

- [54] **ELECTROSTATIC
ELECTROACOUSTIC TRANSDUCER**
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both of Pa.
- [73] Assignee: **Non-Acoustic Audio Corporation**,
Washington, D.C.
- [22] Filed: **Oct. 31, 1969**
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- [52] U.S. Cl.**179/111 R, 179/1 G, 179/182 R**
- [51] Int. Cl.**H04r 19/00**
- [58] Field of Search.....**179/111, 107, 157, 106, 1 R,
179/1 ST, 107 BC; 340/5 T; 321/15;
128/2.05, 2.1 Z, 2 Z, 412**

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[57] **ABSTRACT**

An electroacoustic transducer apparatus for electrostatically transducing audio frequencies from electrical signals to sound or from sound to electrical signals. One embodiment includes a headset having a pair of insulated electrodes positionable on opposite sides of and in contact with a wearer's head near the auditory centers. A single-channel audio signal is coupled through an isolation transformer and a fixed or automatic d.c. bias circuit to the electrodes. Each electrode and the adjacent head tissue form plates of a capacitor and the insulation there between constitutes the dielectric. On application of an electric audio signal, the tissue is caused to vibrate and propagate pressure waves in accordance with the frequency and amplitude of the signal and thereby produce monaural sound reproduction. In another embodiment, two stereo channels of electric audio signals are similarly coupled to the headset electrodes with their common output coupled to a third uninsulated electrode in contact with the wearer's body for producing three-dimensional sound reproduction. In still another embodiment, an insulated electrode constitutes a sound pickup having its output connected through a d.c. bias circuit directly to the input of an audio signal responsive device such as a loud speaker system or recorder. When held against the wearer's head near the vocal center, the electrode and the tissue adjacent thereto act as the plates of a capacitor and the insulation constitutes the dielectric. Vibration of the tissue due to sound propagation from the vocal center produces an electric signal in accordance with the frequency and amplitude of the vibration.

10 Claims, 8 Drawing Figures

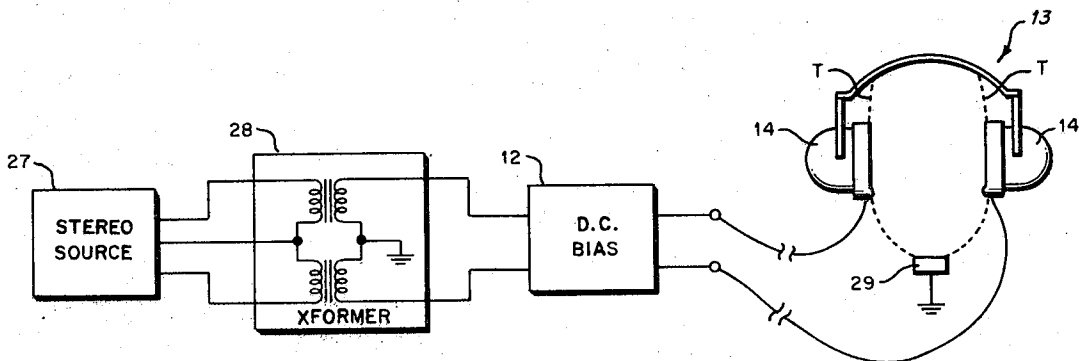


Fig. 1

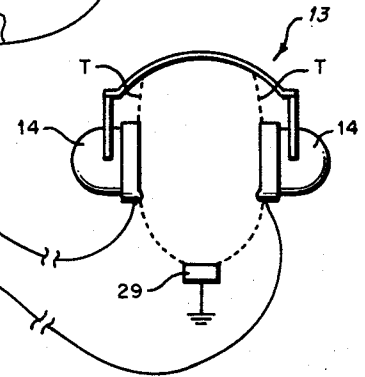
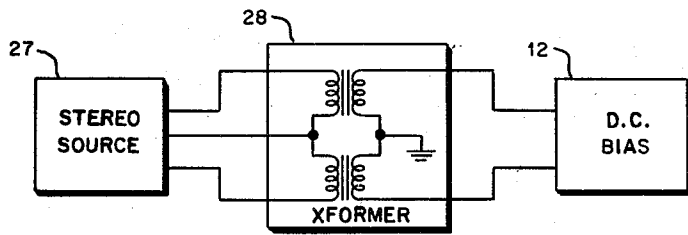
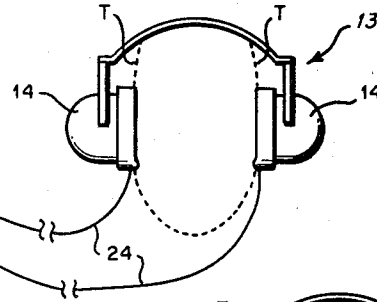
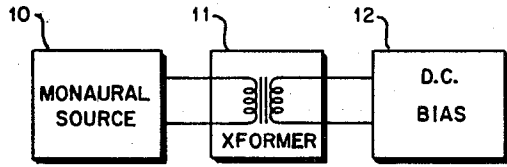


