ossicle bone chain. The sac also reduces the danger of rupturing the oval window, and does prevent electrical shock or stimulus from passing therethrough to the oval window.

FIG. 9 shows a hearing aid that delivers an electrical stimulus to oval window 30, such hearing aid comprising two units, a first, or transmitting unit 144 and a second, or receiving, unit 146. Unit 144, which is encased within plastic housing 148 and has an outwards extending pull tab 150, is situated within ear canal 15. Unit 144 includes a microphone 152, such as an electret microphone, a battery 154 or another suitable power source; a volume control circuit 156; and a transmitting coil 158. Transmitting coil 158 can radiate RF energy or magnetic vibrations through the skin to energize receiving unit 146.

Unit 146, which is implanted just beneath the skin in the mastoid bone defining the ear canal, includes a receiving coil 160, a conducting wire 162, and an electric
cally stimulated device 164 affixed to promontory 41 between the oval and round windows leading into the inner ear. Device 164 may be a piezoelectric crystal, a diode or may merely be a continuation of conducting wire 130. In all instances, the electric stimulation cooperates with the natural functioning of the ossicle bone chain to increase the hearing of the wearer of this two unit hearing aid.

FIG. 10 shows a pressure sensitive device 166 and an actuating button or diaphragm 168 positioned immediately adjacent thereto. The button is implanted just under the skin behind auricle 11. The pressure sensitive device may well be a Pitran transducer of the type discussed above, so that manual pressure applied to button 168 will press the stylus 170 positioned therebelow against the transducer and produce a variable voltage. Such voltage can be fed into the implanted battery or power source 172 to recharge same, whenever needed. A second button 174 and a second pressure sensitive device 176 can produce a voltage to be fed to volume control circuit 178; when such circuit is sensitive to voltage levels. If circuit 178 is not so responsive, button 174 and second pressure sensitive device 176 can be omitted without serious impairment to the efficiency of the implanted hearing aid.

FIG. 11 shows a first, or preferred, embodiment of a hearing aid that utilizes transmitting means secured to the inner side of ear drum 16 to transmit signals through the air in the middle ear cavity to sensing means disposed adjacent to the oval window 30, promontory 41, or round window 42. Whereas the sound powered embodiments of FIGS. 2-9 utilize mechanical transmission of sounds through the ossicle bone chain, and the embodiment of FIG. 10 relies upon electrical stimulation, the embodiments of FIGS. 11-17 focus primarily upon transmission between the ear drum and implanted sensing means and pay only incidental attention to the sound mechanically transmitted through the ossicle bone chain.

The hearing aid of FIG. 11 is identified generally by reference character 180 and includes a small transmitter 182 which assumes the form of a charged piece of material on the inner side of ear drum 16; the transmitter may be a magnet, a fragment of phosphor, a radio active isotope or a charged particle. The receiving unit includes either an electret microphone 184, a magnetic diode, or a transistor gate that is sensitive to magnetic variations, and a piezoelectric crystal 186 positioned in the area of promontory 41. The electret microphone might be one-eighth inch in diameter, and can be obtained from Bell Laboratories and numerous other commercial sources; the magnetic diodes are also available from similar sources. It will be noted that the ossicle bone chain can be left intact while utilizing hearing aid 180.

The negatively or positively charged piece of material 182 serves to vary the output of electret microphone 184. The electret in microphone 184 has a static potential, and the plus or minus charge held by piece 182 will repel, or attract, the electret at the same rate that sound is striking drum 16. The minute voltage variations produced by the electret are sent via appropriate leads (not shown) to a remotely situated high gain amplifier circuit 188; after suitable amplification, the voltage is returned over lead 190 and is impressed upon crystal 186 situated adjacent to oval window 30 to cause same to vibrate. Additionally, hearing aid 180 may employ a remotely located power source 192 with, or without, a remote volume control circuit; the power source and the volume control are implanted in the mastoid bone at locations removed from one another. Both power source 192 and high gain amplifier circuit 188 (if such circuit employs a FET or other magnetic responsive device) are recharged by magnetic induction in a manner that has already been explained in connection with FIG. 10. A reed switch 194 is inserted into the circuitry of FIG. 11 to cut off the power to crystal 186 while the battery or power source 192 is being recharged.

