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Continuation-in-part of application Ser. No.
682,152, Nov. 13, 1967, now Patent No.
3,497,637, and a continuation-in-part of
446,267, Apr. 6, 1965, now abandoned.
This application Jan. 8, 1970, Ser. No.
1,334.

[54] **HEARING SYSTEMS**
11 Claims, 3 Drawing Figs.

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 [51] Int. Cl. **H04r 25/00**
 [50] Field of Search **179/107 R,**
107 BC, 107 E, 107 H, 107 S; 128/1.5

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ABSTRACT: The present invention relates to the stimulation of the sensation of hearing in persons of impaired hearing abilities or in certain cases in persons totally deaf utilizing RF

energy. More particularly, the present invention relates to a method and apparatus for imparting synchronous AF or "acoustic" signals and so-called "transdermal" or RF signals. Hearing and improved speech discrimination, in accordance with one aspect of the present invention, is stimulated by the application of an AF acoustical signal to the "ear system" conventional biomechanism of hearing, which is delivered to the brain through the "normal" channels of hearing and a separate transdermal RF electrical signal which is applied to the "facial nerve system" and is detectable as a sensation of hearing. Vastly improved and enhanced hearing may be achieved by imparting an AF acoustic signal to the ear system by means of "conventional" transducers, such as electroacoustic speakers of "in the ear" hearing aids; piezoelectric or mechanical transducers of conventional "bone conduction"-type hearing aids; and so-called "intraoral bone conduction transducers" of the type employed in the hearing system disclosed in Puharich and Lawrence U.S. Pat. No. 2,995,633 and No. 3,170,993 and No. 3,156,787, and by simultaneously applying a transdermal signal, which signal is an RF carrier signal amplitude modulated with AF information across the head of the subject, the head acting as capacitance in LC series resonance of the RF carrier frequency. Importantly, the applied balanced transdermal signal is in the form of a substantially pure sine wave, and it is applied to the head through one bare and one insulated electrode. The applied transdermal signal is applied to the periaural and stylomastoid regions of the head and, accordingly, the apparatus of the invention may be readily adapted for use in the temples of "eyeglass" hearing aid devices.