Fig. 7

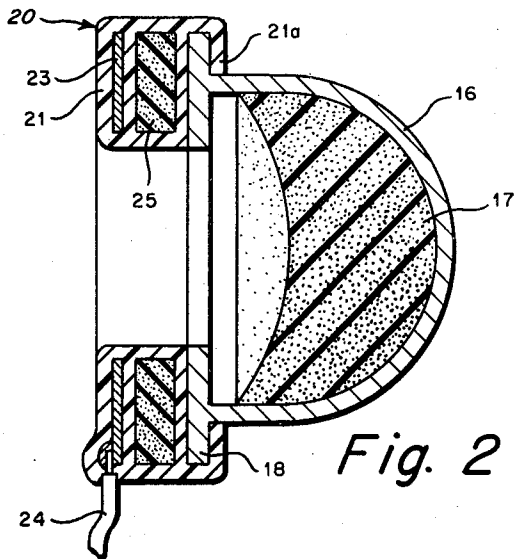
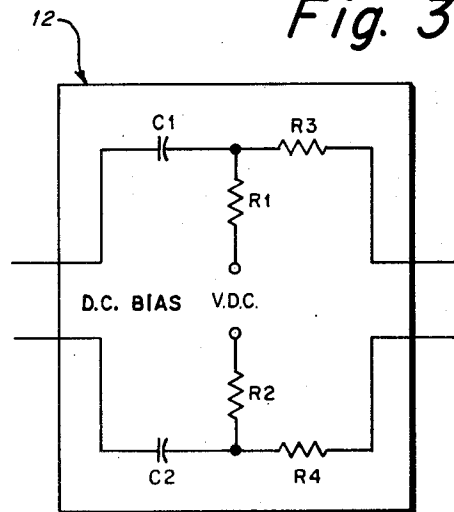


