Nov. 7, 1961 D. T. N. WILLIAMSON ET AL 3,008,013

ELECTROSTATIC LOUDSPEAKERS

Filed July 15, 1955 4 Sheets-Sheet 1

Fig. 1.

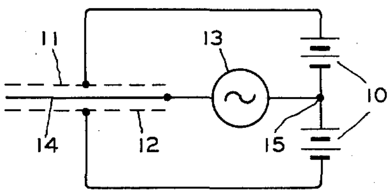

Fig. 2.

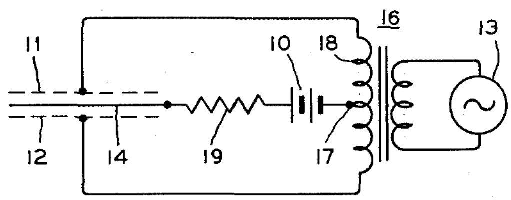

Fig. 3.

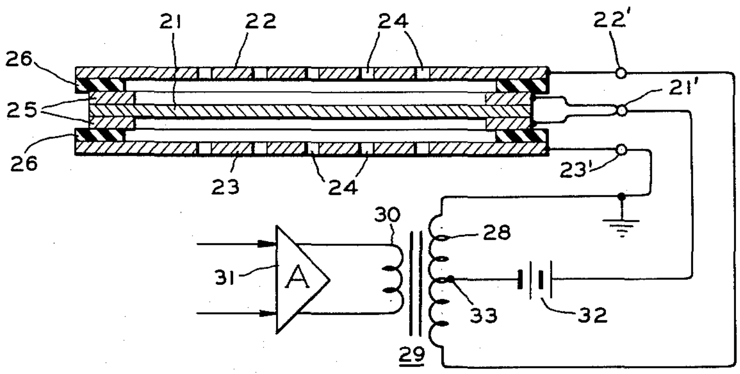

Fig. 4.

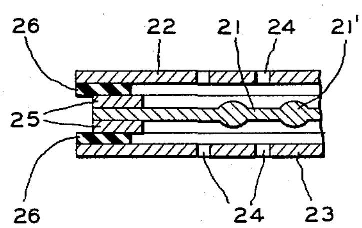

Fig. 5.

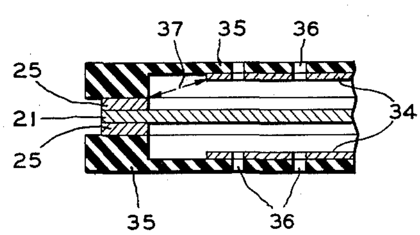

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FIG. 6.

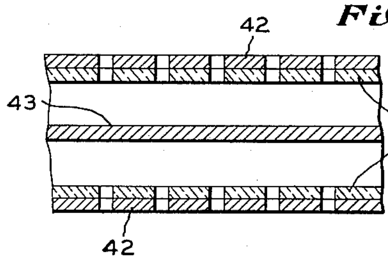

FIG. 7.

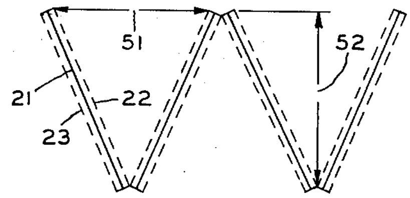

FIG. 8.

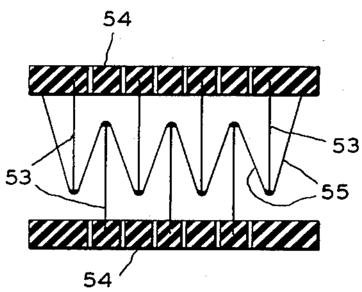

FIG. 9.

