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(54) **ELECTROHYDRODYNAMIC SOUND DEVICES**

(57) **Abstract:**

This invention relates to electrokinetic methods and apparatus and more particularly to methods and apparatus employing electro-hydrodynamic principles in transducing between electrical energy and, sound.

In accordance with the present invention electric energy is transduced into sound and conversely sound is transduced into electric energy without the aid of diaphragm membranes or other moving parts.

Heretofore, loudspeakers such as those used in connection with radio and television circuits have made use of a moving cone, diaphragm or the like to produce sound waves. It is well known in the loudspeaker art that cones or diaphragms introduce distortion due to their mass and inertia. In general, the greater the mass of the moving member the greater is this distortion. The movement of the diaphragm always lags behind the electrical signal and never accurately reflects the true signal wave form. In the development of loudspeakers, design engineers have resorted to lighter and lighter diaphragms. It is customary today to make such diaphragms out of paper or paper-like materials, which are shaped to retain sufficient rigidity to withstand the forces applied. The cone is an example. In electrostatic loudspeakers, thin plastic membranes are usually employed which contain wire grids or other electrically conducting means to make them respond to a modulated electrostatic field. The present invention utilizes an electrohydrodynamic effect or electrostrictive hydrodynamic effect which I have discovered in which air itself, as a die-electric, is caused to move in accordance with thDapplied signal. The distortion introduced 6y a moving diaphragm or membrane is eliminated. Movement of the air is produced by a non-linear electrostatic field, and the principles involved are similar to those set forth in my prior U.S. Patent Nos. 2,949,550 and 3,0181394.

It is the principal object of the present invention to provide improved transducers between electrical energy and sound which have no moving parts, and which are adapted for greatly simplified loudspeakers and microphones.

It is a further object of the present invention to provde a loudspeaker or microphone with a wide spectrum of frequency response virtually without resonance peaks.

It is a further object of the present invention to provide a unitary loudspeaker with two input channels for stereo reproduction.

It is a further object of the present invention to provide a loudspeaker or microphone which can be made highly directional.

It is a further object of the present invention to provide a loudspeaker or microphone having electrodes in which the shock hazard is eliminated.

Other objects and advantageous features of the present invention will be apparent from the description and claims.

The nature and characteristic features of the invention will be more readily understood from the following description, taken in connection with the accompanying drawings forming part hereof in which:

FIGURE 1 is a perspective view illustrating a plurality of flat plate electrodes and wire electrodes together with an electrical circuit for use as a loudspeaker;

FIG. 2A is a similar perspective view with a simplified diagram of the electrical circuit set forth in FIG. 1;

FIG. 2B is a similar perspective view with a circuit diagram showing a different arrangement of components;

FIG. 3 is a chart of the voltage impressed upon the above units, indicating the range and possible cause of distortion;

FIG. 4 is a view similar to FIG. 1 showing the use of two channels to provide stereo reproduction;

FIG. 5 is a perspective view of an alternative form of the invention employing a curved plate electrode, and an elongated wire electrode;

FIG. 6 is a sectional view of the apparatus shown in FIG. 5, showing the direction of sound emanation from the intense divergent electrostatic field surrounding the wire electrode;

FIG. 7 is a diagrammatic view showing a plurality of the reflecting devices of FIG. 6 in an array for collinear beams;

FIG. 8 is a diagrammatic view showing a plurality of the reflecting devices of FIG. 6 in an array for divergent beams;

FIG. 9 is a diagrammatic view showing a plurality of the reflecting devices of FIG. 6 in an array for convergent beams;

FIG. 10 is a diagrammatic view of a simple form of an electrohydrodynamic microphone with associated electrical circuit in block diagram;

FIG. 11 is a diagrammatic view of a flat-plate array microphone in which the incident sound waves, upon entering the plate array and passing the related wire grid produce an audio signal output; and

FIG. 12 is a diagrammatic view of a microphone of highly directional characteristics, utilizing an array of reflecting surfaces and wire grid.

It should, of course, be understood that the description and drawings herein are illustrative merely and that various modifications and changes can be made in the structure and methods disclosed without departing from the spirit of the invention.