Fig. 2

Fig. 3



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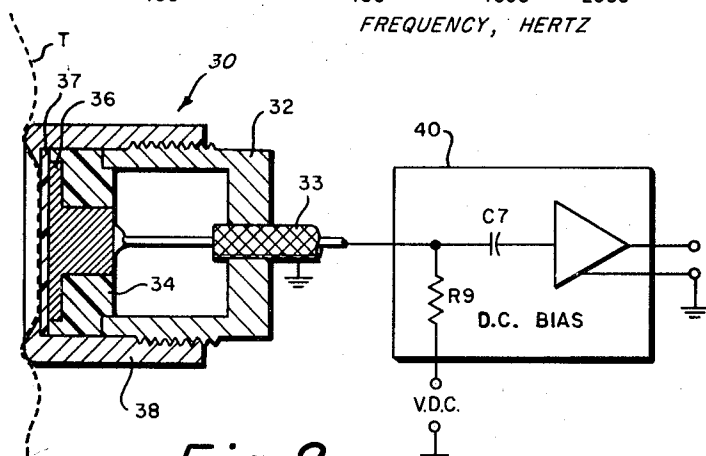
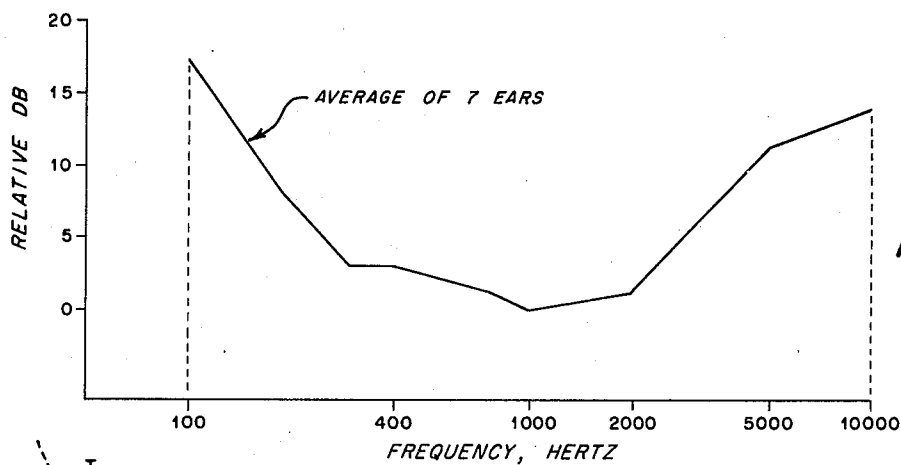
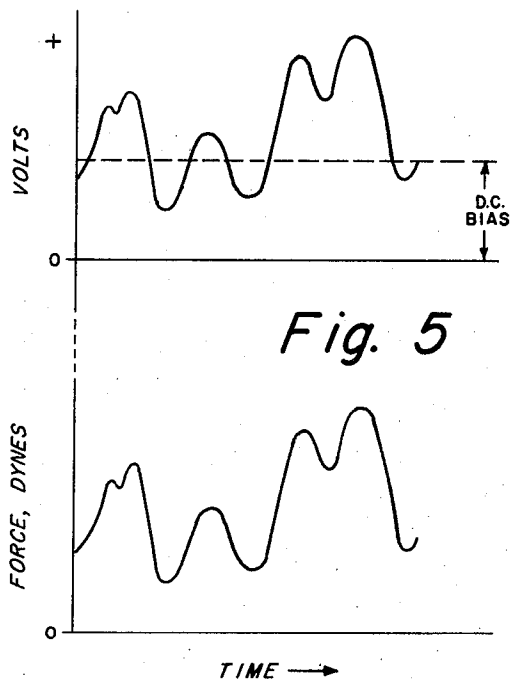
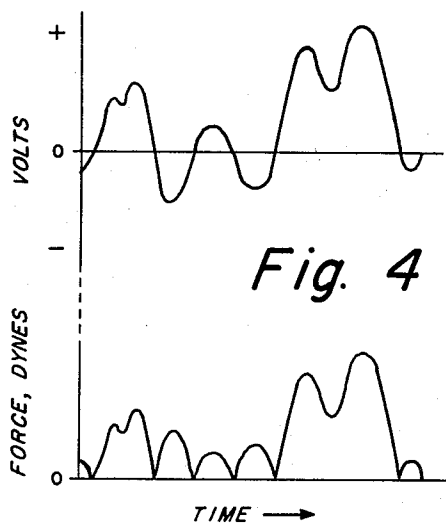


Fig. 8

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ELECTROSTATIC ELECTROACOUSTIC TRANSDUCER

STATEMENT OF GOVERNMENT INTEREST

The invention described herein may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

BACKGROUND OF THE INVENTION

The present invention relates to electroacoustic transducers utilizing capacitatively coupled electrodes, and more particularly to novel improvements in such transducers as applied to headsets and pickups used in sound detection and reproduction.

Electrical signals are normally converted to acoustic waves in air by means of transducers held near to the ears or near other facial areas that are acoustically coupled through the bones of the head to the normal auditory centers where the sensation of sound is produced. Conversely, acoustic waves are normally converted to electrical signals by means of transducers mechanically responsive to acoustic pressure waves propagated in air.

Such transducers are usually complex electrical and mechanical devices which involve relatively high production costs. At relatively low atmospheric pressure such as experience by pilots at high altitudes and at high ambient pressures such as experienced by scuba divers in deep sea, the normal acoustic coupling via air efficiency is substantially degraded. Such devices are also susceptible to ambient noise. This last factor has often led to combining the transducer with bulky and discomforting structure for excluding ambient noise.

