

July 8, 1952

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2,602,906

TRANSDUCER

Filed Sept. 20, 1950

Fig. 1

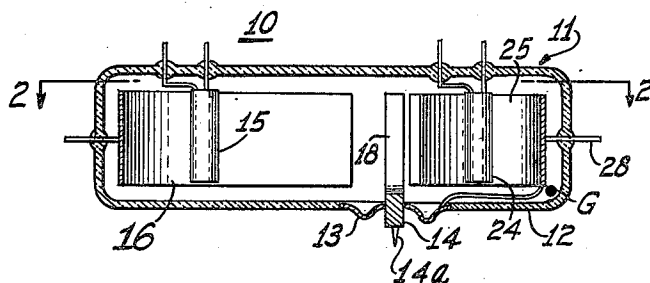


Fig. 2

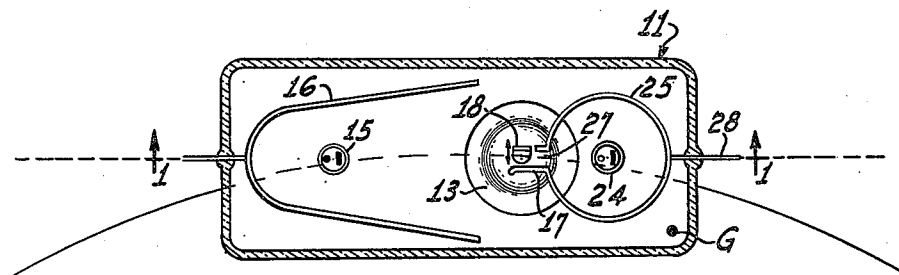
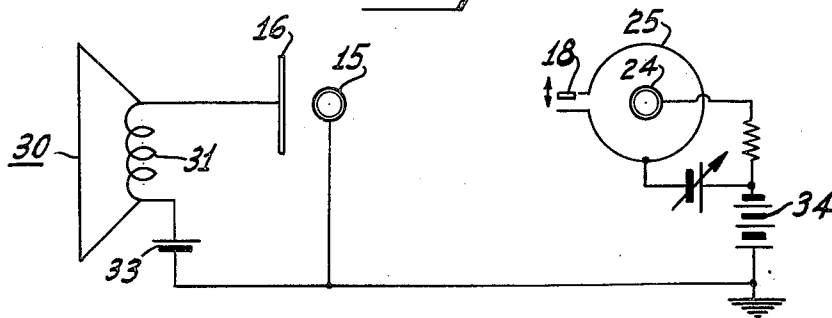


Fig. 3



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2,602,906

TRANSDUCER

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Application September 20, 1950, Serial No. 185,748

7 Claims. (Cl. 313-148)

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This invention relates to improved transducers, such as microphones or phonograph pick-ups, for converting mechanical movements into electrical signals. More particularly it relates to a novel kind of transducer which includes a gas discharge valve arranged therein to afford great power sensitivity and a very low output impedance.

Substantially all of the transducers of the prior art, including those of the vacuum tube types, have been incapable of delivering (or controlling) more than extremely small amounts of power. Because of this most sound transmitting and sound reproducing systems have included audio amplifiers between their transducers and reproducers. The presence of amplifiers in these systems has made them more costly and has been largely to blame for what may be called poor overall conversion efficiencies. The latter fact is due to a multiplication of the individual losses entailed in the numerous energy conversions required in the amplifiers, such as in the conversion of heater current into thermionic emission; in the conversion of A. C. line power into suitable direct potentials for amplifier tube anodes; and in the conversion of the high impedance of the output tubes (s) of the amplifier to a suitable value for matching that of the reproducer. An example of an undesirable result of poor "overall conversion efficiency" is that the life of batteries employed in portable phonographs is much less than what it might be ideally.

It is an object of the present invention to devise improved transducers capable of controlling the delivery of such large amounts of power to utilization devices, such as transducers, that the need for amplifiers as in the prior art is very much reduced or eliminated.