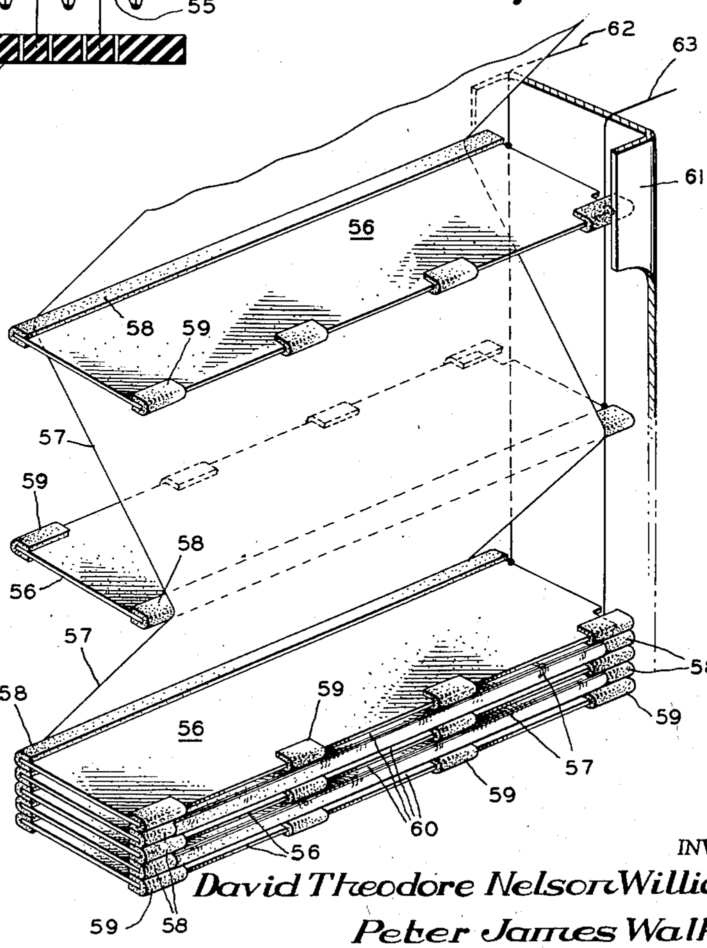

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Fig. 10.

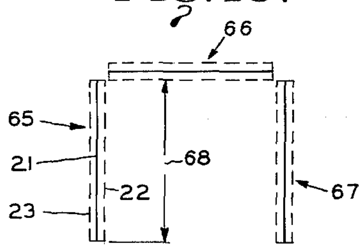

Fig. 12.

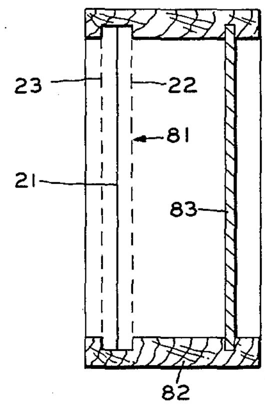

Fig. 11.

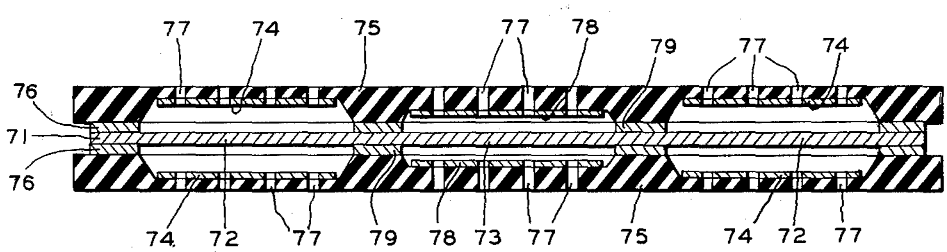

Fig. 13.

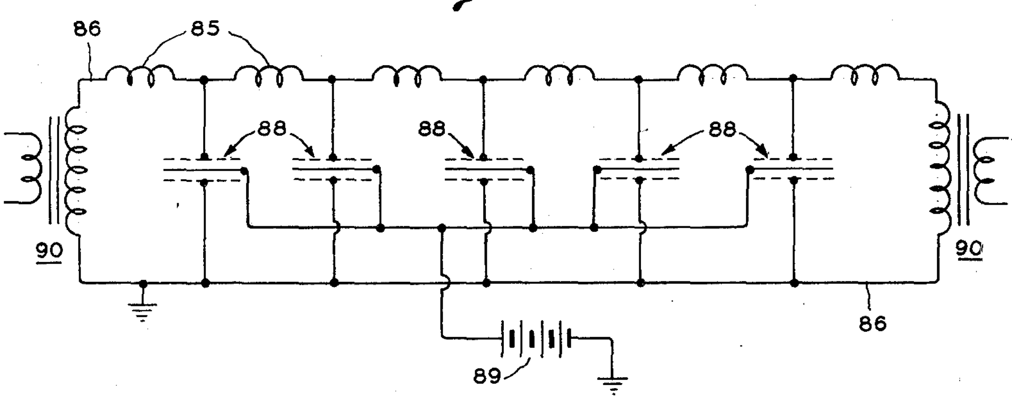

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Fig. 11a.