FIG. 12 shows an alternative form of hearing aid, designated generally by reference numeral 196, that relies upon transmitting means affixed to the inner side of the ear drum and sensing means disposed adjacent to the oval window 30, promontory 41, or round window. The distance between the transmitting means on the ear drum and the sensing means on the promontory is approximately one-quarter of an inch; obviously, effectively bridging such a small distance without transmission loss or distortion is a relatively simple task for existing solid-state devices.

Hearing aid 196 includes a first minute magnet 198 with a hook 200 that is slipped over the malleus or hammer 17 near its point of contact with the inner face of ear drum 16. Hook 200 might also be anchored in the vicinity of chorda tympanum 16a; see FIG. 1. Continuing interiorly through the middle ear cavity, hearing aid 196 further includes a second magnet 202 that is operatively associated with a stylus 204 affixed to diaphragm 206. The stylus is positioned in operative relationship to a pressure sensitive device 208, such as a Pitran transducer, which produces a variable voltage proportional to the pressure applied thereto by the stylus. The voltage output from device 208 is led over leads 210 and 212 to a remote tuning and amplifying circuit 212 and a remote charging circuit 214, respectively. The output from control circuits 212 and 214 is applied to crystalline situated in the area of promontory 41, which device may be a piezoelectric crystal capable of bucking, twisting or bending. Under certain circumstances control circuits 212 and 214 may be omitted. In either event, the motion of the crystalline device is related directly to the sound striking ear drum 16 and the ossicle bone chain is left intact, thus leaving the natural automatic gain control (AGC) facility of the ossicle bone chain unimpaired.

FIG. 13 diagrammatically shows another sensing circuit that will respond to the variations in the magnetic field transmitted thereto by magnet 198. The circuit of FIG. 13 also includes the second magnet 202 which is secured to the diaphragm 218 of an electret microphone 220. The movement of magnet 198 as sound energy strikes the ear drum causes magnet 202 to move in response to changes in the magnetic field established therebetween. The movement of magnet 202 pumps electret microphone 220 and produces a variable voltage output that is led, over appropriate leads, to remote tuning circuit 222 and remote charging circuit 224. After the voltage has been properly regulated, it is applied to crystalline device 226, which vibrates in the area of promontory 41.

FIG. 14 diagrammatically shows another sensing circuit that will respond to the variations in the magnetic field transmitted thereto by magnet 198 affixed to the inner side of the ear drum. The second or receiving
magnet 202 utilized in the embodiments of FIGS. 12 and 13 is replaced by a transistor gate 228 that is responsive to changes in the intensity and polarity of magnetic fields; one common type of gate 228 is a field-effect transistor (F.E.T.). The small output voltage across gate 228 is suitable regulated by control circuits 222, 224, before being applied to a crystalline device 229 situated in the area of promontory 41.

FIG. 15 diagrammatically shows yet another sensing circuit that will respond to the variations in the magnetic field transmitted thereto by magnet 198 affixed to the inner side of the ear drum. The second or receiving magnet 202 utilized in the embodiments of FIGS. 12 and 13, or the transistor gate 228 of FIG. 14, is replaced by a Hall-effect device 230 that is responsive to changes in the intensity and polarity of magnetic fields. The small output voltage across device 230 is suitably regulated by control circuits 222, 224, before being applied to a crystalline device 231 situated in the area of promontory 41.

Numerous modifications can readily be effectuated in the hearing aid depicted in FIGS. 12-15. For example, a small fragment of phosphor or other radio-active isotope could be substituted for magnet 198. Also, crystalline devices 216 and 226 (FIGS. 12 and 13, respectively) could be eliminated, and the variable voltage appearing across the receiving means could be utilized directly to stimulate, or shock, the oval window, promontory, or round window. Alternatively, the crystalline devices could be eliminated and a diode substituted therefor; such diode would receive the voltage produced by the sensing means and act as a rectifier to pulsating D.C. voltage that could be applied directly to the oval window, thus providing electrical stimulus to the auditory nerves of the inner ear.

FIGS. 16-17 disclose a two unit hearing aid that employs an audio responsive light emitting unit and light sensing means on opposite sides of the ear drum that respond to sounds striking the ear drum. The audio responsive unit is identified by reference numeral 230 and is encased in a plastic housing 232 that fits within the ear canal 15; the housing has a pull tab 234 for removing the unit. Within housing 232 is a miniature microphone 236, a long-lived, rechargeable battery 238, an amplifier 240 and a circuit 242 for energizing light source 244 that extends through the housing and emits a beam of collimated light down the ear canal.