It is a further object of the present invention to devise improved transducers capable of controlling the delivery of large amounts of power directly to a low impedance load, such as a reproducer, without the need of an impedance transformer.

In general, these objects have been attained by devising a transducer which controls the current in a utilization circuit by the use of a novel type of gas tube valve. The internal impedance of this valve has an extremely low average value which is variable over a usefully large range in response to microscopic mechanical movements such as those imparted to a phonograph stylus. As a result the transducer is able directly to modulate the flow of electrical energy through

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a closed load circuit between a low-voltage external source, such as a battery consisting of one or a few $1\frac{1}{2}$ volt dry cells, and a low impedance reproducer. The low impedance of the gas tube valve result from the fact that the load current which it controls passes from its cathode to its anode not as an electron discharge across an insulating open space but as a conduction current through a dense plasma.

The production of plasma is by an auxiliary electron space discharge and therefore is independent of the heavy electron conduction load current and of the output signal variations that occur in it during operation. Valving action is effected by modulating a constriction in the stream of the auxiliary ionizing discharge to thereby modulate the plasma density and the series resistance which it offers to the conduction current.

In the drawings:

Figure 1 represents a longitudinal sectional view of one photograph pick-up embodiment of the present invention. The section is taken along the line 1-1 of Figure 2 and in a plane which is vertical when the pick-up is in its operating position (resting on a horizontal flat photograph record);

Figure 2 represents another longitudinal sectional view of the embodiment of Figure 1, this section is taken along the line 2-2 of Figure 1 and in a plane perpendicular to that of the section of Figure 1; and

Figure 3 is a schematic circuit diagram of a sound reproducing system using the pick-up shown in Figures 1 and 2.

The pick-up 10 shown in Figures 1 and 2 comprises a gas-tight envelope 11 of substantially rectangular shape. Most of the envelope 11 is made of rather thick glass and is quite rigid. However, its bottom 12 comprises a flexible, disc-shaped portion (disc 13) consisting of a circular relatively thin metal diaphragm formed with a number of concentric corrugations and having its entire periphery fused to the edges of an opening in the glass part of the bottom.

A rigid stylus 14 is carried in, and extends and is sealed through, the center of the disc 13. In this arrangement, and due to the flexibility of the disc, transverse vibrations imparted to the needle point 14a on the external end of the stylus 14 are imparted (with a reversal of direction) to its internal end. In other words, the center (f) of the disc acts as a fulcrum for the stylus at a point intermediate its external and internal ends.

The internal load current path through pick-up 10 extends between a main cathode 15 and a main anode 16 and in the operation of the pick-up conduction over this path is through an extremely low impedance ionized gas plasma. In the novel gas valve employed herein, this plasma is established within the tube by ionizing its gaseous filling, G, by the action of an independent or auxiliary electron current flow. The auxiliary current flow is readily distinguishable from one load current flow through the tube. The following are two points of distinction:

The auxiliary flow includes as one component a "space discharge" electron current (as distinguished from "conduction" electron current) in which electrons attain sufficient velocities to ionize the gaseous filling, G, of the tube; and (2) the overall path of this space discharge is different from that of the load current, e. g., it starts at an emissive electron source other than that at which the load current path starts (this is the case herein where the two paths start at different cathodes); or it terminates at a collector other than the anode for the load current path; or it both starts and terminates at different electrodes than the internal load current path.

An auxiliary cathode 24 is mounted within the envelope 11 on the far side of the main cathode 15 from the main anode 16. It is surrounded by a cylindrical shield 25 having a narrow slot 27 on its side toward the main cathode 15. The shield causes the ion-producing electron discharge to be formed as a directed stream having a narrow cross-section, i. e., "a constriction," in the region just beyond the point where the electrons emerge from the slot 27. With this type of construction, a plasma of very high density and therefore of very high conductivity, can be provided by an auxiliary electron discharge of surprisingly low current, i. e., it can be economically provided.