Preliminarily, it may be noted that in accordance with the basic aspects of this invention as a loudspeaker, electrodes of large surface area are connected together to form a group. Similarily, electrodes of small surface area are connected together to form another group. The groups are placed in close spacial relationship, connected in polarity opposition and energized by a source of high potential, which may be either radio frequency or direct current, in series with a source of high voltage alternating current to provide a modulated voltage, the alternating current being the high voltage output of a modulation transformer which is energized by the signal or directly by the plate circuit of high voltage amplifier tubes. The microphone operates in a converse manner, with the incident sound producing an electrical signal in the output which can be amplified.

In accordance with the invention electrodes of unequal surface area are employed, energized by a source of high potential in combination with an external electrical circuit to produce or detect a flow of the surrounding dielectric medium.

In accordance with the invention, also, charged electrodes of unequal surface area are employed in combination with an alternating current feeder circuit, to produce sound waves.

In accordance with the invention, also, charged electrodes of unequal surface area are employed in combination with an alternating current sensing circuit to transduce sound waves into electrical signals.

Referring now more particularly to FIG. 1 of the drawings, a simple loudspeaker is shown operating on the principles of electrosttictive hydrodynamics. Flat conducting plates 15 are mechanically fixed in parallel relationship by separators 16 which may also serve as insulators, and insulating supports 14 are also provided. The insulating character of the supports 14 may be eliminated if the plates 15 are grounded. Bus bars 17 are provided to electrically connect the plates 15.

The plates 15 are shown merely for purposes of illustration and description as horizontal but any other desired orientation may be employed, other related components being similarly reoriented to remain in predetermined spacing and arrangement with respect to the plates 15.

Frames 18 and 19 are provided with fine wires 20 strung parallel therebetween at predetermined spaced locations. The frames 18 and 19 are mounted in supporting insulators 21.

The wires 20 which serve as electrodes are preferably in a plane, vertical if the plates 15 are horizontal, and with the wires 20 for best results midway between the respective planes of the plates 15. The spacing of the wires 20 from the plates 15 should be sufficient to prevent breakddown or sparking for the maximum voltage swings which occur. It is preferred that the wires 20 making up this grid be of corrosion resistant metal, such as stainless steel, and the wires should be of the order of .002 to .008 inches in diameter, wires of the order of .005 inches in diameter being particularly suitable. Wires with either round or square cross-section may be used, the latter being found to be slightly superior, both in operation and mechanical strength. Where the total peak voltage is of the order of 20 KV, the plates are approximately 2 inches wide and one-half inch apart, the spacing between the wire grid and the edges of the plates being approximately one inch. Where lower voltages are used, these dimensions may be reduced. It is convenient to use the lowest voltages possible commensurate with good operating characteristics. The operating characteristics can be further improved by coating the plate electrodes 15 with a partially conducting material having a resistance of the order of 10^5 to 10^6 ohms per cubic centimeter. One such material comprises a synthetic resinous coating material loaded with carbon black and applied as a surface coating. Such electrode coating serves several purposes, including protection against damaging sparkover, reduction of point discharges from sharp or uneven edges, reduction of ozone generation, reduction of current requirements, elimination of accidental shorting, and elimination of electrical shock hazard.

The grid frame which includes the wires 20 is connected by a conductor 22 to one terminal of a step-up transformer 23, thence to a bias supply 24, and which may be the positive output of a high voltage direct current bias supply or a high voltage r.f. supply. The negative side of this bias supply 24 is connected by a conductor 25 to the bus bar 17. A high voltage capacitor 26 is placed across the output of high voltage bias supply 24 to provide a low impedance path for audio signals from the transformer 23 and to reduce AC ripple or hum. In general, direct current as a bias supply (with polarity as indicated) is preferable. Under certain circumstances where a background hiss can be tolerated, radio frequency current may be employed, in which event the capacitor 26 is not used. A power amplifier 30 provides amplification for the (audio) input signals. Voltage limiting devices, such as resistors 27 and 28 may be employed to prevent sparkover or disruptive discharge and also to prevent injury to a person touching the wires 20 or plates 15.

Referring now to FIG. 2A the circuit shown in FIG. 1 is there set forth as a block diagram. In most cases it is convenient to include a ground connection 31 as shown, although this is not essential. Sound waves are emitted from the device largely in the direction indicated by the arrows.

In FIG. 2B, an alternative connection is indicated in the block diagram. In this case, the high voltage bias supply 24 is connected to the wire grid which includes the wires 20 by a conductor 32 and the output of the modulation transformer 23 is delivered by a conductor 33 to the plates 15.