The light sensing means is disposed on the opposite side of ear drum 16 in the area of promontory 41 and in substantial alignment with light source 244. The light sensing means includes a light responsive resistor 246 connected to an amplifier 248, the output of such amplifier being fed to remote control circuits 250, 252 and thence to crystalline device 254. A suitable resistor 246 would be a cadmium sulphide cell or photocell or a selenium cell. The vibration of device 254 in the area of promontory 41 augments the sound energy mechanically transmitted from the ear drum through the ossicle bone chain. If desired, crystalline device 254 could be omitted and the output voltage from amplifier 248 could be impressed directly upon the area of promontory 41 to electrically stimulate the auditory nerves. Alternatively, crystalline device 254 could be omitted and the output voltage from amplifier 248 could be fed to a diode that would convert the voltage into a pulsating D.C. stimulus.

The transmitting unit 230 converts the sound or audio energy striking microphone 236 into light pulses emanating from light source 244. Since ear drum 16 is opaque and the ear canal is dark, the light pulses are easily detected by diode 246 and the circuitry associated therewith for converting the light energy into electrical energy.

FIG. 18 shows yet another embodiment of a hearing aid constructed in accordance with the principles of the instant invention. This embodiment also comprises two units, a first or transmitting unit 256, and a second, or receiving unit 258. Unit 256, which is encased within plastic housing 260 and has an outwardly extending pull tab 262, is situated within ear canal 15. Unit 256 includes a microphone 264 for receiving auditory energy, a battery 266 or other suitable power source, an amplifying circuit 268, and a transmitting device 270, such as a coil. Unit 258 comprises a receiver 272 operatively associated with a small, rechargeable battery 274 and a crystalline device 276. The receiver, the battery and the crystalline device are implanted within the mastoid bone a short distance from ear canal 15. Unit 256 sends RF, magnetic or electrostatic signals to implanted receiving unit 258. Unit 258 then converts the signal into a vibratory movement of crystalline device 276; such movement is transmitted to the cochlea by bone conduction through the mastoid bone.

The hearing aid embodiment of FIG. 18 is particularly well suited to overcome tinnitus, a physical or mental condition associated with the auditory system that produces a sensation of ringing, whistling or buzzing in the ears of the person so afflicted. The transmitting units can be removed from the ear canal and tuned so as to transmit various sounds to the ear nerve, the characteristics of the transmitted sound being selected so as to mask the unpleasant sounds associated with tinnitus.

FIG. 19 illustrates an ear mold 278 that fits into auricle 11 and extends into ear canal 15 towards ear drum 16. Ear mold 278, which may be utilized in connection with the manually operable rechargeable devices of FIG. 10 or in lieu thereof, is a custom-made, hollow shell with a first charging coil 280 secured therein in a fixed position consistent with the fixed position of implanted power source 172 which has a receiving coil 173. Charging coil 280 radiates energy to coil 173 for implanted power source 172 to thereby recharge same. A second charging coil 282 may be used to adjust the implanted volume and/or frequency tuning circuit 178; however, care must be exercised to position the coils as far apart as space will permit, thus isolating the coils and circuits from one another.

A charging magnet 284, or other polarizing device, is situated at the innermost end of ear mold 278, which is reduced in diameter to avoid discomfort to the person temporarily wearing same during the fitting process. The charging magnet or polarizing device causes variations in the polarity and intensity of the magnet or radioactive fragment attached to the inner side of ear drum 16, as shown in FIGS. 11-15. The charging coils 280 and 282 in ear mold 278 are powered over appropriate leads from a remote, adjustable control device 284 that is simply plugged into a conventional wall outlet.

At periodic intervals, the wearer of the hearing aid will visit a clinic and have the ear mold inserted into his ear. Trained personnel will then readjust the control
circuits for the hearing aid without resort to surgical procedures.

Many of the above described hearing aids can be implanted in the first instance by the simple surgical procedure of cutting and laying back the ear drum to expose the middle ear cavity. Other hearing aids can be implanted by drilling through the mastoid bone behind the ear toward the middle ear cavity; an accurately drilled hole will be aligned with the area of the oval window 30, promontory 41 and the round window so that the various sensing devices can be positioned thereagainst. Drilling through the mastoid leaves the ear drum intact and reduces the potential side-effects of such initial surgical procedure.