The shield 25 is supported on a rod 28 which in the example herein is fused through an end of envelope 11 to serve as a terminal pin. This construction makes it possible to use a circuit in which one can control the bias between the auxiliary cathode 24 and the shield 25. This can be useful as a way of electrically varying the amount of constriction produced by the shield 25 without physically changing the width of its slot 27. However, it is entirely feasible to operate the auxiliary cathode and the shield at the same potential. Therefore, for some embodiments the shield 25 may simply be mounted by one or more rods which are secured to the interior of the envelope at suitable presses without necessarily extending any of the rods through to the outside of the envelope. In such an arrangement an internal inter-connection may be used for causing the shield and the auxiliary cathode to have the same potential. Moreover, as indicated by extensive experimentation, it is also feasible simply to allow this shield to "float."

The slot 27 is formed between a lip 17 which is an integral portion of the shield 25 and, as such, is stationary, and a movable shutter 18. The shutter 18 is mounted on the internal end of the stylus 14 in a position parallel to and somewhat spaced from the lip 17. It is apparent that in this arrangement a transverse vibration of the stylus 14 will modulate the width of the slot 27.

The pick-up device 10 shown herein may be processed in any of a number of ways well known in the art to provide a gaseous filling within its envelope prior to sealing off. Any suitable gas or mixture of gases may be utilized. The gas

pressure for a particular pick-up will be in accordance with its specific electrode geometry and spacings and must be such as to favor the formation of a self-sustaining ionizing discharge. A number of gas tubes of the kind employed in the present pick-ups have been found to operate satisfactorily with a filling of helium at a pressure of approximately 750 microns. However, as is well known other gases and other pressures may be used, e. g., gas pressures which lie within the range between approximately 100 microns and several millimeters of mercury.

One of a number of principles governing the operation of this pick-up can be best explained with reference to a common type of triode found in the class of prior art gas tubes known as thyatrons. This is a triode having a control grid which comprises an electron-opaque element, such as a metal plate, mounted cross-wise to the electron discharge path between the cathode and the anode and formed with a single aperture, such as a small hole or a narrow slot, through which any electron discharge which takes place must pass. This grid is generally used only for controlling the anode-cathode potential at which this tube will fire. Its use is so restricted because of the fact that once the tube is ionized the grid "loses control." That is, variations in its potential will cease to have any significant influence on the behavior of the tube. Since this is so, it is obvious that such variations will not be effective to control the anode-cathode current in the essential manner for using the tube as a class A amplifier, i. e., according to a substantially linear function of the instantaneous grid voltage.

It is of interest to consider some of the phenomena which occur within the tube. As soon as it fires, a positive-ion sheath immediately forms about all parts of the grid (if it is negatively biased) including the edges of its aperture. Thus, the effective size of the aperture is suddenly changed (reduced). Moreover, if the bias is then changed the sheath thickness will vary, and this will further change the size of the aperture (will further reduce it if the bias change is in the direction to increase its magnitude). Yet, it is observable that during the occurrence of all such changes the cathode-anode current nevertheless remains substantially constant. A phenomenon which may be responsible for this is also observable at the same time. It is that each change in the effective size of the grid aperture is accompanied by a change in the density of the plasma. Moreover, the same thing occurs if the changes in the aperture size are effected physically (without dependence on the existence of a grid sheath and on inducing variations in the thickness thereof).

Part of the method of the present invention is to use the very plasma-density variations, which apparently are responsible for preventing modulation of the auxiliary electron current, as a means for causing modulation of the main electron current. By so doing the ability to control the plasma density by changing the width of the slot 27 is directly translated into ability to control the low internal impedance of the load current path through the pick-up.

In the operation of this device, large currents of the order of one ampere per anode volt may circulate through the load circuit within a range of main-anode-to-main cathode potentials of between about zero volts and a saturating potential of about $1\frac{1}{2}$ to 2 volts. With a hard tube this would not be at all possible. One reason for

this is that the emission from the cathode of a hard tube is space-charge-limited at low anode potentials. Moreover, such currents are not even possible in a gas tube (despite its freedom from space-charge-limited cathode emission) if it be of the prior art type in which the ionizing electron current moves between the same electrodes as the load current. This is due to the fact that the current cannot continuously exceed the value at which the IR drop in the external circuit will reduce the applied voltage below the value needed for sustaining ionization.