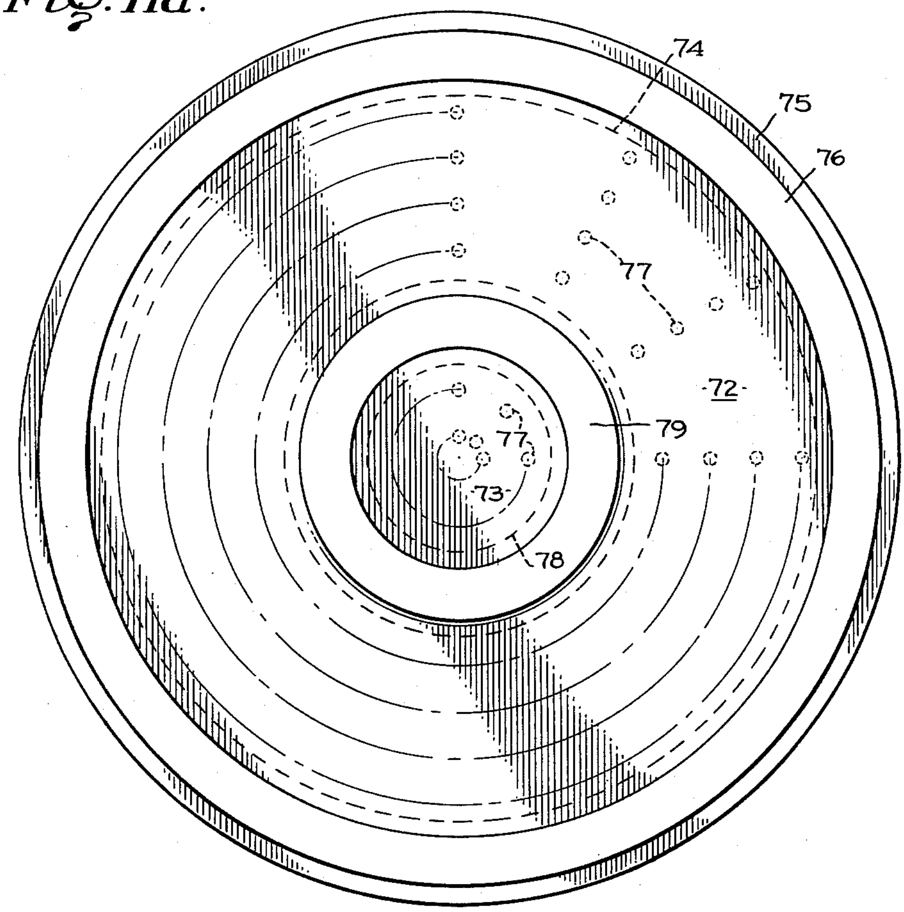
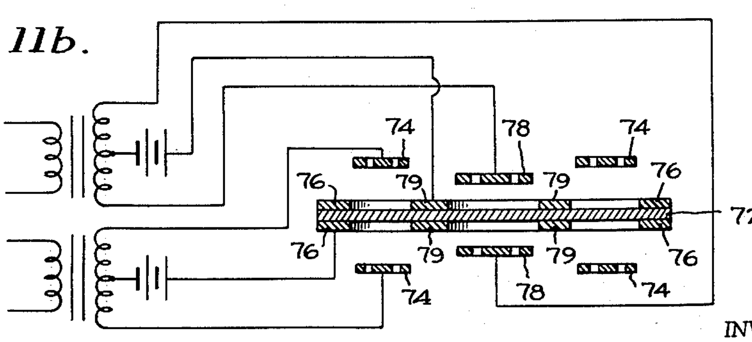


Fig. 11b.



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ELECTROSTATIC LOUDSPEAKERS

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Claims priority, application Great Britain July 20, 1954
10 Claims. (Cl. 179—111)

This invention relates to electrostatic loudspeakers, by which term is meant a loudspeaker which depends for its action on the force of electrostatic attraction between a movable or flexible diaphragm electrode and a rigid plate electrode secured closely parallel to it.

To reduce non-linear distortion it is usual to locate the diaphragm between two such fixed plate electrodes, one at least of which may be perforated or may be of lattice construction to allow motion of air through it.

To increase the sensitivity and avoid a frequency-doubling effect caused by attraction taking place on both halves of the signal waveform it is also usual to apply a steady polarizing voltage so as to maintain a biassing potential between the diaphragm on the one hand and each of the two fixed plates.

The polarizing and audio-frequency signal voltages may be applied in either of two ways:

(1) The positive terminal of the polarizing source **10** (see FIGURE 1 of the accompanying drawings) is connected to one fixed plate **11** and the negative terminal to the other fixed plate **12**, the signal voltage from a source **13** being applied between the diaphragm **14** and the point **15** of mid potential of polarizing source **10**; or

(2) The signal voltage from source **13** is applied by way of a transformer **16** (see FIG. 2) to the fixed plates **11** and **12** and the polarizing voltage **10** is applied between the diaphragm **14** and a centre tap **17** on the transformer secondary **18**.

For good sensitivity the polarizing voltage should be high, and difficulty has been experienced with known arrangements of the above-described kinds through the tendency of a spark discharge to occur between the diaphragm and the plates.

With arrangement (2), the damaging effect of such a discharge may be reduced by inserting a resistance **19** (see FIG. 2) of high value in the connection between the polarizing source **10** and the diaphragm **14**; this resistance has the effect of preventing the full polarizing voltage from being applied continuously once a spark current develops but does not prevent a spark from occurring. With loudspeakers of all but the smallest size, however, this arrangement is not satisfactory because the capacitive charge stored in the loudspeaker is considerable and sufficient in itself to cause damage if a spark should occur.

With arrangement (1), the insertion of resistance large enough to prevent sparking is not practicable because all connections carry the signal currents and the presence of such a resistance would increase the time-constant of the circuit too much.