The chart of FIG. 3 shows the voltages normally utilized in the apparatus shown in FIG. 1. The line V1 represents the steady negative bias voltage applied to plates 15. The line V2 represents the alternating potential supplied to grid wires 20 by the modul-6 ation transformer 23. It is desirable at all times to keep the potential difference between the plates 15 and wire grid 20 above the operating threshold. If this potential difference should fall below this operating threshold, a condition present in overmodulation, distortion is introduced. This distortion arises from so-called "clipping" of that portion of the cycle under the threshold. For this reason, the bias voltage supplied by the bias supply 24 should always be substantially greater than the output voltage of the modulation transformer 23.

Referring now to FIG. 4 apparatus is there shown for establishing two channels for stereo reproduction. On each side of the plates 15, in spaced relation thereto as previously explained for the grid wires 20, two sets of grid wires 20 and 20a are provided spaced equally on each side of plates 15. This balanced structure provides two channels, emitting sound waves in opposite directions and providing stereo effect. The grid 20, in cooperation with plates 15, produces sound emission toward the left, indicated by the arrows as channel 2. The grid 20a produces sound emission toward the right, indicated by the arrows as channel 1. Direct current bias voltage from supply 24 is applied to the plates 15 as before, but in the case of FIG. 4, separate modulation transformers 23a and 23b and associated amplifiers 30a and 30b are required for each of the two channels.

Referring now to FIG. 5 a slightly different sound emission device is there illustrated, in which a plate 115, preferably of metal, and having a curved conducting surface 35, is used as the larger electrode, and, at the same time, as a reflecting surface. Electrohydrodynamic pressure waves arising in the region around the fine wire 20 are reflected by the plate 115 and emerge in a common direction as indicated by the arrow. As in FIG. 1, the large plate 115 may be coated with semi-conducting material.

In FIG. 6 there is shown a preferred cross section for the plate 115 of FIG. 5. The cylindrically curved plate 115 has parabolic form in interior cross-section as at 135. Sound waves originating near the wire 20 are reflected so as to form a collinear beam as indicated by the arrows.

FIG. 7 represents the cross-section of an assemblage of curved plate electrodes 115 and wire electrodes 20, of the type shown in FIG. 6, in a linear array of reflecting surfaces. The sound wave front is flat and highly directional.

FIG. 8 illustrates a convex array of the curved plate electrodes 115 and wire electrodes 20 which produces a divergent wave front of FIG. 6, and FIG. 9 shows a concave array of these electrodes which would produce a convergent wave front.

Referring now to FIG. 10 a simple microphone utilizing electrohydrodynamic principles is there shown, with a plate 215 having a parabolic conducting surface 235 so that incoming sound is relected so as to converge in the region of the wire electrode 220. The variations in air density so produced in the limited region of the small electrode 220 cause fluctuations in the current from bias power supply 224. These current fluctuations are sensed in a step-down transformer 223 and fed to an amplifier 230 where the output signal becomes available.

FIG. 11 is a sectional view with block electrical diagram of a multiplicity of microphones, operating according to the same principles as that shown in FIG. 10. Single fine wires 220 are positioned at the focus of the curvature of the reflectors 215 so as to concentrate the pressure variations of the incoming sound. The electrical circuitry for this multiple microphone is the same as that shown for a single microphone in FIG. 10.

In FIG. 12 a modified microphone construction is shown. Spaced parallel plates 315 have the incoming sound passing therebetween. The wires 320 have the electrostatic field converging thereon disturbed by the incoming sound. This disturbance creates a varying current in the bias voltage from the supply $32^{1}+$, is sensed by step-down transformer 323 and fed into an amplifier 330 to produce an alternating signal output. It will be noted that the system shown in FIG. 12 is virtually the same as that shown in FIG. 1, except that the device of FIG. 12 operates as a microphone rather than as a loudspeaker.

In all the foregoing circuits, the plates 15, 115, 215 and 315 are shown as the cathode and the fine wires 20, 120, 220 and 320 as the anode. In most applications, this is the preferred polarity because it produces less coronal hiss. The units are operative, however, at either polarity. Radio frequency current may be employed where coronal hiss, with an ultra-sonic emission, can be tolerated.

Coating the plates or reflector electrodes 15, 115, 215, and 315 with semi-conducting material is beneficial in nearly every case.