In the operation of the pick-up 10 its main-anode-to-main-cathode potential is always well below the particular ionizing potential. Therefore, any electron space discharge which accompanies the electron conduction over the load current path will occur at too low an energy level to contribute to the production of plasma and therefore its variations will not affect the plasma density. This will avoid the possibility of behavior in the nature degeneration or regeneration.

Figure 3 is a circuit diagram of a sound reproducing system employing the pick-up 10. The utilization device is a loud speaker 30 having a voice coil 31 of a low impedance, such as a few ohms. The primary source of energy for driving the voice coil 31 is a low voltage battery 33. This battery should be a high-current source, such as a member of series-parallel-connected $1\frac{1}{2}$ volt large size dry cells, a storage battery, or the like. The battery 33 is connected in series with the voice coil 31 and the load current path of the pick-up. The source of energy for the auxiliary discharge is a battery 34 which does not have to supply much current but must provide a sufficient potential, e. g., 15-45 volts to ionize the gaseous filling, G.

Preferably the potential applied from battery 34 across the ionizing discharge path should only slightly exceed the ionizing potential since excessive potentials tend to favor the development of large amplitude "plasma oscillations" which, of course, would spuriously modulate the load current.

A variable bias is represented at 35. This component is not essential for the circuit to be operative. However, it provides a convenient variable control-parameter which may be used, for example, as a "volume control." Applying or increasing the negative bias to the shield 25 will cause a sheath to form about it or thicken one already there to effectively decrease the quiescent size of its slot 27, i. e., the size thereof for the rest position of the stylus 14.

It will be noted that in this arrangement the main cathode 15 and the main anode 16 together constitute a composite anode for the internal auxiliary discharge originating at the auxiliary cathode 24. In the operation of the pick-up the main cathode 15 is copiously bathed in plasma with the result that even for extremely low main anode potentials (in fact for zero anode potential) the space charge of the electrons surrounding it appears to be completely neutralized. Under such conditions the load circuit currents have such magnitudes as to indicate internal impedances of the order of one or two ohms and in general appear to be limited only by the emission capabilities of the cathode. The current which can be observed to flow even for an anode potential of zero volts apparently is energized by the thermal velocities of the electrons emitted from the main cathode. That this is a correct

explanation seems to be borne out by the fact that the anode current does not drop to zero until the anode potential is made negative to an extent corresponding to the highest thermal velocities of the emitted electrons.

I claim:

1. A transducer comprising: a sealed envelope containing a gaseous filling; within the envelope a main cathode and a main anode in spaced-apart relationship at the opposite ends of a load current path for carrying through the transducer a conduction load current which may be accompanied by an electron discharge current, means for producing an ionizing auxiliary electron discharge over an auxiliary discharge path which does not coincide over all of its length with said load current path but has a portion in proximity thereto to provide a conductive plasma between said anode and cathode, said last mentioned means comprising means for producing a constriction in the path of the auxiliary discharge; and means responsive to mechanical forces exerted externally of said envelope for varying said constriction in correspondence therewith.

2. A transducer comprising: a sealed envelope containing a gaseous filling; within the envelope a group of electrodes including a main cathode and a main anode for carrying a load current through the transducer; means for producing an ionizing discharge of electrons along a path within said envelope which, taken as a whole, is different than the path, taken as a whole, of said load current but has a portion in proximity thereto to provide a conductive plasma between said main anode and main cathode, said means including, as two of its elements, an emissive source of ionizing electrons and a collector thereof, at most one of said elements being included in said group of electrodes, said means further including a shield interposed between said source and said collector of ionizing electrons and having an aperture in alignment with the discharge path thereof for producing a constriction therein; a flexible portion for said envelope; a movable element positioned effectively to define a perimeter of said aperture and linked to said flexible portion for responding to mechanical flexings thereof to vary said constriction.