An object of the present invention is to provide an improved electrostatic loudspeaker.

Another object is to provide an electrostatic loudspeaker with improved linearity.

Another object is to provide an electrostatic loudspeaker which allows the application of a high polarizing potential to the diaphragm electrode without causing injurious sparking to occur in operation between it and the fixed plate electrodes.

As electrostatic loudspeaker units in accordance with the invention have characteristics which make them suitable for combination in arrays, another object is to provide an array of such units.

A further object is to provide a loudspeaker stage including at least one electrostatic loudspeaker unit having improved linearity, which stage is adapted for the application of a high polarizing potential at the diaphragm electrode of the unit without causing injurious sparking to occur in operation between it and the fixed plate electrodes.

In the accompanying drawings,

FIGURES 1 and 2 are schematic diagrams of known arrangements of electrostatic loudspeakers,

FIGURE 3 shows an electrostatic loudspeaker stage in accordance with one embodiment of the invention, in part as a schematic diagram and in part as a section through a loudspeaker unit, the thickness of the components being considerably exaggerated for clarity,

FIGURES 4 and 5 show to an enlarged scale parts of FIGURE 3 but to a modified construction,

FIGURE 6 shows a section through a part of a loudspeaker unit in accordance with another embodiment.

FIGURES 7 and 8 are sectional views of arrays of loudspeaker units in accordance with the invention,

FIGURE 9 is a view in perspective of another array, partly in expanded form,

FIGURES 10 and 11 are sectional views of two other arrays,

FIGURE 11*a* is a plan view of the composite array of FIGURE 11 with the upper plate electrode structure removed,

FIGURE 11*b* is a schematic diagram of the energizing circuitry of the loudspeaker stage of FIGURE 11,

FIGURE 12 is a sectional view through another embodiment,

and FIGURE 13 is a schematic diagram of a further embodiment.

In carrying out the invention in accordance with one form by way of example, an electrostatic loudspeaker includes a number of loudspeaker units each of which comprises a flexible diaphragm **21** (see FIG. 3) of resistive sheet material such as a plastic of suitable resistivity or coated to have suitable resistance—for example nylon—the sheet being sandwiched between two closely-parallel plates **22** and **23** which can be of metal or conductive material or conductively coated material or of conducting material with an insulating sheath depending on constructional and operating requirements. The size of the units is determined either by constructional requirements or by acoustic loading requirements of that particular radiating area. By way of example a rectangular unit of 6" x 6" size might form part of a larger area of similar units, or on its own would be suitable for radiating medium and high audio frequencies. Suitable values of the resistance of the diaphragm will be discussed later, in which discussion it is to be understood that reference is being made to the electrical surface resistance of the diaphragm, rather than to its volume resistivity. Plates **22** and **23** are thick enough to be rigid and both of them are perforated, as depicted at **24**, to provide apertures for the emission of sound waves and prevent "cushioning" of the vibration. The diaphragm is secured in tension by being clamped throughout its periphery between peripheral conductive members in the form of metal strips or foils **25**. These strips are themselves clamped between plates **22** and **23**, strips **26** of polythene or other convenient insulating material being interposed between strips **25** and the plates to ensure that the diaphragm is insulated from the plates.

Conductive strips **25** should extend inwards, as shown in the drawing, beyond insulation strips **26** to prevent any leakage between the diaphragm and the plates which would cause a voltage drop across a free part of the diaphragm, for such a voltage drop would prevent the full polarizing voltage from appearing on the diaphragm and would render the performance of the loudspeaker unit unpredictable. The spacing between the diaphragm and the plates is sufficient to allow free vibration of the diaphragm at the maximum amplitude required. Suitable terminals 22' and 23' are provided in electrical connection with the plates and a further terminal 21' connected to the conductive strips 25 and hence to the diaphragm. The units may be assembled side by side with the outer surfaces of the perforated plates coplanar. Other possible assemblies will also be discussed later.

The two plate terminals 22' and 23' of each unit are connected respectively to the ends of the secondary winding 28 of a signal output transformer 29 common to all the units the primary winding 30 of which is energized by the final stage 31 of signal amplification. Each unit is polarized by connecting a source 32 of high tension of several hundred volts per centimetre of spacing between the diaphragm terminal 21' and a centre tap 33 on transformer secondary 28; as a safety precaution the more accessible of the two plates, plate 23, say, is connected to earth.

Provided the charge on the diaphragm is substantially incapable of changing during the period of one half cycle of the lowest frequency being handled, a simpler method of connection may be adapted, and the polarizing supply may be returned to either end of the transformer secondary 28 instead of to the centre tap 33.

The electrical resistance of diaphragm 21 is determined by three considerations. In the first place the resistance must be high enough to maintain substantially constant any charge carried by any elemental area of either side of the diaphragm when the diaphragm is vibrating at an audio frequency.

