TRANSDUCER FOR STIMULATION OF FACIAL NERVE SYSTEM WITH R-F ENERGY

Filed Nov. 13, 1967
The invention is directed to a highly efficient transducer of laminar construction which couples a radio frequency signal source with selected sites of the "facial nerve system." The transducers are substantially bonded laminar form and includes a first layer of conductive material such as a fine wire mesh; a second layer of polyester film; and a third layer comprising a laminate of polyester insulating film-metal foil-polyester insulating film. All three layers are effectively independent of each other and are preserved as a unit by limited bonding at peripheral portions. In one advantageous embodiment for use in noise-attenuating applications, the loosely bonded laminar transducers are provided with a generally annular configuration and are disposed upon the ear cushions of headsets, ear defenders, protective helmets, or the like. For these applications, the annular transducers are of sufficient size to surround the entire periaural areas of the head of a listener and they include integral central portions which extend across the transducers to provide central electrostatic speakers adjacent the ears of the listener. The annular, noise attenuating transducer, when connected to a transdermal signal source and placed against the periaural areas of the head, provides a listener with both a transdermal stimulus and an acoustic stimulus and makes hearing possible in deafening, high noise environments of 100-135 decibels (db measured in relation to A.S.A. standard reference level of .0002 dyne per square centimeter pressure).

RELATED PATENTS AND APPLICATIONS

The new and improved transducers for highly efficient transdermal energy transfer are intended for use in transdermal hearing systems of the type in which radio frequency energy is applied to the facial nerve system to stimulate hearing in accordance with the principles recited in U.S. Patents 2,995,633; 3,170,993; 3,267,931; and 3,156,787; and copending application Ser. No. 446,267, filed Apr. 7, 1965. The new transducers may also be employed in systems which provide therapeutic benefits to the facial nerve system. The transdermal teachings of copending application Ser. No. 633,035, filed Apr. 24, 1967. The present application is a continuation-in-part of said copending applications Ser. Nos. 446,267, filed Apr. 7, 1965, and 633,035, filed Apr. 24, 1967.

BACKGROUND OF INVENTION

In accordance with the teachings of the aforementioned patents, "transdermal electrical hearing," hereinafter referred to as transdermal (TD) hearing, may be stimulated in a subject by establishing an electrical field at selected sites of the facial nerve system adjacent the ear through a pair of insulated electrodes. Advantageously, the electrical stimulus is an alternating current wave which has been amplitude modulated (at least 30% modulation) by an audio frequency signal.

Where reference is made to the facial nerve system, it is intended to encompass the facial network comprising the trigeminal or V nerve, the facial or VII nerve, the glossopharyngeal or IX nerve and the autonomic nerves together with their sympathetic and parasympathetic branches. This system is illustrated in U.S. Patent No. 2,995,633 and in other published literature, such as "The Growth Concept of Nervous Integration" by Daniel E. Schneider, Monograph No. 78, The Nervous and Mental Diseases Monographs, New York, 1949 (see p. 78). The nerves of this system are confined to facial areas according to such recognized works as "Human Anatomy," Morris Jackson, 9th ed., 1933, Blakiston & Co., Philadelphia.

A typical system for stimulating hearing through the facial nerve system essentially comprises a transdermal signal generator and a pair of capacitive couplers for applying the transdermal signal to the subject in LC series resonance (at the carrier frequency). A preferred transdermal signal generator includes an oscillator capable of generating carrier signals of approximately 20 to 60 kHz, a modulator through which an audio signal may be impressed thereupon, and a pair of output terminals. The transdermal output signals are coupled with the skin of the patient at selected sites of the facial nerve system (e.g., contralateral areas of the head) by transducers having parameters which will effect an LC series resonant coupling of the load (e.g., head of the subject) with the transdermal signal at substantially the carrier frequency. While the establishment of the LC series resonant coupling or the "tuning" of the transdermal signal to the patient to obtain peak resonance current may be accomplished manually, it is preferred to employ an automatic system of the type generally disclosed in aforementioned copending application Ser. No. 446,267. That automatic system detects the resonant frequency of each transducer-load configuration (which, of course, will vary from person to person and will vary from time to time with a single subject as his physiology changes) and adjusts the carrier frequency correspondingly.