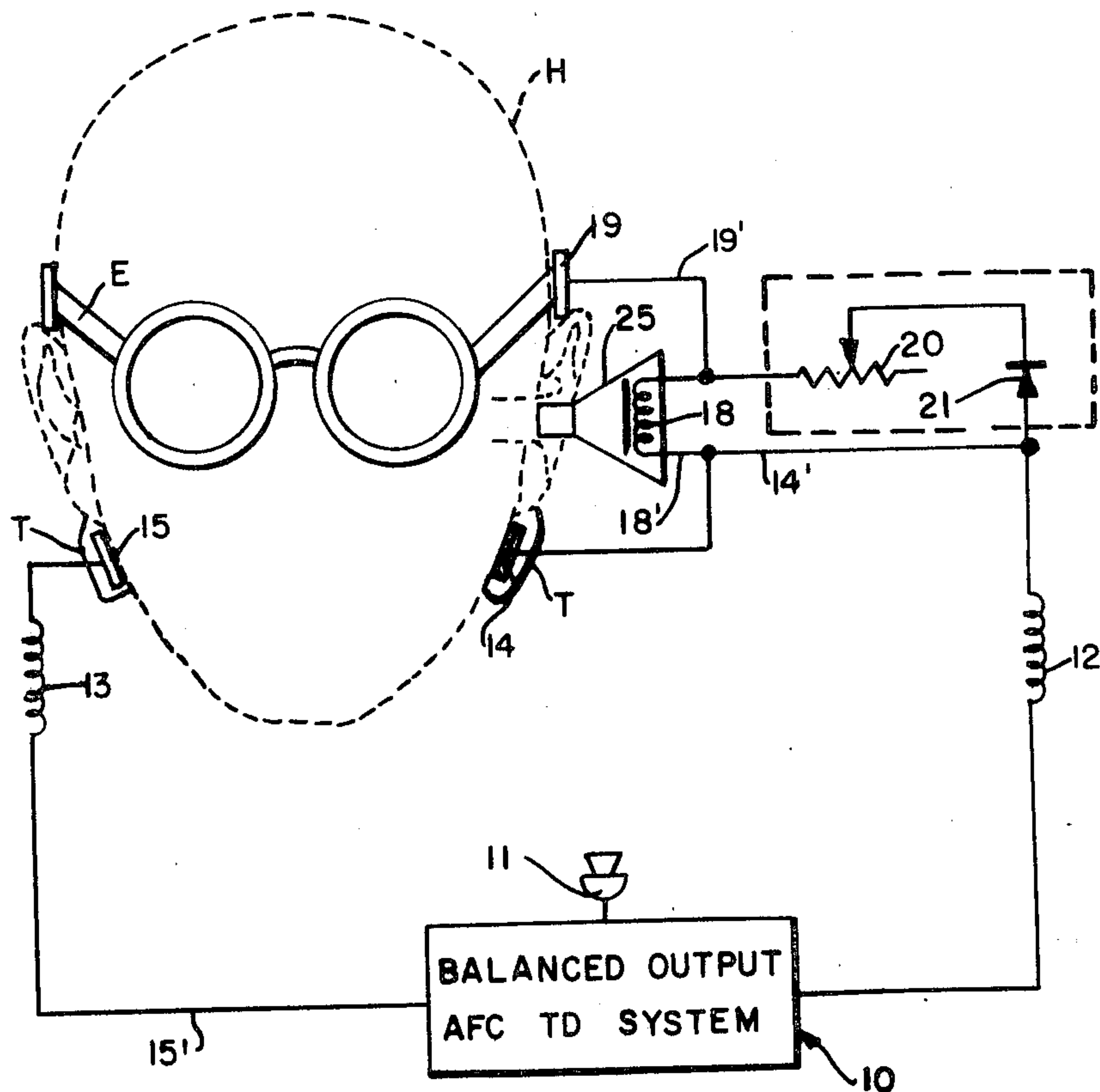


FIG. 1