This reduces non-linearity due to the quadratic nature of the forces which are involved if the diaphragm potential is fixed. Due to the fact that in any practical loudspeaker the diaphragm does not operate as a rigid piston because of the necessity for supporting members and because acoustic impedances are not always uniformly distributed over its area, the same degree of improvement is not obtainable by the insertion of resistance external to a conducting diaphragm.

The resistance must also be high enough to prevent injurious sparking in normal operation. So that if a spark should tend to occur between a small area of the diaphragm and one of the plates, the discharge current flowing in the areas of the diaphragm adjacent to the discharging area causes the potential of the discharging area to be reduced below the value required to maintain the discharge. Only a very small charge is dissipated before the voltage becomes thus reduced and the spark is accordingly rendered harmless.

Thirdly, the upper limit to the value of the resistance is determined by the necessity of allowing the polarizing charge to spread uniformly across the diaphragm. Resistance values of the order of several hundred megohms per unit square are found to satisfy all these requirements in loudspeakers of normal size; resistance values of the order of several thousand megohms may however be used. As used herein, the term "megohms per unit square" has reference to the electrical surface resistance of sheet material the resistive nature and surface condition of which are such that much of the current flow therethrough is across the surface of the sheet, and means the electrical resistance presented by such sheet material to the flow of current from edge to edge across the surface of a square sheet, which resistance is independent of the actual dimensions of the sheet.

The upper limit to the value of the polarizing potential is determined by the onset of ionization in the spaces between the diaphragm and the plates; which will occur at approximately 70 volts per mil of the space between either plate and the diaphragm.

It will be noticed that the energizing system is that of arrangement (2) (FIG. 2), previously mentioned, that is, the AF currents which energize each unit flow only in the outer electrodes; a diaphragm resistance that is high enough to satisfy the requirements indicated above is far too high for the diaphragm to take the AF currents—in accordance with arrangement (1)—without considerable attenuation and distortion.

The use of the conductive strips 25 is rendered advisable because of the high resistivity of the diaphragm. If the polarizing potential were to be applied at a point or at a few points on the periphery of the diaphragm and the intervening portions of the periphery were separated from the plate electrodes merely by the insulation strips 26, the leakage through the latter from the diaphragm would prevent the diaphragm from being uniformly charged. The insertion of conductive strips between the diaphragm and the insulating supports removes these leakage paths from the high-resistance diaphragm itself and transfers the leakage directly on to the power supply where it need cause no embarrassment.

Where the diaphragm area is small compared with the wavelength radiated, the frequency response may be equalized by loading parts of the diaphragm either by thickening or by adding button-shaped portions of other material, in each case as depicted at 21' in FIG. 4. At the higher frequencies these loaded parts remain relatively stationary and vibrational displacement occurs mainly in the intermediate areas of low mass, from which areas effective treble radiation takes place. At the lower frequencies the diaphragm vibrates as a whole, the increased mass lowering the bass resonance frequency.

In the construction of FIG. 3 there is some wasteful capacitance in areas not contributing to sound output. These areas are constituted in effect by the plates 22 and 23 on the one hand and the conductive strips 25, the insulation 26 acting as the dielectric. To prevent such loss the modified construction shown in FIG. 5 may be employed.

In this construction the plate electrodes are in the form of metallized areas 34 carried on the inner surfaces of rigid sheets of insulation 35 between the peripheries of which are clamped the conductive strips 25 and diaphragm 21, which components may be as already described with reference to FIG. 3. Components 34 and 35 are perforated, as depicted at 36, for emission of sound. The metallized areas 34 stop short of the diaphragm periphery so that no portions of the plate electrodes constituted by these areas are in register with the conductive strips 25. There is accordingly less capacitive loss in areas not usefully constituting to sound output.

The distance 37 between the periphery of each metallized area 34 and the inner periphery of the strip 25 on the same side of the diaphragm should be great enough to prevent an ionizing discharge but short enough for a fringing field to be established to the furthermost limit of the free diaphragm.

In electrostatic loudspeakers where the signal is applied between the fixed plates, conditions of operation are occasionally such that the voltages applied are sufficiently high to cause sparking between the fixed plates through the diaphragm. This damages the diaphragm and is acoustically unpleasant. Although it is possible to prevent this by sheathing the fixed plates in insulating material, practical difficulties are experienced in the production of perforated sheathed electrodes in keeping the sheathing continuous.

By the use of a perforated dielectric shield 41 (see FIG. 6) of high permittivity placed between each fixed electrode 42 and the diaphragm 43, the field conditions may be arranged to preserve the field strength in the major portion of the air gap, and therefore not substantially to alter the operating conditions of the loudspeaker. By doing this, however, the distance between the fixed electrodes has been increased and the field strength in the air between the conducting surfaces through the perforations substantially reduced. In order to maintain the polarizing field in the gap, and to prevent the dielectric shield **41** acquiring a charge, the material of the shield should have sufficient conductivity and be in electrical contact with the adjacent fixed electrode.