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. An electrohydrodynamic transducer comprising a plurality of electrodes connected in first and second groups, a source of potential connected to said groups in polarity opposition, and modulating means connected to said source, the first of said groups comprising electrodes having terminal edges and being of greater area than the second of said groups, the electrodes of the second of said groups being spaced from and offset with respect to said terminal edges.

2. An electrohydrodynamic transducer as defined in claim 1 in which the electrodes of said first group are flat parallel plates.

3. An electrohydrodynamic transducer as defined in claim 1 in which the electrodes of said first group are flat parallel plates and the electrodes of said second group are elongated elements.

4. An electrohydrodynamic transducer as defined in claiml in which the electrodes of said first group have on an exposed portion thereof a high resistance conducting coating.

5. An electrohydrodynamic transducer as defined in claim 1 in which the electrodes of said first group are curved plates.

6. An electrohydrodynamic transducer as defined in claim 1 in which the electrodes of said first group are plates with interior surfaces parabolic in transverse cross section.

7. An electrohydrodynamic transducer as defined in claim 1 in which the electrodes of the second group are spaced from the electrodes of the first group on one side thereof and a third

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. An electrohydrodynamic transducer comprising a plurality of electrodes connected in first and second groups, a source of potential connected to said groups in polarity opposition, and modulating means connected to said source, the first of said groups comprising electrodes having terminal edges and being of greater area than the second of said groups, the electrodes of the second of said groups being spaced from and offset with respect to said terminal edges.

2. An electrohydrodynamic transducer as defined in claim 1 in which the electrodes of said first group are flat parallel plates.

3. An electrohydrodynamic transducer as defined in claim 1 in which the electrodes of said first group are flat parallel plates and the electrodes of said second group are elongated elements.

4. An electrohydrodynamic transducer as defined in claiml in which the electrodes of said first group have on an exposed portion thereof a high resistance conducting coating.

5. An electrohydrodynamic transducer as defined in claim 1 in which the electrodes of said first group are curved plates.

6. An electrohydrodynamic transducer as defined in claim 1 in which the electrodes of said first group are plates with interior surfaces parabolic in transverse cross section.

7. An electrohydrodynamic transducer as defined in claim 1 in which the electrodes of the second group are spaced from the electrodes of the first group on one side thereof and a third

group of electrodes are provided spaced from the electrodes of the first group on the other side thereof, the electrodes of the second and third groups each having modulating means connected thereto.

8. An electrohydrodynamic transducer as defined in claim 1 in which the electrodes of the first group are curved plates disposed in parallel relation and faced in parallel relation.

9. An electrohydrodynamic transducer as defined in claim 1 in which the electrodes of the first group are curved plates disposed in parallel relation and faced in converging relation.

0. An electrohydrodynamic transducer as defined in claim 1 in which the electrodes of the first group are curved plates disposed in parallel relation and faced in diverging relation.

1. An electrohydrodynamic transducer as defined in claim 1 in which said source of potential and said modulating means are connected in series.

2. An electrohydrodynamic transducer as defined in claim 1 in which said source of potential is connected to one group of electrodes, said modulating means is connected to another group of electrodes, and a connection to ground is provided between said source and said modulating means.

0. An electrohydrodynamic transducer comprising at least two different electrodes in fixed spaced relation to each other, one of said electrodes having a greater surface area than the other of said electrodes, a source of potential connected to said electrodes in polarity opposition, and modulating means connected to said source, said electrode of greater surface area having on an exposed portion thereof a high resistance conducting coating.

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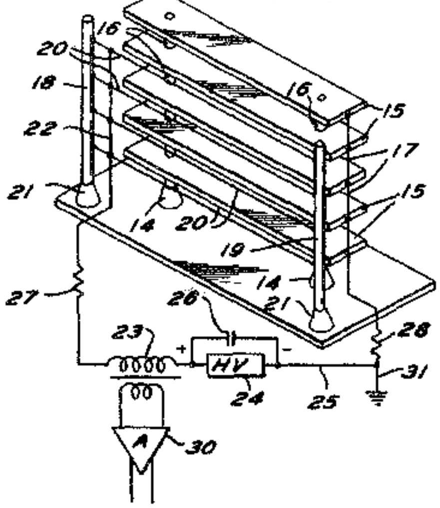