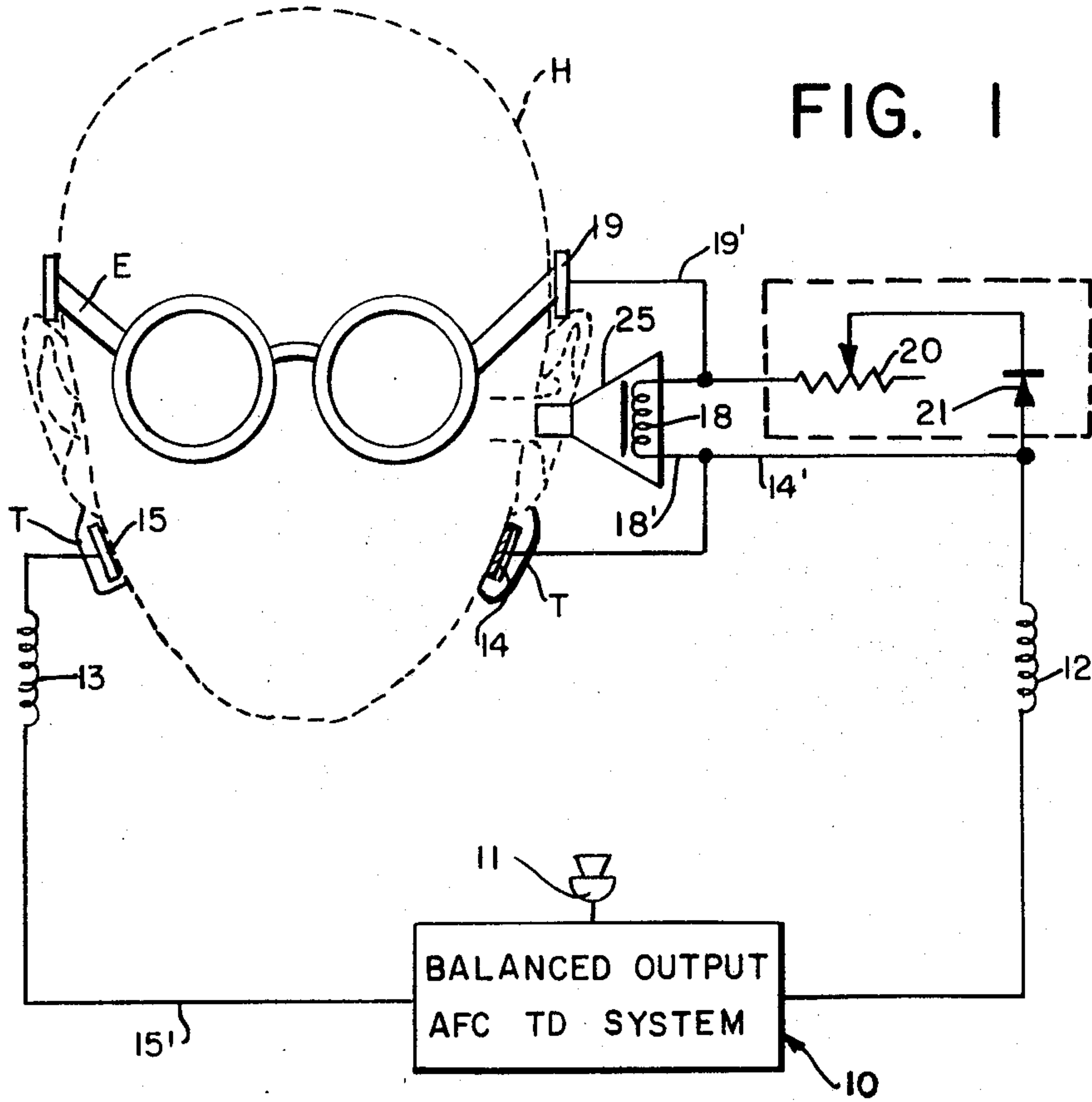
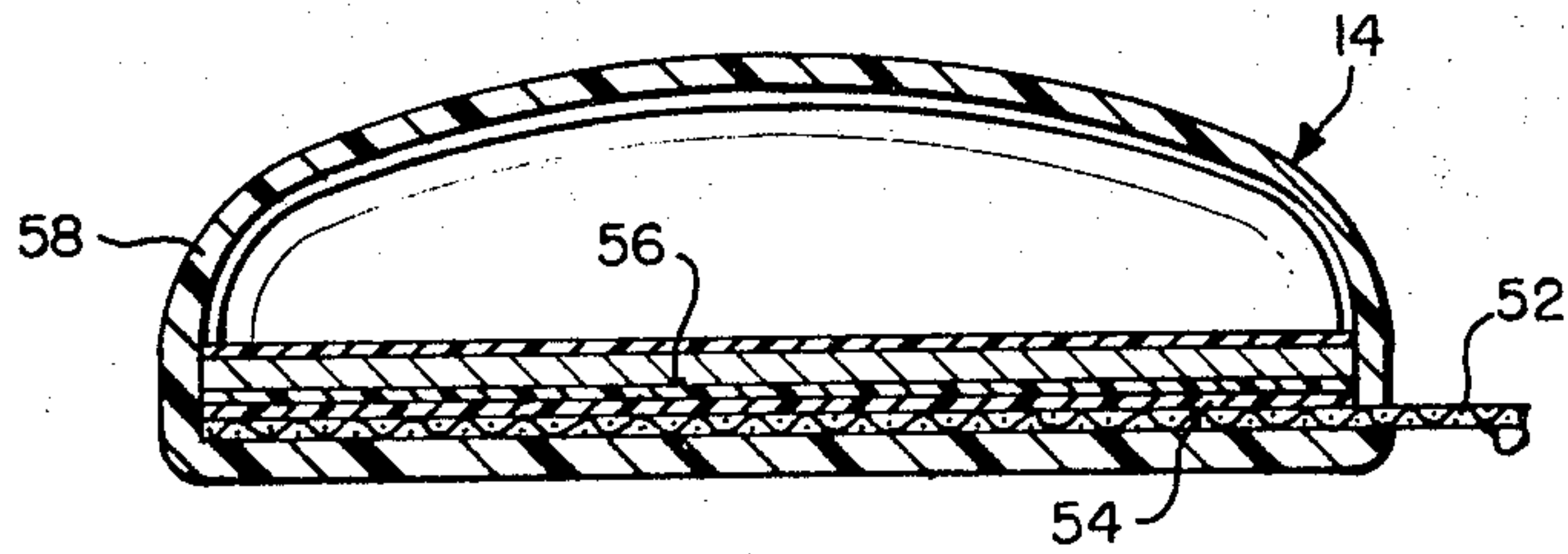