SUMMARY OF THE INVENTION

The present invention is directed to an improved transducer construction for use in conjunction with transdermal hearing systems and/or therapeutic systems of the type shown and described in the aforementioned patents and copending applications. More specifically and as an important aspect of the invention, the new transducer configuration and the transdermal hearing system in which it is incorporated, may be employed in conjunction with conventional acoustic communications systems (radio, telephone, etc.) to enable persons to hear speech for the first time in deafening or extraordinarily high noise environments or to enjoy improved hearing in normal environments. Thus, the improved transducer can be employed in conjunction with conventional sound reproducing equipment (phonographs, tape recorders, etc.) to provide listeners with extremely high quality sound.

In high noise environments of 100-135 db, such as in the cockpit of an aircraft in which there is much noise generated by extreme vibration and heard by bone conduction as well as through the ear system, it is often most difficult and sometimes impossible for personnel with normal hearing using ordinary headsets and earphones to hear effectively and comfortably audio information due to the interference caused by this ambient noise. Thus, while the audio signals transmitted to conventional headphones (including those equipped with ear cups, ear defenders, or other sound absorbing or sound attenuating devices) and important to hearing as loud as tolerable, the transmitted signals may nevertheless be drowned out or made imperceptible by ambient noise.

As a significant aspect of the invention, it has been determined that significant attenuation of ambient noise
may be achieved, with resultant improved speech discrimination and audition, by supplementing normal acoustic hearing systems, such as the telephonic systems, with a transdermal hearing system. As a more specific aspect of the invention, the new transducer may be given a configuration in which at least a portion of the transduction surface and gives rise to a mechanical acoustic stimulus which is audible through the normal hearing mechanisms of the user, the so-called "ear system." This combined acoustic and transdermal stimulation of the subject, hereinafter referred to as "dual-stimulus" hearing, in addition to having utility in high noise environments, provides an excellent system for listening in normal noise environments to musical or vocal sounds with unique high fidelity.

In accordance with the invention, the new and improved transducer is of generally laminar construction and typically includes three distinct and independent layers held together as a unit. Specifically, the layers comprise a first layer of conductive material such as fine wire mesh; a second layer of polyester film; and a third layer comprising a laminate of polyester insulating film-metal foil-polyester insulating film. The unbounded laminar transducer may assume a variety of forms ranging for example, from disc shapes for use in transdermal hearing or therapeutic systems to generally annular shapes for use in the new dual-stimulus systems.

More specifically, the new and improved transducer may be fabricated as an integral part of a headset having a pair of ear defenders, with the object of achieving a noise attenuation and attendant speech discrimination in high noise environments when the transducer is energized by a transdermal signal and placed against contralateral sites of the head. The peripheral surface portions of each of the ear defenders, the annular resilient cushions that normally surround and tightly engage the entire periaural areas of the head to block out ambient noise, comprise transdermal transducers, while the central surface portions comprise electroacoustic transducers. Thus, the wearer of the modified headphones will be equipped to receive audio information by simultaneously applied stimuli including an acoustic stimulus directed into the ear canal and a transdermal stimulus applied to the skin of the entire periaural areas of his head.

For a more complete understanding of the present invention and a better appreciation of its many advantages, reference may be had to the following detailed description taken in conjunction with the accompanying drawing.

DESCRIPTION OF THE DRAWING

FIG. 1 is a schematic arrangement of a new and improved dual-stimulus hearing system embodying the principles of the present invention;

FIG. 2 is a perspective view of a new and improved transducer integrated into an ear defender;

FIG. 3 is a cross-sectional view of the transducer of FIG. 2 taken along line 3—3 thereof; and

FIG. 4 is a fragmentary, perspective view of a disc-like transducer embodying the principles of the invention.