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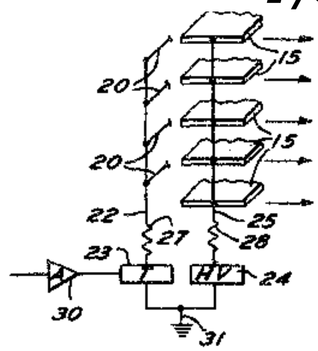

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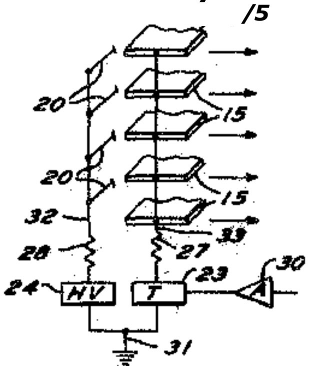

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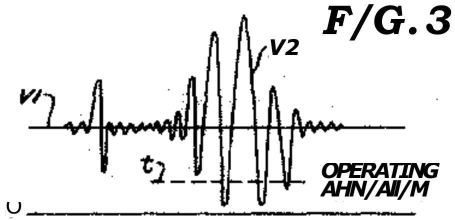

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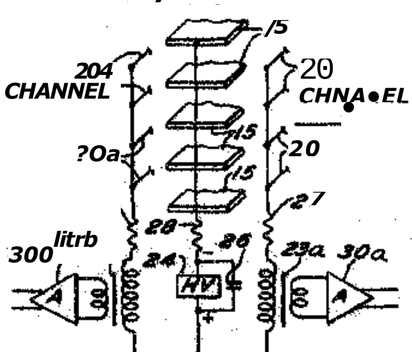

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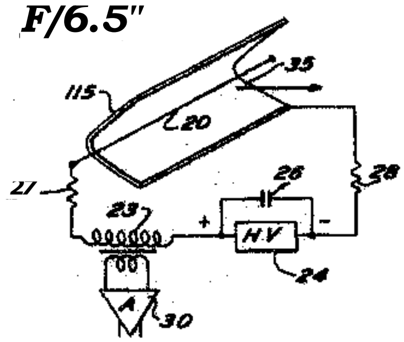

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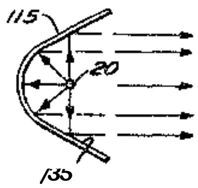
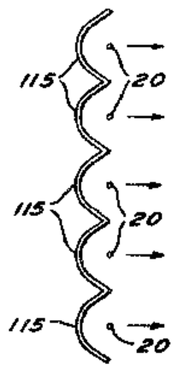
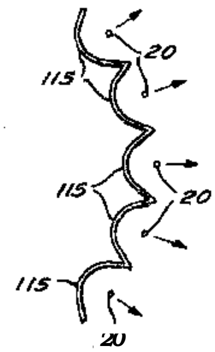


FIG. 6

FIG. 7 FIG. 8 FIG. 9





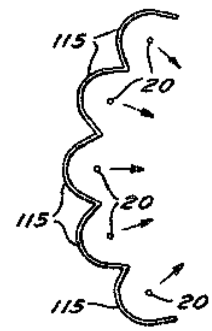


FIG. 10

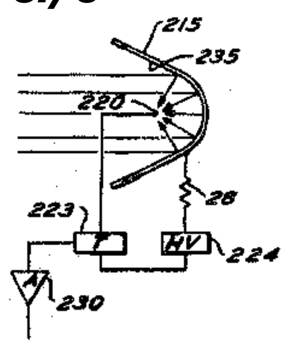
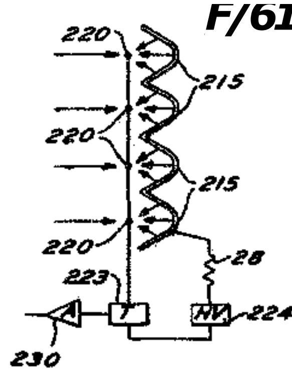


FIG. 11



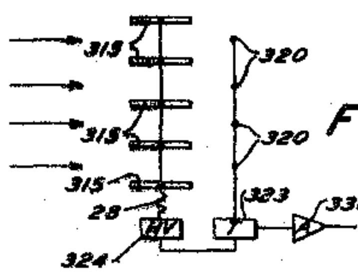


FIG. 12

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