FIG. 2



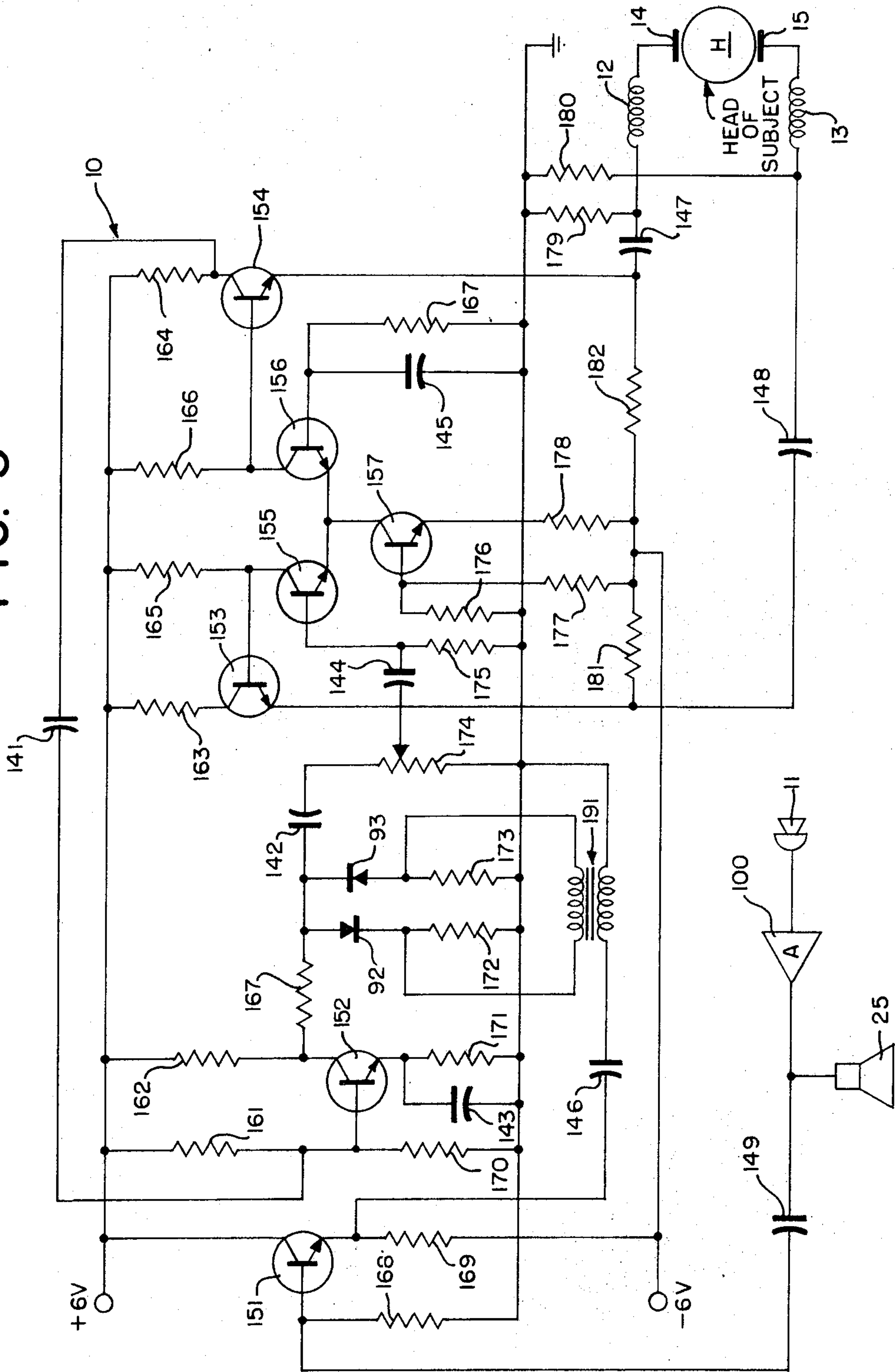
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FIG. 3



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HEARING SYSTEMS

RELATION TO COPENDING APPLICATIONS

This application is a continuation-in-part of our copending application Ser. No. 682,152, filed Nov. 13, 1967, and now U.S. Pat. No. 3,497,637, and a continuation-in-part of our copending application Ser. No. 446,267, filed Apr. 6, 1965, now abandoned. This application is also related to our copending application Ser. No. 633,035, filed Apr. 24, 1967, now U.S. Pat. No. 3,563,246. This pertinent subject matter of the aforementioned applications is hereby incorporated by reference.

SUMMARY OF THE INVENTION

Heretofore, several systems employing so-called "dual stimulation" have been proposed for use in the aiding of the hearing of persons who are partially deaf. Some of these systems have employed dual modes of acoustical stimulation; for example, a conventional air-conducted acoustical signal may be delivered to the ear canal through an earphone type of speaker while a separate bone-conducted acoustic signal is delivered to the same normal channels of hearing, i.e., ear system or conventional hearing biomechanism, through an appropriately situated bone conductor. It has also been broadly proposed heretofore to combine acoustic hearing with electrically stimulated hearing to aid deaf or partially deaf persons. The present invention is directed to a specific improvement in the latter type of dual stimulation hearing systems and provides a significant improvement in hearing and speech discrimination over what has heretofore been obtainable in the art.