DESCRIPTION OF PREFERRED EMBODIMENTS

It is well known that, in relatively quiet environments, ordinary earphones (telephonic receivers), will suffice to provide an audible acoustic signal to the ear system of a subject having normal hearing. In demanding environments (less than 100 db), ear mufffs, ear cushions or other ear encircling, cup-shaped mechanical noise attenuators may be employed to block out enough ambient noise to make a telephonic acoustic stimulus intelligible through the normal ear system. However, in high noise environments (100-135 db), speech discrimination is unreliable, if not impossible, in spite of the use of mechanical attenuators such as ear defenders, due to the transmission of much of the ambient noise to the brain through bone conduction.

In accordance with the principles of the present invention, audio information, which ordinarily would be unintelligible with conventional telephonic receivers in high noise environments, may be heard for the first time in such environments by stimulating the facial nerve system with a transdermal stimulus while simultaneously stimulating the ear system with an in-phase acoustic stimulus. Specifically, the transdermal stimulus is an R-F carrier modulated by an audio signal which modulated signal is also used to generate the acoustic stimulus.

The new dual-stimulus system in high noise environments (100-135 db) includes a headset 10 having a pair of ear defenders suspended from a headband 14. The transdermal (TD) signal is capacitively coupled to the periaural areas of the head by new transducers 20. In accordance with the principles initially set forth in pending application Ser. No. 446,267, the TD signal is coupled to the head in series resonance at the carrier frequency, and the established series resonant coupling is maintained at all times by an automatic frequency modulator oscillator system 16 which automatically varies the generated carrier frequency to compensate for any changes in the capacitive coupling circuit for such an automatic system is disclosed in pending application Ser. No. 446,267, and is to be considered incorporated herein by reference.

Advantageously and in accordance with further teachings of application Ser. No. 446,267, the carrier frequency selected for use in the new dual-stimulus hearing system will be on the order of the sixth harmonic of the dominant audio frequency to be heard by the listener, which dominant audio frequency will range from approximately 200-8000 Hz. The selected carrier frequencies, however, must be greater than audible frequencies to which the user will respond under transdermal stimulation accordingly, carrier frequencies will range from approximately 30-150 kHz, with a carrier on the order of 50 kHz being especially well suited for quality hearing of speech and music. Advantageously, and in order to minimize power consumption, the carrier frequency is chosen to be as close as the aforementioned sixth harmonic as practicable.

In accordance with the principles of the present invention, highly efficient transdermal energy transfer to the facial nerve system and the simultaneous creation of an acoustic stimulus from a transdermal signal may be accomplished with the new transducers 20 in a manner which makes voice hearing with adequate speech discrimination possible in a high noise environment. Specifically, and as shown in FIGS. 2 and 3, the new transducer is mounted on an ear cushion 22 of rubber or similar sponge-like, resilient material having a wide and thick annular flange 24, the interior walls 26 of which define a cylindrical cavity or acoustic chamber 28.

More specifically, a conductive layer 30 is contour molded over the surface of the ear cushion flange 24 but does not extend across the cavity 28. Advantageously, the stratum 30 is fabricated of fine copper wire mesh having approximately 250 lines per inch. A thin insulating film 32, advantageously a .25 mil polyester film such as polyethylene terephthalate (available from E. I. du Pont de Nemours under the trademark Mylar) is contour molded over the wire mesh layer 30 and extends across the chamber 28 in spaced relation to its bottom wall 34. A third layer 36, comprising but not limited to a composite film-laminated between two sheets of polyester film 40, advantageously identical to the insulating film 32 (i.e., .25 mil Mylar), is contour molded over the surface of the second layer 32.