To avoid these disadvantages and extend the application of acoustic transducers to use in high altitude, deep water and high noise environments, electrostatic acoustic transducers have been more recently investigated as valid substitutes. In one configuration of the prior art, an audio amplitude modulated radio frequency signal is applied through insulated electrodes to the wearer's head on or near the ears. This device, however, utilizes an r.f. carrier signal and drive circuitry for maintaining audibility of very weak input signals. Nevertheless, the output levels are severely limited by the demand to avoid any form of diathermy (r.f. heating) in the wearer's head.

SUMMARY OF THE INVENTION

Accordingly, among the many purposes and objects of the invention, it is a general purpose to provide a novel and improved electroacoustic transducer apparatus which is not adversely affected by ambient pressures, which has virtually distortion-free signal reproduction at acoustic levels up to the pain threshold, and which is relatively simple in construction and inexpensive to manufacture.

It is another object of the invention to provide a new electroacoustic transducer apparatus which is particularly suitable for use by high performance aircraft pilots operating in severe noise environments and at high altitudes, and by scuba divers operating in the high pressure environment of deep water.

Briefly, these purposes and objects and others are accomplished in one embodiment by a headset having a

pair of insulated electrodes positionable on opposite sides of and in contact with a wearer's head near the auditory centers. A single-channel audio signal is coupled preferably through an isolation transformer and a fixed or automatic d.c. bias circuit to the electrodes for producing monaural sound reproduction. In another embodiment, two stereo channels of audio signals are similarly coupled to the headset electrodes with their common output coupled to a third uninsulated electrode in contact with the wearer's body for producing three-dimensional sound reproduction. In a third embodiment, an electrostatic pickup adapted to be placed against the wearer's skin near the vocal center has its output coupled directly to the input of an audio signal response device.

It is postulated that the present invention operates on the same principles as the well-known condenser microphone except that the tissue of the skin replaces the diaphragm as one of the plates of the condenser and is maintained in continuous direct acoustic coupling contract with an electrostatically charged plastic dielectric element.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a schematic diagram of one embodiment of a transducer apparatus constructed according to the invention for monaural sound reproduction;

FIG. 2 is a cross-sectional view of one earphone of the apparatus of FIG. 1;

FIG. 3 is a schematic diagram of a d.c. bias circuit as applied in the apparatus of FIG. 1;

FIG. 4 represents typical audio signals in terms of applied voltage and resulting force of prior art devices;

FIG. 5 represents a typical audio signal in terms of applied voltage and resulting force of the apparatus of FIG. 1;

FIG. 6 represents a typical frequency response curve for the apparatus of FIG. 1;

FIG. 8 is a schematic block diagram of another embodiment of a transducer apparatus constructed according to the invention for stereophonic sound reproduction; and

FIG. 9 is a cross-sectional view of a microphonic pickup in combination with a schematic diagram of another transducer apparatus constructed according to the invention for detecting acoustical signals.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to FIG. 1 of the drawing, there is illustrated a monaural audio source 10 such as a radio receiver or tape recorder-player which produces an audio signal characterized by a frequency and amplitude varying voltage across two output terminals. The signal is connected through an isolating transformer 11 to two inputs of a d.c. bias circuit 12. The transformer 11 essentially steps up the voltage for matching the source output impedance to the load impedance. This is desired to ensure the maximum signal level at the point of electrical coupling to the body. The d.c. bias 12, as shown in more detail in FIG. 3 includes input terminals respectively connected through series-connected resistor R1 and capacitor C1, and resistor R2 and capacitor C2 to a regulated d.c. voltage. The resistors R1 and R2 act as current limiters in event of an

electrical short across the dielectric of the earphones described below, and the capacitors C1 and C2 as couplers and isolators. The respective junctions of the capacitors and resistors are connected through current limiting resistors R3 and R4 to two output terminals electrically connected to a headset indicated generally by the numeral 13.