Specifically, the vastly improved results of the method and apparatus of the new invention are obtained by the employment of a new and improved transdermal transmitting system; the employment of new and improved transdermal transducer means for coupling the transdermal signal to the subject; and the employment of specific circuit parameters to achieve maximum improvement in hearing.

More specifically, the apparatus of the present invention delivers an acoustic signal to an earphone or bone conductor type transducer and simultaneously delivers a transdermal signal to the head of the user at contralateral, periaural, and/or stylomastoid regions of the head. The applied transdermal signal is a narrow width, amplitude modulated carrier signal, which carrier is usually in the range of 18 to 36 kHz. and which carrier is generated and coupled to the head of the subject in a manner whereby the transdermal signal is constantly driven across the head at peak LC series resonance of the carrier frequency. Appropriate circuitry is provided in order to maintain the transdermally applied signal at the peak LC series resonance despite changes in the capacitance of the coupling of the transdermal signal to the head of the subject which may be occasioned by physiological changes in the subject.

Importantly and in accordance with an important principle of the present invention, improved speech discrimination is achieved by applying the transdermal signal to the head in the form of a substantially pure sine wave. Heretofore, applied sine waves have tended to be distorted by the head. However, in accordance with the invention, when the signal is applied to the stylomastoid regions of the head through one bare transdermal electrode and one insulated transdermal electrode placed contralaterally of the head, distortion of the sine wave is effectively eliminated.

In the case of totally deaf subjects who cannot "hear" any acoustic signals whatever through the conventional hearing biomechanism, i.e., the "ear system," the use of two bare electrodes has enabled the totally deaf to perceive sounds transmitted to the brain "transdermally" through the single stimulus of a transdermal, amplitude modulated RF signal, coupled in peak LC series resonance of the carrier frequency.

For a more complete understanding of the present invention and a better appreciation of its attendant advantages, reference should be made to the following detailed description taken in conjunction with the accompanying drawings.

DESCRIPTION OF DRAWINGS

FIG. 1 is a schematic view of a dual stimulus hearing system, mounted in an eyeglass frame and embodying the principles of the present invention;

FIG. 2 is an enlarged, cross-sectional view of an improved transdermal electrode means for use in coupling transdermal signals to a subject for the practice of the present invention;

FIG. 3 is a preferred circuit arrangement for transdermal signal generating apparatus of the present invention.

DETAILED DESCRIPTION OF THE PRESENT INVENTION

Referring now to FIG. 1, audio information is introduced through microphone 11 to a transdermal signal generator 10, of the type disclosed in copending applications Ser. No. 633,035, now U.S. Pat. No. 3,563,246; Ser. No. 682,152; now U.S. Pat. No. 3,497,637; and Ser. No. 446,267, now abandoned. The output of signal generator 10 is applied both "acoustically" and "transdermally" to the head H of a subject in the following manner and in accordance with the principles of the present invention.

The transdermal (TD) signal, an amplitude modulated balanced RF signal, is coupled to the contralateral stylomastoid regions of the head through two separate inductors 12 and 13, a dielectric covered electrode 14, and a bare metal electrode 15, which electrodes are mounted on the inner surfaces of eyeglass temples T, as shown in FIG. 1. That is to say, the TD signal levels are balanced on each side of the head for optimum speech discrimination in accordance with the invention. The dielectric covered electrode 14, which is shown in greater detail in FIG. 2 and described more specifically hereinafter, is placed on the same side of the head as the magnetic speaker 25 or other conventional transducer such as a bone conductor, which imparts an amplified acoustic signal directly into the ear system of the subject. The bare electrode 15 is always placed on the opposite side of the head from the speaker 25 and the dielectric covered electrode 14, in accordance with a specific aspect of the present invention and in order to minimize distortion of the pure sine wave type of transdermal signal applied to the head. As shown in FIG. 1, electrodes 14 and 15 are connected to the output of the TD transmitter 10 by conductors 15' and 14', respectively.

The transdermal (TD) signal generator 10 may advantageously incorporate certain of the features described in a copending application, Ser. No. 633,035, filed Apr. 24, 1967, now U.S. Pat. No. 3,563,246, by Henry K. Puharich and Joseph L. Lawrence and also certain features described in an earlier application, Ser. No. 446,267, filed Apr. 6, 1965, now abandoned, by the same inventors. Reference to these applications may be made for further details.