3. A transducer comprising: a sealed envelope containing a gaseous filling; within the envelope a main cathode and a main anode positioned to constitute a diode for carrying a load current through the transducer; means for producing an ionizing discharge of electrons, along a path within said envelope other than the path of the load current through said diode, to provide a conductive plasma between said main anode and main cathode, said means including an auxiliary cathode as a source of ionizing electrons and said main cathode as at least a portion of a collector of ionizing electrons; means including a shield interposed between said auxiliary cathode and said collector of ionizing electrons and having an aperture in alignment with said first-mentioned path for producing a constriction in the ionizing discharge; a flexible portion for said envelope; a movable element positioned effectively to define a perimeter of said aperture and linked to the inside of said flexible portion for responding to mechanical flexings thereof to vary said constriction.

4. A transducer comprising: a sealed envelope containing a gaseous filling; within the envelope a group of load circuit electrodes including a main cathode and a main anode having, respec-

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tively, electron-emitting and electron-receiving surfaces which define the opposite ends of a predetermined load current path; means for producing an ionizing discharge of electrons along a different path within said envelope to provide a conductive plasma which is continuous over substantially all of said load current path, said means including an auxiliary cathode and at least one of the electrodes of said group thereof to act as a collector of ionizing electrons; means for producing a constriction in the path of the ionizing discharge, said last mentioned means comprising a shield for blocking the movement of electrons from said auxiliary cathode to said collector over most of the possible lines of electron travel therebetween but having an opening so that it does not block their movement over other possible lines falling within said different path; a flexible portion for said envelope; a lever sealed through said flexible portion to extend from the interior of said envelope to the exterior whereby a movement imparted to the external portion of the lever will be reproduced at its internal portion; and means within the envelope for responding to movements of said lever to vary the density of said plasma and thereby the conduction which it provides in the load current path, said means including a movable element which is mechanically linked to the internal portion of said lever and is positioned to define a perimeter of said opening for responding to movements of the lever to vary the opening and thereby the constriction.

5. A transducer comprising a gas filled envelope containing a main cathode and a main anode having surfaces defining the ends of a load current path; means, including at least two elements to act respectively as a source of ionizing electrons and a collector thereof, for producing an ionizing discharge along a different path to produce a conductive plasma between said anode and cathode; said last mentioned means comprising means for producing a constriction in the path of the ionizing discharge; and means responsive to mechanical forces exerted externally of said envelope for varying said constriction.

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6. A transducer comprising: a sealed envelope containing a gaseous filling; a main cathode and a main anode in said envelope for carrying a load current through the transducer; means for producing an ionizing discharge of electrons along a path within said envelope which, taken as a whole, is different than the path, taken as a whole, of said load current to provide a conductive plasma between said main anode and main cathode, said means including an emissive source of ionizing electrons and a collector thereof, said means further including a slotted shield interposed between said source and said collector of ionizing electrons with its slot positioned to constrict the ionizing discharge, said envelope having a flexible portion; a movable element linked to the inside of said flexible portion and positioned to respond to mechanical flexings thereof to alter the effective cross-sectional area of said slot.

7. A transducer including an envelope having a gaseous medium therein, a main cathode and a main anode within said envelope for carrying a load current through said transducer, auxiliary cathode means providing ionizing electrons directed toward said main cathode, a shield interposed between said cathodes and having an aperture producing a constriction in the discharge from said auxiliary cathode, said envelope having a flexible portion, a movable element adjacent said aperture for varying the effective area thereof to vary the constriction in said ionizing discharge and connection between said flexible portions of said envelope and said movable element whereby said movable element responds to a flexing of said flexible portion of said envelope.

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REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

Number	Name	Date
1,507,884	Engler	Sept. 9, 1924
1,871,253	Bauer	Aug. 9, 1932