The headset 13 includes a pair of earphones 14 which receive the signal from the respective output terminals of the bias circuit 12. As shown in more detail in FIG. 2, each earphone 14 comprises a cup-shaped rigid housing 16 formed with a peripheral flange 18 about its open end and filled with a sound absorbing material such as plastic foam. The earphone 14 also includes an annular cushion, generally indicated as 20, secured to the flange 18 for providing a comfortable, contiguous contact with the wearer's head around each ear. The cushion 20 comprises an outer flexible dielectric cover 21 with a slightly elastic lip 21a formed to be stretched over the outer flange 18 for securing the cushion 20 firmly thereto. Within the cover 21 adjacent to the surface that contacts the wearer's head, is contained a pliable electrode 23 connected through an electrical conductor 24 to a respective output terminal of the bias circuit 12. The cover 21 also forms a cavity therein between the electrode 23 and the flange 18 for receiving a soft resilient material 25. This enables the covering 21 and electrode 23 to deflect and conform to the shape of the head around the ears. It is contemplated that the cover 21, particularly where it contacts the wearer's skin, be a polyvinyl plastic or similar material having a relatively high dielectric constant and within good design practice be as thin as possible in order to maintain optimum coupling for audio signal transmission efficiency. The electrode 23 may be of any electrically conductive material such as lead, silver or brass, taking the form of thin sheets, metalized fabrics, metal coatings, liquid conductors and the like.

The graphs of FIGS. 4 and 5 are included to visually illustrate the effect of applying a fixed d.c. bias to the audio signal. As shown in FIG. 4 in which the audio signal is unbiased, the force generated by the audio signal varies with the magnitude of voltage deviation from zero regardless of polarity. Accordingly, all negative voltages appear as positive forces indistinguishable from positive voltages. This results in distortion of the audio output signal. As shown in FIG. 5 where a d.c. bias voltage is added to the audio signal at least equal to the maximum anticipated negative voltage in the audio signal, all voltages become positive so that the variation in force becomes a replica of the voltage signal. In this manner, distortion is substantially reduced. The d.c. bias also has the same effect as using a relatively high-polarized dielectric material for the cover 21.

FIG. 6 is an actual frequency versus db threshold hearing curve for a system constructed according to the invention of FIG. 1. It is a measure of the hearing threshold voltage (in terms of decibels) of the system relative to the threshold voltage (in db) of the system operating at 1,000 Hz and serves to illustrate that it closely conforms to the normal hearing curve of the human ear and is therefore useful in both voice and music systems.

Limiting resistors R7 and R8 are also provided respectively from the cathodes of D1 and D2 to the

junction of capacitor C5 and R5 and junction of capacitor C6 and resistor R6.

Referring now to FIG. 8, there is illustrated another embodiment of the invention for producing three-dimensional sound. A stereo audio source 27, such as a multiplexing radio receiver or recorder-player, has three output terminals; two of independent audio signals and a common ground. The audio signal outputs are connected to one terminal of respective primary windings of an isolating transformer 28, and the ground to the other terminals of each primary winding. One terminal of each secondary winding is connected to respective inputs of d.c. bias circuit 12 or 12' (FIG. 3 or 7); the other ends of the secondary windings are connected to ground. The output terminals of the bias circuit 12 are connected to respective electrodes 23 of earphones 14. A separate uninsulated electrode 29, adapted to be placed in direct contact with the wearer's body, is connected directly to ground.

The two systems of FIGS. 1 and 8 can now be compared. In FIG. 1, the earphones 14 and the adjacent tissue T at each ear constitute two series-connected capacitors in which the tissue at each ear vibrates in unison to effect monaural sound reproduction. In FIG. 8, the earphones 14 and the adjacent tissues T constitute two parallel-connected capacitors and the tissues vibrate independently to effect stereophonic sound reproduction.

Referring to FIG. 9, there is shown another embodiment of the invention in which audio signals in a body are converted to electrical signals. A microphone indicated generally by the numeral 30 includes a cylindrical base 32 closed at one end but for an opening for receiving a coaxial cable 33. The open end of the base receives a nonconductive bushing 34 having embedded therein an electrode 36 with an exposed planar surface. The electrode 36 and base 32 are electrically connected respectively to the center conductor and shield conductor of cable 33. A dielectric 37, such as vinyl plastic, is retained against the exposed surface of the electrode 36, and a retaining nut 38 is threadingly engaged over the open end of the base 32 for securing the bushing 34, electrode 36 and dielectric 37 to the base 32.