More specifically and with reference to FIG. 1, the output of the transdermal signal generator 10 includes the pair of electrodes 14, 15, one of which is covered with a dielectric material (14) and the other of which is bare (15), although in certain applications (e.g. for totally deaf persons) both may be bare. In series with the electrodes 14, 15 are large inductances 12, 13, advantageously in the range of 2 to 30 millihenries and adjustable within that range for the accommodation of different subjects. The TD signal generating circuitry of the transmitter 10, once energized and periodically pulsed, will oscillate at a frequency, herein referred to as the carrier frequency, which is substantially in a circuit resonant relation with the body of the subject, for maximum effectiveness of the power input, as described in more detail in the above-mentioned copending applications.

Desirably and as an important aspect of the invention, the inductances 12, 13 are selected, with respect to a given sub-

ject, to provide a carrier signal at a frequency on the order of about 18 to about 36 kHz. By designing and constructing the circuit for the TD transmitter 10 so that the inductances 12, 13 are the primary determinants of resonant frequency, in relation to the capacitance of the coupled electrodes 14, 15, the resonant frequency may be kept constant notwithstanding momentary changes in circuit capacitance due to physiological and other changes in the body of the subject.

In accordance with the principles of the present invention, an in-phase acoustic or AF signal is simultaneously applied to the head of the subject through a conventional transducer such as an electromagnetic speaker of an earphone 25. The acoustic signal is derived from the transdermal transmitter 10 and is applied to the coil 18 of the magnetic speaker 25 by connecting one side of the coil 18 to the conductor 14' by conductor 18', while the other side of the coil 18 is connected to a conductor 19' which is connected to an auxiliary bare metal electrode 19, which is placed against the side of the head (above the ear) opposite the site of the bare transdermal electrode 15. In accordance with the principles of the invention, two separate circuits will be completed through the head, a transdermal circuit between the electrodes 14 and 15 and the acoustic circuit in which one side of the coil 18 is connected directly to the TD transmitter while the other side of the coil 18 is connected through the head to the other side of the TD transmitter 10.

In accordance with the principles of the invention, vastly improved hearing and speech discrimination may be obtained by a person having impaired hearing when the stem of FIG. 1 is operated in the following manner. A desired audio input in the form of an audio (AF) signal may be delivered to the transdermal transmitter system 10 through an input microphone 11 and the RF output of the transmitter will then be transmitted to the head of the subject applied thereto in the form of synchronous transdermal (RF) signals and acoustic (AF) signals, the combined effect of which, on hearing, will be significantly better than if either type of signal stimulation had been used independently. That is to say, using a conventional acoustic type earphone hearing aid, the subject's hearing and speech discrimination abilities typically will be enhanced (over completely unaided hearing) approximately 50 percent; the same may be said for the use of a transdermal type hearing aid by itself. However, when both AF and RF stimulations are used simultaneously and in accordance with the inventive principles, hearing abilities and speech discrimination have been enhanced (over completely unaided hearing) as much as 75 percent. Therefore, there is a definite increase in hearing (in terms of PB speech discrimination) over and beyond what has heretofore been available by the use of either pure acoustic stimulation or pure transdermal stimulation, which is attributed to synergistic effects of the combination of AF and RF signals in the manner described.

More specifically and by way of example, a sample group comprised of 12 hard of hearing patients was measured in a "first or control testing" with standard audiometry techniques, and it was found that the average speech discrimination ability of the group was 26.2 percent as measured with phonetically balanced words, or the "PB test." This measurement represented a "control" or standard for comparison. Thereafter, the 12 patients took several weeks of TD therapy in accordance with the principles and inventions set forth in detail in our copending application, Ser. No. 633,035, filed Apr. 24, 1967, for "Electrotherapy System." When measured in a "second testing" with the same type of acoustic earphone PB test as used in establishing the control level, the average PB speech discrimination score of the group showed 43.0 percent or an increment of 16.8 percent. Following the "second testing," the group of patients was tested in a "third or TD testing" with the TD signal rather than the acoustic signal, as the speech signal source, and the average PB speech discrimination of the group was 54 percent, an increment of 27.8 percent. Following the second and third testing, the group was tested with the signal source of the invention which combined

the earphone signals of the second testing and the TD signal of the third testing, which signals were synchronously applied in accordance with the invention. Remarkably, the average PB speech discrimination score of the group was raised to 73.8 percent, an improvement of 47.6 percent.