Since sundry additional modifications may be made in the configuration and materials of the instant implanted hearing aids, it is to be understood that all matter herein set forth or shown in the accompanying drawings is to be interpreted as illustrative in nature and not in a limiting sense.

We claim:
1. An implantable, sound powered hearing aid comprising:
   a. transducer means positioned interiorly of the ear drum in proximity to the oval window within the middle ear cavity,
   b. said transducer means being pressure sensitive so as to generate a variable voltage output in response to the application of pressure thereto,
   c. stylus means secured to either the hammer, anvil or stirrup of the ossicle bone chain located in the middle ear cavity in operative relationship to said pressure sensitive transducer means,
   d. said stylus means being pressed against said transducer means by the ossicle bone chain with a variable force when sound strikes the ear drum to thereby produce a variable voltage, and
   e. conducting means to lead said variable voltage to the area of the oval window to electrically stimulate same.

2. The hearing aid as defined in claim 1 further including a piezoelectric crystal positioned in the area of the oval window, said conducting means impressing said variable voltage upon said crystal to cause same to vibrate and thus stimulate the auditory nerve.

3. The hearing aid as defined in claim 1 further including a diode positioned in the area of the oval window, said conducting means leading said variable voltage to said diode which rectifies same into pulsating D, C. voltage and thus stimulates the auditory nerve.

4. The hearing aid as defined in claim 2 further including an amplifying circuit connected between said pressure sensitive transducer means and said piezoelectric crystal, said amplifying circuit amplifying the variable voltage produced by said transducer means before said voltage is impressed upon said crystal.

5. The hearing aid as defined in claim 2 further including an auxiliary power supply, connected to said piezoelectric crystal, to impress its voltage thereupon.

6. The hearing aid as defined in claim 5 further including a tuning circuit connected between said pressure sensitive transducer means and said piezoelectric crystal and in operative relationship to said power supply, said tuning circuit adjusting the frequency at which said crystal will vibrate.

7. The hearing aid as defined in claim 5 further including recharging means for said auxiliary power supply, said recharging means comprising a button under the skin of the wearer of the hearing aid, a stylus secured to said button, and a pressure sensitive transducer means situated in operative relationship to said transducer means, said transducer means connected to said auxiliary power supply to supply a variable voltage thereto, said button being manually depressed to press the stylus against the transducer means whenever said auxiliary power supply requires recharging.

8. The hearing aid as defined in claim 2 wherein said stylus means comprises a piezoelectric bar with a pin extending outwardly therefrom.

9. The hearing aid as defined in claim 8 wherein said piezoelectric bar produces a variable voltage as said bar is stressed when sound striking the ear drum is transmitted through the ossicle bone chain, and circuit means for amplifying the variable voltage before applying same to the oval window area.

10. The hearing aid as defined in claim 1 wherein the transducer means are held in a rectangular package, said package being positioned in the opening of the stapes of said ossicle bone chain with one corner of the package bearing against the footplate of the stapes.

11. The hearing aid as defined in claim 1 further including a resilient fluid filled sack interposed between the ossicle bone chain and the area of the oval window and a piezoelectric crystal disposed thereupon, said conducting means impressing said variable voltage produced by said pressure sensitive device upon said crystal which vibrates atop the sack and transmits said vibrations therethrough to the area of the oval window.

12. The hearing aid as defined in claim 11 further including a collar situated atop said transducer means, said collar engaging the free end of the anvil of the ossicle bone chain.

13. The hearing aid as defined in claim 1 wherein said transducer means and said stylus means are slipped between the joint formed by the anvil and stirrup of the ossicle bone chain.

14. An implanted hearing aid comprising:
   a. a transmitting unit encased in a housing and positioned within the ear canal, said transmitting unit including:
      1. a miniature microphone for producing a variable voltage proportional to the sound striking same,
      2. a power source for energizing said microphone,
      3. an amplifying circuit for increasing the voltage produced by said microphone,
      4. a transmitting coil operatively connected to said microphone, said power source, and said amplifying circuit for radiating an electromagnetic field of variable intensity, and
   b. a receiving unit including:
      1. a receiving coil implanted in the mastoid bone in proximity to said transmitting coil, said coils being inductively coupled together, and
      2. conducting means implanted in the mastoid bone to lead the variable voltage received by said coil to the area of the oval window to electrically stimulate same.