In accordance with an important aspect of the invention and for minimum distortion in hearing, the three layers comprising the new transducer are substantially completely unbonded to one another. However, to main-
tain the structural integrity of the transducer, the layers are joined together by cement along innermost and outermost circumferences 42, 44, respectively, of the flanges 30, 32, 36. To maintain the integrity of the transducer structure 20 and the cushion 22, a plastic expander ring 46 may be inserted in the acoustic chamber 28 and over the loose transducer layers 30, 32, 36. As shown in Figs. 1 and 3, the wire mesh layers 30 of the transducers are connected to the transdermal signal generator 16 by conductors 46.

In accordance with the inventive principles, the transdermal signals which are generated by the automatic frequency modulator oscillator system 16, when applied to the head of a subject through the transducers 20, provide two modes of hearing stimulation. The peripheral portions of the transducers effectively capacitatively couple the transdermal signal to the facial nerve system to effect transdermal (electrical) hearing, while the central portions of the transducer 20 function as electroacoustic speakers to provide acoustic signals to the ear system. Since a common signal is used to develop the transdermal and acoustic stimuli, both stimuli will be in phase with one another and the phase relationship of the dual stimuli is believed to be greatly responsible for the remarkable speech perception that may be obtained in high noise environments with the new transducers 20. Thus, in a high noise environment, where acceptable intelligible hearing (at least 70% articulation) has heretofore been unobtainable, the new system utilizing combined acoustic and transdermal stimulation makes voice hearing and speech discrimination possible for the first time. As a matter of fact, tests have shown that the dual-stimulus system of the present invention provides effective noise attenuation of approximately 50-60 decibels (pressure A.S.A. standard) in high noise environments.

While a complete and positive explanation for the efficacy of the new dual stimulus system in these high noise environments has not yet been completely developed, it is tentatively postulated that noise attenuation is realized by driving a "cylindrical wall" of electrical signals across the head, which signals are believed to affect at least a partial phase cancellation of acoustic bone conducted noise and/or to provide a shield against acoustic noise entering the ear system.

In any event and regardless of the theories for the excellent performance of the new system, it has been clearly established that voice hearing, with excellent speech discrimination, in high noise environments may be obtained by stimulating the ear system and the entire periaural areas of the facial nerve system with in phase acoustic (mechanical) and transdermal (electrical) stimuli. Moreover, it has been established that speech discrimination for people with impaired hearing is aided more effectively by the application of combined acoustic and transdermal stimuli to a listener than by the utilization of either type of stimulus alone.

As should be understood, the transducer 20 having peripheral transdermal transducer portions and central electroacoustic transducer portions may assume other configurations for different hearing applications. For example, while the entire periaural area should be contacted for hearing in high noise environments, a discontinuous or U-shaped transducer rather than a circular or elliptical transducer may be employed for high-fidelity hearing in normal environments.

As a further specific aspect of the present invention, the new transducer may assume an alternate embodiment in the form of a disc 58, as shown in Fig. 4. Specifically, the transducer 50 will include three layers, which correspond to the layers 30, 32, 36 of the transducer 20 and therefore comprised a fine wire mesh conductor 52; a 0.25 mil Mylar film 54 superimposed on the mesh; and a heat bonded laminate 56 of 0.25 mil Mylar-1 mil aluminum foil-25 mil Mylar superimposed on the layer 54. Similarly to the strata of the transducer 20, the layers 52, 53, 56 loosely contact one another but are substantially unbonded throughout their interfaces. Furthermore, the integrity of the transducer 50 may be preserved mechanically by uniting the peripheral portions of the layers with cement or using a plastic housing disc 58 to hold the layers in the aforementioned contacting, but unbonded, relation. The disc transducer 50 may be used to advantage in any transdermal system such as those transdermal hearing and therapeutic systems illustrated and described in the aforementioned copending applications.