Electrostatic loudspeaker units in accordance with the invention have characteristics which make them suitable for combination in arrays. Some arrays of such units will now be briefly considered.

Where economy of space is to be considered, the units may be arranged in a zig-zag formation, as shown in FIG. 7. Since a considerable area of each diaphragm is effective in moving the air through the relatively small exit port **51** of each V-shaped cavity, quite a large amplitude of vibration is produced there by quite a small amplitude of vibration of the diaphragm. Because of this it is possible to reduce the spacing between the diaphragm and the plate electrodes and to employ a lower polarizing voltage and signal voltages, facilitating the design of the output transformer. The depth **52** of each V-shaped cavity should not be substantially greater than a quarter of a wavelength of the highest frequency to be radiated.

Where only a small space is available—for instance where the loudspeaker is part of a domestic radio receiver—the zig-zag formation may be used in the modifier form shown in FIG. 8. The electrodes **53** are stacked in parallel with each other by two frames **54** of insulating material, the arrangement being such that adjacent plates have opposite edges free. The spacing between electrodes is shown much exaggerated. The diaphragm **55** takes the form of a continuous sheet which interleaves the fixed plates in a zig-zag manner, passing over each of the free edges in turn, each edge being insulated where the diaphragm passes over it. Each plate **53** (except the two outermost plates at the ends of the stack) thus serves as the outer electrode of two adjacent loudspeaker units. The supporting frames **54** are designed to allow the emission of sound waves from between consecutive electrode plates; the latter accordingly need not be perforated. Since each plate (except the two outermost) forms part of two units it is subjected in operation to equal and opposite electrostatic forces and hence need not be of great rigidity; each plate may accordingly be in the form of a sheet of non-conducting material the surfaces of which carry a metallic coating.

In a development of the foregoing arrangement (see FIG. 9) the stack of fixed plates may be self supporting, instead of being supported by frames. Each plate **56** rests on the plate beneath, as depicted in the lower part of the drawing, with a portion of the diaphragm **57** intervening. As with the embodiment of FIG. 8, the diaphragm is again in the form of a single sheet, being separated by insulation **58** where it passes over the edge of a plate; this is clearly depicted in the upper part of the drawing, where two of the plates are shown widely spaced apart to reveal the method of construction. The edge of each plate opposite to that over which the diaphragm passes has several short strips **59** of insulation folded over it at widely spaced intervals to insulate the plate from the diaphragm where it passes over the edges of the plates on each side and to maintain a space between consecutive plates to allow vibration of the diaphragm.

The sound waves issue through the gaps **60** between the spaced strips **59** of insulation. The assembly is retained in position by two vertical U-shaped channels which contain the respective ends of the plates. One of these is shown at **61**, the other being omitted for clarity. Connections from alternate plates are made to a lead **62**, contained in channel **61**, the intervening plates being connected to another lead **63**.

If in a large composite loudspeaker the frequency range is divided and applied to separate sections of the whole

area, then it is possible to arrange matters so that the depth of a complete folded loudspeaker is no longer limited by the quarter-wavelength restriction previously mentioned. By way of example, a complete loudspeaker can be folded as in FIG. 10, so as to have two side panels **65** and **67** and a rear panel **66**. If the two side panels **65** and **67** are arranged to handle low frequencies only, then the dimensions can be arranged so that acoustic resonances which would normally be associated with the cavity depth **68** occur at frequencies above the upper frequency limit of the side panels. Since these side panels are not themselves producing energy at the resonance frequencies concerned and are of low mechanical impedance it follows that they are acoustically transparent and the complete system behaves as if there were no resonant enclosure.

Although in the foregoing descriptions the applications of the invention have been confined to individual units, such applications are by no means so restricted. By way of example, FIG. 11 shows a diametrical section through a circular composite unit, with the thicknesses of the components again exaggerated, while FIG. 11*a* is a plan view of the same unit with the upper plate electrode structure removed so as to show the concentric arrangement of the diaphragm electrodes. The circular diaphragm **71** is rendered conductive over two separate portions, an annular portion **72** for lower-frequency reproduction, and concentric with it a circular portion **73** for upper-frequency reproduction; in effect, therefore, two separate diaphragm electrodes **72** and **73** are provided.

The corresponding plate electrodes are similar to the kind already described with reference to FIG. 5. Those associated with diaprhagm electrode **72** are in the form of annular metallic films **74** carried on the inner surface of rigid discs **75** of insulation. Annular conductive strips **76** are employed as before to apply the high potential to the periphery of diaphragm **72**. Perforations **77** are formed through discs and films for the emission of sound.

The plate electrodes associated with diaphragm **73** are in the form of circular metallic films **78** also carried by discs **75**. Annular conductive strips **79** engage the periphery of diaphragm **73**. Discs **75** are so moulded that films **78** are located nearer the associated diaphragm **73** than are films **74** to the associated diaphragm **72**, since the latter requires a greater amplitude of vibration. These different spacings require the application of different polarizing potentials; no difficulty is experienced in applying these since conductive strips **76** and **79** are electrically independent.