In accordance with one more specific aspect of the present invention, the dielectric covered electrode 14 may have the following configuration which has been found to couple, in a highly efficient manner, transdermal signals to the head of the subject. The electrode 14 comprises three layers, 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—0.25 mil Mylar superimposed on the layer 54. The layers 52, 54, 56 loosely contact one another but are substantially unbonded throughout their interfaces. Furthermore, the integrity of the electrode 14 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 electrode 14 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 and may be formed as an integral part of an eyeglass hearing aid.

In the illustrated configuration of the electrode 14, 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 conductor layers of the electrodes tend to maximize the nonuniform 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 conductor. Furthermore, it is believed that the laminated layer which contacts the skin of the subject tends to smooth out nonuniformities of energy concentration which exist in the other two layers. That is to say, the foil conducts laterally of the direction of energy transfer, thus counteracting and preventing undue energy concentrations at the skin-electrode 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 electrode 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 an electrode configuration having only two layers, a conductor 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.

The operation of the new system is quite simple and is as follows. The output signal from the TD transmitter 10 is applied transdermally and in peak LC series resonance to the head of the subject through the dielectric covered electrode 14 and the oppositely placed bare electrode 15 in the manner described hereinabove. The acoustic signal is applied to the head of the subject in phase with the transdermal signal through the acoustic earphone 25 or, if desired, through another appropriate suitable acoustic transducer such as a conventional bone conductor. Regardless of the choice of acoustic transducer (it being understood that it is possible in some instances to employ an intraoral, bone conductor type transducer), the acoustic transducer is placed on the same side of the head as the dielectric covered electrode of the transdermal electrode pair 14, 15. In this manner, through a mechanism not yet completely understood, there appears to be some synergistic effect between the dielectric covered electrode 14 and the acoustic transducer 25. The dual AF and RF signals then provide the subject with a vastly enhanced sensation of hearing in comparison to the hearing improvement that has heretofore been available with either of a transdermal type signal stimulation or an acoustic type signal stimulation.

The principles of the present invention may be used to adapt existing, conventional acoustic hearing aids in the following manner, without otherwise altering a conventional hearing aid, i.e., one comprising a microphone, amplifier, and earphone. It is necessary only to attach one side of the conventional coil 18 of the hearing aid earphone 25 to the head via conductor 19' and bare electrode 19 while conducting the other side of the conventional hearing aid speaker coil 18 to the same side of the head through an insulated electrode 14 appropriately directly connected to the other side of the speaker coil 18. Additionally, an adjustable resistance of from 0 to 10 kilohms and a diode of the type IN 34 are placed in series with the speaker coil 18, as shown in FIG. 1. With these two modifications, a conventional acoustic-type hearing aid may contribute to improved hearing performance by its further combination with a transdermal system comprising the transmitter 10, the inductors 12 and 13 and the capacitive coupling electrode 15 and the capacitive coupling dielectric covered electrode 14, in the manner generally shown in FIG. 1. This modified system will ordinarily employ only the microphone 11 of the transdermal system and will dispense with the microphone of the hearing aid (not shown). The RF transdermal signal and the AF acoustic signal are independently delivered in synchronism to the head H of the listener through the electrodes 14, 15 and the earphone 25, respectively. It should be understood, however, that the diode 20 and the resistor 21 illustrated in FIG. 1 are necessary only when adapting a conventional hearing aid of "synergistic boosting" by a separately provided transdermal stimulation system. When the combined stimulation hearing system is supplied as an original unit, such as shown in FIG. 3, the volume control arrangement, provided by the resistor 20 and the diode 21, is not necessary.

A circuit arrangement of a transdermal transmitter 10 having a balanced output and "automatic carrier frequency control" is illustrated in FIG. 3. The output of the TD signal generator of FIG. 3 is applied to the head of the subject through inductors 12, 13 and a pair of electrodes 14, 15, one of which is bare and one of which is dielectrically covered. As mentioned hereinabove, in certain applications where stimulation of hearing in the totally deaf is desired through transdermal stimulation only, it is necessary to employ two bare electrodes which are applied to contralateral stylomastoid sides of the head.

The circuit of FIG. 3, comprises five transistors 151-155, respectively; 21 resistors, reference numerals 161-181, respectively; nine capacitors, 141-149, respectively; and one transformer 191, appropriately interconnected by conductors in the manner shown in FIG. 3. In this version of an "automatic carrier frequency controlled transdermal transmitter," the transistors 151, 156, and 157 cooperate to form a constant current differential amplifier which feeds the emitter followers of the transistors 153 and 154. These transistors 153 and 154 in turn feed a series resonant circuit, which includes the inductors 12 and 13 and the human head, itself, which is, of course, disposed therebetween, as shown. In this manner, the head of the subject functions as a capacitor, as should be understood.