In both of the illustrated transducer configurations 20, 50, the unbonded laminar construction provides highly effective transdermal energy transfer (i.e., more power and less distortion) from a signal source to the nervous system. It is theorized that the wire mesh or electrode layers of the transducers tend to maximize the non-uniform distribution of energy of the TD signal while the loose or floating intermediate Mylar film layers tend to provide infinite capacitive adjustments as the layer flaps freely relative to the electrode. Furthermore, it is believed that the laminated layer which contacts the skin of the subject tends to smooth out non-uniformities of energy concentration which exist in the other layers. That is to say, the foil conducts laterally of the direction of energy transfer, thus counteracting and preventing undue energy concentrations at the transderm-skin interface.

The importance of the multiple layers and the significance of their loose or unbonded relationship may be demonstrated by a comparison to a similar, but bonded, structure. Were the transducer layers to be bonded at their interfaces, energy transfer would occur, however hearing improvement and minimization of distortion would be significantly less than that for the unbonded arrangement. Likewise, while a transducer configuration having only two layers, an electrode layer and a Mylar layer, would, in fact, transfer transdermal energy, the efficiency of the transfer is significantly less than when the third layer of a Mylar-aluminum-Mylar laminate is employed.

It will be appreciated that the new transducers and dual-stimulus hearing system of the present invention enable persons to hear, with excellent speech perception, voice communications in high noise environments. Moreover, it will be understood that the unbonded laminar transducers of the invention may be employed to great advantage in any transdermal hearing or therapeutic apparatus in which it is necessary or desirable to couple the human body to a high frequency, transdermal signal source. Accordingly, it should be understood that the invention as herein specifically illustrated and described is intended to be representative only, as certain changes may be made therein without departing from the clear teachings of the disclosure. Therefore, reference should be made to the following appended claims in determining the full scope of the invention.

What is claimed is:

1. A hearing apparatus for high noise environments and the like, comprising:
   (a) a transdermal signal generator adapted to generate a radio frequency signal modulated by an audio frequency signal; and
   (b) a pair of transducer means adapted to capacitively couple said transdermal signal to areas surrounding the ears of a subject;
   (c) each of said transducer means being generally annular in configuration and being sufficiently flexible to conform generally to the contours of the anatomical areas surrounding the ears of a subject;
   (d) generally cup-shaped sound attenuators having resilient annular cushions adapted to engage each of the periaural areas of the head;
   (e) said annular cushions being substantially the same size as said annular transducer means;
   (f) said transducer means are mounted on said cushion portions;
3,497,637

(g) said annular transducer means thereby being adapted to develop an audible acoustic stimulus corresponding to the audio frequency component of said transdermal signal when both of said transducers are in contact with the periaural areas of a subject.

2. A hearing apparatus in accordance with claim 1, in which
(a) each of said annular transducer means includes a first layer, a second layer, and a third layer;
(b) said first layer comprises a layer of conductive material adapted to be directly connected to said signal sources;
(c) said second layer comprises a thin self-supporting film of insulating material superimposed on said layer of conductive material;
(d) said third layer comprises a laminate of insulating film-conductive foil-insulating film superimposed on said self-supporting film and adapted to contact the skin of said subject; and
(e) means to maintain said layers in unbonded surface contact with one another are included.

3. A hearing apparatus in accordance with claim 2, in which
(a) each of said annular cushions defines a central acoustic chamber;
(b) said second and third layers extend across said acoustic chamber and are adapted to provide an acoustic stimulus when energized by a transdermal signal while in contact with the periaural areas of the head of a subject.

References Cited
UNITED STATES PATENTS
1,983,178 12/1934 Lybarger 179—107
2,972,018 2/1961 Hawley 179—1
3,393,279 7/1968 Flanagan 179—107
3,084,229 4/1863 Selsted 179—111

KATHLEEN H. CLAFFY, Primary Examiner
THOMAS L. KUNDERT, Assistant Examiner