The polarizing and audio-frequency signal voltages may be applied to each of the two units of the composite array shown in FIGS. 11 and 11*a* in a manner similar to that illustrated in FIG. 3. As shown in FIG. 11*b*, the two plate electrodes **74** of the outer annular unit are connected respectively to the ends of the secondary winding of a lower-frequency signal output transformer, while the two plate electrodes **78** of the circular unit are similarly connected to the ends of the secondary winding of an upper-frequency signal transformer. Each unit is individually polarized by connecting a source of high tension between at least one each of conductive strips **76** or **79** and a centre tap on the secondary of the associated signal output transformer.

Where the diaphragm electrode is small compared with the wavelength radiated the frequency response may be equalized by mounting the loudspeaker unit **81** (see FIG. 12) as the front closure member of a shallow box **82** the back closure member of which is a stretched membrane **83** of thicker material than the diaphragm electrode of the unit. At the higher frequencies the diaphragm vibrates alone, the backward radiation being cushioned by the air in the box without causing appreciable vibration of the membrane because of the latter's greater mass. At the lower frequencies the diaphragm and the membrane together with the air enclosed between them vibrate as a whole; the mass of the air and the mass of the membrane are thus effectively added to the mass of the diaphragm and so reduce the bass resonance frequency.

A stereophonic two-channel sound system with novel acoustic properties may be attained from an array of spaced units by arranging them for AF energization as the consecutive elements of a delay line, which itself is energized at each end by signals derived from different channels.

By way of example a number of units may be mounted side by side across the wall of a room each unit being coupled to the adjacent unit by a suitable inductor. If a signal is now fed in at one end of this structure, which forms a delay line, there will be a time delay in the electrical signals applied to the loudspeaker surface across the room. It follows that the wavefront of the sound will no longer be parallel with the loudspeaker diaphragm, but will be tilted. A separate signal fed into the other end of the delay line will produce a wavefront of the same tilt but in the opposite direction. Since the perceived direction of a source of sound is always perpendicular to the wavefront it follows that the observer will perceive two sound sources the aspect angle of which is constant and entirely independent of the listener's position over a large area. Such an arrangement is shown in FIG. 13. The delay line is formed by connecting together in series an appropriate number of inductors **85** to form a series path **86** and interconnecting opposite points on the path by way of the plate electrodes of loudspeaker units **88**, which accordingly act as shunt capacitors. The diaphragm electrodes are connected in parallel to one pole of a source **89** of high potential the other pole of which is earthed. Incoming signals are applied by way of transformers **90** to the ends of the line, these signals being derived from appropriately spaced microphones (not shown) at the transmitting station.

The series inductors **85** need not be separate components. The plate electrodes of each unit **88** may themselves be made inductive—for example, by being formed of spiral conductive tracks sprayed on perforated insulating plates, the perforations lying in between the turns of the spiral coil.

A true binaural effect may be achieved, in a loudspeaker of large total area with its units mounted in side-by-side relationship across an auditorium, by scanning the units horizontally, and if necessary vertically, in synchronism with a similar scanning of an array of microphones at the transmitting studio. Scanning may be accomplished electronically or by a simple rotating selector switch.

In such a case there is reproduced in the auditorium a replica of the sound waves passing through a plane in the concert hall.

This feature of an electrostatic loudspeaker of large total area is of importance in cinema applications, especially where the radiating surface forms the screen on which the picture is projected. For this purpose the outside surface of one of the perforated plates of the loudspeaker may be treated with reflecting beads in the manner of a cinema screen, or preferably embossed with a pattern of small lenses calculated to give the correct light distribution.

What we claim is:

1. A loudspeaker stage comprising a composite array of at least two electrostatic loudspeaker units each having two rigid outer plate electrodes in close parallel relationship, an individually vibratable diaphragm electrode of flexible sheet material having a high electrical surface resistance located between and spaced from said plate electrodes, and means for insulating said diaphragm electrode from said plate electrodes, driving means for applying audio-frequency signals to the plate electrodes of each of said units, the frequencies of the signals applied to the plate electrodes of one of said units being higher

than those applied to the plate electrodes of a second unit, thereby producing a difference in the amplitudes of vibration of said diaphragm electrodes, the spacing between the diaphragm electrode and the associated plate electrodes of said second unit being greater than the spacing between the diaphragm electrode and the associated plate electrodes of said first-named unit so as to permit free vibration of each diaphragm electrode at the maximum amplitude produced by the audio-frequency signals applied to the associated plate electrodes, and means for continuously applying to said diaphragm electrodes polarizing voltages differing in accordance with the differences in said spacings, the electrical surface resistance of each of said diaphragm electrodes being of the order of from several hundred to several thousand megohms per unit square, said resistance being such as to maintain substantially constant any electrostatic charge carried by any elemental surface area of said diaphragm electrode despite changes of capacitance when the diaphragm electrode is subjected to audio-frequency vibration, and to allow sufficient current to flow in the surface of said diaphragm electrode from said voltage applying means to maintain a substantially uniform electrostatic charge thereon despite leakage due to ionization.