In accordance with the principles outlined hereinabove, at resonant frequency of this circuit, the current within the circuit peaks and the voltage drop across the resistor 164 becomes maximized. This maximum voltage across the resistor 164 is in turn fed to the base of the transistor amplifier 152 and through a modulation network comprised of diodes 92 and 93 and fed back to the input of the differential amplifier. Therefore, the transistors 152, 153, 154, 155, and 156, in accordance with the principles of the invention, form an oscillator circuit, the frequency of which is determined by the inductors 12 and 13, and instantaneous capacitance of the head H. In this circuit, the resistor 174 provides a level adjustment.

As shown and as will be appreciated, the audio signal is introduced into the circuit of FIG. 3 through the microphone 11 and is fed from a conventional hearing aid amplifier 100 to the base of the emitter follower 151, which drives the above-

described modulation transformer 191. The resistors 180 and 181 prevent the appearance of DC on the coil side of the capacitors 47 and 48.

While the circuit of FIG. 3 is currently preferred for operating the system of the present invention, it should be understood that any appropriate transmitting circuit which is adapted to deliver an amplitude modulated carrier signal in the range of approximately 18 to 36 kHz. to the head of a subject in LC series resonance will be acceptable for the purposes of the present invention. Accordingly, the circuit of FIG. 3 should be taken as illustrative of the principles of the invention and not limiting thereof.

We claim:

1. A method for enhancing speech discrimination by a human subject of an AF signal comprising the steps of
 - a. amplifying said AF signal and introducing said amplified signal to a region immediately adjacent the "ear canal" of said subject,
 - b. modulating an RF carrier signal with said AF signal to produce a transdermal signal,
 - c. balancedly applying said predetermined sites of transdermal signal to the facial nerve system of the subject at opposite sides of the head at the periaural and stylomastoid regions thereof,
 - d. the applications of said amplified AF signal and of said transdermal signal being synchronous.
2. The method of claim 1, further characterized in that
 - a. said TD signal is applied to each side of the head through an inductor.
3. The method of claim 2, further characterized in that
 - a. said transdermal signal is applied to the head at peak LC in series resonance at the carrier frequency.
4. The method of claim 1, further characterized in that
 - a. said transdermal signal is applied through a pair of electrodes one of which is bare and the other of which is insulated,
 - b. said bare electrode is placed on a first side of the head and said AF signal is applied to the opposite side of the head.
5. Apparatus for enhancing speech discrimination in a hard of hearing subject, comprising
 - a. means for amplifying an AF signal and introducing said amplified signal to a region immediately adjacent the "ear canal" of said subject,
 - b. means for modulating an RF carrier signal with said AF signal to produce a transdermal signal,
 - c. means for balancedly applying said transdermal signal to the facial nerve system of the subject at opposite sides of the head at predetermined sites of the periaural and stylomastoid regions thereof,
 - d. the applications of said amplified AF signal and of said transdermal signal being synchronous.
6. The apparatus of claim 5, further includes
 - a. a pair of inductor means through which said transdermal signal may be applied to the head of the subject.
7. The apparatus of claim 5, further characterized in that
 - a. said transdermal signal is applied to the head at peak LC series resonance at the carrier frequency.
8. The apparatus of claim 5, which is further characterized in that
 - a. said means for balancedly applying said transdermal signal to the facial nerve system of the subject at opposite sides of the head at predetermined sites of the periaural and stylomastoid regions thereof includes a pair of electrodes, one of which is bare and the other of which is insulated.
9. The apparatus of claim 5, further characterized in that
 - a. means for amplifying said AF signal and introducing said amplified signal to a region immediately adjacent the "ear canal" of said subject, and said means for balancedly applying said transdermal signal to the facial nerve system of the subject at opposite sides of the head at predetermined sites of the periaural and stylomastoid regions thereof are housed within a frame means.

10. The apparatus of claim 9, in which

- a. said frame means includes an eyeglass frame and temples,
- b. said means for balancedly applying said transdermal signal to the facial nerve system of the subject at opposite sides of the head at predetermined sites of the periaural and stylomastoid regions thereof includes a pair of electrodes mounted on inner surfaces of said temples. 5

11. The apparatus of claim 8, in which said insulated electrode comprises

- a. a first layer comprising a layer of conductive material adapted to be directly connected to said signal source, 10

- b. a second layer comprising a thin self-supporting film of insulating material superimposed on said layer of conductive material,
- c. a third layer comprising 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
- d. means maintaining said layers in unbonded surface contact with one another.

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