The cable 33 is electrically connected to a d.c. bias supply 40 with its input connected to the center conductor of the cable 33 and the shield to ground. A d.c. voltage is applied between ground and a limiting resistor R9 to the input terminal. The bias circuit input also connects through a coupling capacitor C7 to an amplifier 41 the output of which comprises two terminals; one the audio output signal and the other a ground reference. When the microphone 30 is placed against the tissue T of the body with the dielectric 37 and nut 38 in contiguous contact, as shown in FIG. 9, audio vibrations of the tissue directly induce electrical signals in the charged dielectric and at the output of the d.c. bias circuit 40 useful for sound reproduction in a loud speaker or recording system.

Some of the many advantages of the present invention should now be readily apparent. The use of an electrostatic coupling for sound reproduction directly from the tissues of the skin affords a very simple and inexpensive audio apparatus. Ambient pressure variations in the surrounding atmosphere do not degrade

audio transmission efficiency, surrounding noise is excluded, and there are no requirements for radio frequency carrier signals requiring additional circuitry or introducing r.f. heating (diathermy) in the body.

It will be understood of course that various changes in the details, materials, steps and arrangement of parts, which have been herein described and illustrated in order to explain the nature of the invention, may be made by those skilled in the art within the principle and scope of the invention as expressed in the appended claims.

What is claimed is:

1. Electroacoustic audio frequency transducer apparatus comprising, in combination:

a plate-shaped electrode forming a plane surface on one side;

a thin sheet of solid plastic dielectric material having one side continuously directly intimately physically contacting and secured to said surface and the other side formed to directly engage and intimately contact a given predetermined stationary portion of a user's skin for direct acoustic coupling therewith and direct transfer therebetween of audio frequency signals; and

d.c. bias means having two output terminals, one of said terminals electrically connected to said electrode, and the other of said terminals formed to be operatively connected to the user's skin.

2. Electroacoustic audio frequency transducer apparatus comprising, in combination:

a step-up transformer having a primary winding adapted to be connected across a source of audio signal varying about ground datum in frequency and voltage amplitude, and a secondary winding, for increasing the voltage amplitude of the audio signal;

a d.c. bias means having two input terminals connected across the secondary winding for producing the increased audio signal above the ground datum two output terminals thereof;

a pair of separate and independent plastic dielectric covered electrode means formed to be held in continuous stationary direct acoustic coupling engagement against a given stationary portion of a wearer's skin in the vicinity of the ears for direct transfer thereto of audio frequency signals and electrically connected to respective ones of the output terminals of said d.c. bias means; and said transformer being formed to match the impedance of the source and the total impedance of said d.c. bias means and said electrode means when held against the skin.

3. Apparatus according to claim 2 wherein each of said electrode means comprises:

a housing having an opening and filled with sound absorbing material;

a solid-plastic-dielectric-covered annular conductor formed on one surface for directly intimately physically continuously contacting a given location on the wearer's skin for direct transfer thereto of audio frequency signals; and

means for resiliently supporting said conductor about the periphery of said opening.

4. Electroacoustic audio frequency transducer apparatus comprising, in combination:

a step-up transformer having two primary windings adapted to be connected respectively across two sources of audio signals independently varying about ground datum in frequency and voltage amplitude, and corresponding secondary windings having one end of each connected in common to ground, for increasing the voltage amplitude of the audio signals;

a d.c. bias means having two input terminals connected across both secondary windings for producing the increased audio signals above ground datum at two output terminals thereof;

a pair of separate and independent solid-plastic-dielectric-covered electrode means formed to be held in continuous stationary direct acoustic coupling engagement against a given predetermined portion of a wearer's skin in the vicinity of the ears for direct transfer thereto of audio frequency signals and electrically connected to respective ones of the output terminals of said d.c. bias means;

an uninsulated ground electrode formed to intimately contact the wearer's body; and

said transformers being formed to match the impedance of the source and the total impedance of said d.c. bias means and said electrode means when held against said portion of the skin.