2. A loudspeaker stage comprising a composite array of at least two electrostatic loudspeaker units arranged in concentric relationship and each having two rigid outer plate electrodes in close parallel relationship, an individually vibratable diaphragm electrode of flexible sheet material having a high electrical surface resistance located between and spaced from said plate electrodes, and means for insulating said diaphragm electrode from said plate electrodes, the diaphragm electrodes of said units being formed by individually vibratable portions of a continuous diaphragm separated from one another by other portions of the same diaphragm which are fixed relative to the plate electrodes of said units, driving means for applying to the plate electrodes of each of said units audio-frequency signals within a frequency band individual to that unit, the frequencies of the signals applied to the plate electrodes of one of said units being higher than those applied to the plate electrodes of a second unit, and means for continuously applying a polarizing voltage to the diaphragm electrode of each unit with respect to the plate electrodes of the same unit, the electrical surface resistance of each of said diaphragm electrodes being of the order of from several hundred to several thousand megohms per unit square, said resistance being such as to maintain substantially constant any electrostatic charge carried by any elemental surface area of said diaphragm electrode despite changes of capacitance when the diaphragm electrode is subjected to audio-frequency vibration, and to allow sufficient current to flow in the surface of said diaphragm electrode from said voltage applying means to maintain a substantially uniform electrostatic charge thereon despite leakage due to ionization.

3. A loudspeaker stage comprising a composite array of a central electrostatic loudspeaker unit and at least one additional electrostatic loudspeaker unit surrounding and substantially coplanar with said central unit, each of said units having a pair of outer plate electrodes and a diaphragm electrode of flexible material located between and spaced from said plate electrodes, a pair of rigid members of insulating material disposed in parallel relationship on opposite sides of said diaphragm electrodes and having inwardly projecting annular ribs between which are fixed the peripheral portions of said diaphragm electrodes, said plate electrodes being carried by the inner surfaces of said rigid members within said ribs and insulated thereby from said diaphragm electrodes, and a member of good electrical conductivity in contact with the peripheral portion of each of said diaphragm electrodes through which a polarizing voltage may be applied to the associated diaphragm electrode.

4. A loudspeaker stage as claimed in claim 3 wherein the diaphragm electrodes of said units are formed by individually vibratable portions of a continuous diaphragm.

5. A loudspeaker stage as claimed in claim 3 wherein the spacing between the plate electrodes and the diaphragm electrode of the unit in the center of said concentric array is less than the spacing between the plate electrodes and the diaphragm electrode of the surrounding unit.

6. A loudspeaker stage comprising a composite array of electrostatic loudspeaker units folded so as to present two side panels and one rear panel, each of said units having two rigid outer plate electrodes in close parallel relationship, an individual vibratable diaphragm electrode of nylon located between and spaced from said plate electrodes, and means for insulating said diaphragm electrode from said plate electrodes, driving means for applying to the plate electrodes of each of said side panel units audio-frequency signals in only a lower frequency band, additional driving means for applying to the plate electrodes of said rear panel unit audio-frequency signals in only a higher frequency band, and polarizing means for maintaining an electrostatic charge on each of said diaphragm electrodes with respect to the plate electrodes of the associated unit, whereby the side panels are acoustically transparent and the loudspeaker behaves as if there were no resonant enclosure.

7. A loudspeaker stage comprising a composite array of electrostatic loudspeaker units each having two rigid outer plate electrodes in close parallel relationship, an individually vibratable diaphragm electrode of nylon located between and spaced from said plate electrodes, and means for insulating said diaphragm electrode from said plate electrodes, means for applying to the plate electrodes of each of said units audio-frequency signals within a frequency band individual to that unit, the frequencies of the signals applied to the plate electrodes of one of said units being higher than those applied to the plate electrodes of a second unit, and means for con-

tinuously applying a polarizing voltage to the diaphragm electrode of each unit with respect to the plate electrodes of the same unit.

8. A loudspeaker stage as claimed in claim 7 wherein the loudspeaker units are of rectangular shape and are assembled in a zig-zag formation.

9. A loudspeaker stage as claimed in claim 7 wherein the loudspeaker units are stacked with all of their plate electrodes parallel and with their diaphragm electrodes in the form of a continuous sheet which interleaves the plate electrodes in a zig-zag manner.

10. A loudspeaker stage as claimed in claim 7 wherein the loudspeaker units are arrayed in side-by-side relationship and which includes means connecting the respective pairs of plate electrodes of said units for audio-frequency energization as consecutive shunt elements of a delay line, and means for energizing said delay line at each end by audio-frequency signals derived from different channels, whereby a binaural effect is attained.

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