15. The hearing aid as defined in claim 14 further including a piezoelectric crystal positioned in the area of the oval window, said conducting means impressing said variable voltage upon said crystal to cause same to vibrate and thus stimulate the auditory nerve.

16. The hearing aid as defined in claim 14 further including a diode positioned in the area of the oval win-
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dow, said conducting means leading said variable voltage to said diode which rectifies same into pulsating D.
C. voltage and thus stimulates the auditory nerve.

17. An improved hearing aid comprising:
   a. transmitting means secured to the inner surface of the eardrum in the area of the junction defined by
      the hammer and the eardrum, said transmitting means radiating magnetic waves into the middle ear cavity,
   b. receiving means situated within the middle ear cavity on the promontory promontory the area of
      the oval window, said receiving means including:
      1. magnetically responsive means retained upon a flexible diaphragm,
      2. a stylus connected to said diaphragm,
      3. a pressure sensitive transducer for producing a variable voltage in response to the application
         of pressure thereto, said stylus being positioned in operative relationship to said transducer,
      4. said stylus being pressed against said transducer when the transmitting moves relative to the
         receiving means as sound energy strikes the eardrum to thereby produce a variable voltage, and
   c. conducting means to lead said variable voltage to the area of the oval window to electrically stimu-
      late same.

18. The hearing aid of claim 17 wherein the transmitting means is a permanent magnet.

19. The hearing aid of claim 17 wherein the transmitting means is a fragment of phosphor.

20. The hearing aid as defined in claim 17 wherein the transmitting means is a radioactive isotope.

21. The hearing aid as defined in claim 17 wherein the magnetically responsive means is a field-effect tran-
    sistor gate.

22. The hearing aid as defined in claim 17 wherein the magnetically responsive means is a Hall-effect ele-
    ment.

23. The hearing aid as defined in claim 17 further including a piezoelectric crystal positioned in the area of
    the oval window, said conducting means impressing said variable voltage upon said crystal to cause same to
    vibrate and thus stimulate the auditory nerve.

24. The hearing aid as defined in claim 17 further including a diode positioned in the area of the oval win-
    dow, said conducting means leading said variable voltage to said diode which rectifies same into pulsating D.
    C. voltage and thus stimulates the auditory nerve.

25. An implanted hearing aid comprising:
   a. a transmitting unit encased in a housing and positioned within the ear canal, said transmitting unit
      including:
      1. a miniature microphone for producing a variable voltage proportional to the sound striking same,
      2. a power source for energizing said microphone,
      3. an amplifying circuit for increasing the voltage produced by said microphone,
      4. a light emitting device connected to said microphone, said power source, and said amplifying
         circuit for projecting a light beam of variable intensity,
   b. a receiving unit including:
      1. a light responsive sensor implanted on the promontory in the area of the oval window, said light
         emitting device and said light responsive device being in substantial alignment with one another
         and on opposite sides of the opaque ear drum,
      2. said sensor producing a variable voltage proportional to the intensity of the light beam falling
         thereupon,
      3. amplifying means for increasing the voltage produced by said light responsive sensor, and
      4. conducting means to lead the variable voltage produced by said sensor and said amplifying
         means to the area of the oval window to electrically stimulate same.

26. An implanted hearing aid for the treatment of tinnitus comprising:
   a. a transmitting unit encased in a housing and positioned within the ear canal, said transmitting unit
      including:
      1. a miniature microphone for producing a variable voltage proportional to the sound striking same,
      2. a power source for energizing said microphone,
      3. an amplifying circuit for increasing the voltage produced by said microphone,
      4. a transmitting coil operatively connected to said microphone, said power source, and said ampli-
         fying circuit for radiating an electromagnetic field of variable intensity,
   b. a receiving unit implanted in the mastoid bone surrounding the ear canal including:
      1. a second miniature microphone responsive to the electromagnetic field radiated by the trans-
         smitting for producing a variable voltage,
      2. a power source for energizing the second microphone, and
      3. crystalline device that vibrates in response to the voltage applied thereto by the second micro-
         phone, the vibrations being conducted through the mastoid bone to the inner ear to stimulate the
         auditory nerve.

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