5. Apparatus according to claim 4 wherein each of said electrode means comprises:

a housing having an opening and filled with sound absorbing material;

a solid-plastic-dielectric-covered annular conductor formed on one surface for directly continuously intimately contacting and acoustic coupling with the given portion of the wearer's body; and

means for resiliently supporting said conductor about the periphery of said opening.

6. Apparatus according to claim 1 wherein said d.c. bias means further comprises:

an isolation resistor connected at one end to said electrode;

a regulated d.c. voltage source connected between the other end of said resistor and ground;

a capacitor connected at one end to said input terminal; and

amplifier means connected to the other end of said capacitor and having respective output terminals connected to the output terminals of said bias means, one of said terminals being grounded.

7. An electroacoustic audio frequency microphone comprising:

an electrically conductive housing having an opening, the periphery of said opening exposed for intimately directly continuously contacting and acoustically coupling with a given predetermined stationary area of a surface capable of vibrating acoustically;

an electrical insulator mounted in said opening;

a plate-shaped electrode supported by said insulator having a plane surface adjacent to said opening; and

a solid plastic electrically polarized dielectric plate having one side directly intimately contacting and secured on said surface of said electrode and having the other side at said opening exposed for con-

7

tinuously intimately directly contacting and acoustic coupling with a given predetermined stationary portion of an adjacent area of said surface capable of vibrating acoustically for direct transfer therebetween of audio frequency signals.

8. In an electrical apparatus including a source of audio frequency electrical signals having a pair of output terminals; an electroacoustic audio frequency transducer for continuous stationary direct physical acoustic coupling engagement with a predetermined given portion of the body tissue of a wearer, and having a first conductor for connection to one of said output terminals, and a second conductor for connection between the other of said output terminals and the body tissue of the wearer; the improvement wherein said transducer comprises: a conductive electrode connected to said first conductor and having a principal contact surface; and
an electrically polarized sheet of solid plastic dielectric material having a first principal surface for direct continuous physical contact and acoustic coupling engagement with a given predetermined stationary portion of the body tissue of the wearer for direct transfer therebetween of audio frequency signals and a second principal surface covering said principal contact surface of said electrode and

8

secured in direct physical intimate acoustic coupling contact therewith.

9. In an electrical apparatus including an amplifier having a pair of input terminals; an electroacoustic audio frequency microphone transducer for continuous direct physical and acoustic coupling engagement with a source of acoustic vibrations, and having a first conductor for connection to one of said input terminals, and a second conductor for connection between the other of said output terminals and a surface operatively connected with a source of vibrations;

the improvement wherein said transducer comprises: a conductive electrode connected to said first conductor and having a principal contact surface; and an electrically polarized sheet of solid plastic dielectric material having a first principal surface for continuous direct physical acoustic coupling engagement and contact with a given predetermined stationary portion of the surface operatively connected with a source of vibrations for direct transfer therebetween of audio frequency signals and said dielectric material having a second principal surface covering and secured in direct acoustic coupling engagement with said principal contact surface of said electrode.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,689,709

Dated September 5, 1972

Inventor(s) Max A. Salmansohn et al

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

On the cover sheet, line 30 of the ABSTRACT, "propogation" should read -- propagation --. Column 1, line 29, "experience" should read -- experienced --; line 56, after "pressures" insert -- in an air gap --. Column 3, line 62, "illustrated" should read -- illustrate --. Column 5, line 41, after "datum" insert -- at --. Column 6, line 46, "input terminal" should read -- electrode --. Column 8, line 10, "output" should read -- input --; and after line 25, insert the following claim:

10. An electroacoustic audio frequency transducer apparatus comprising, in combination:
- a plate-shaped electrode forming a plane surface on one side;
 - a thin sheet of solid dielectric material having one side disposed in continuous direct contact with said plane surface, and having its other side formed to directly contact a user's skin for direct acoustic coupling therewith and direct transfer therebetween of audio frequency signals; and
 - d.c. bias means having two output terminals, one of said terminals being electrically connected to said electrode, and means for providing a stationary direct electrical connection between the other of said terminals and the user's skin.

Signed and sealed this 20th day of February 1973.

(SEAL)
Attest:

EDWARD M. FLETCHER, JR.
Attesting Officer

ROBERT GOTTSCHALK
Commissioner of Patents

128