ELECTROSTATIC LOUDSPEAKERS

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FIG. 1.

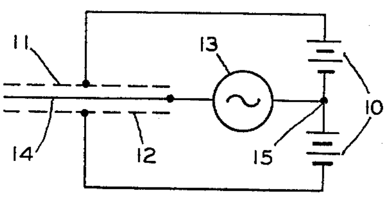


FIG. 2.

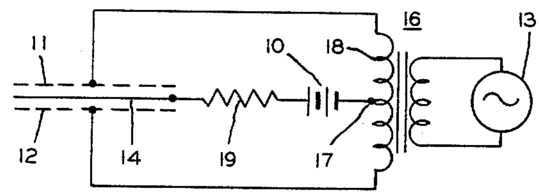


FIG. 3.

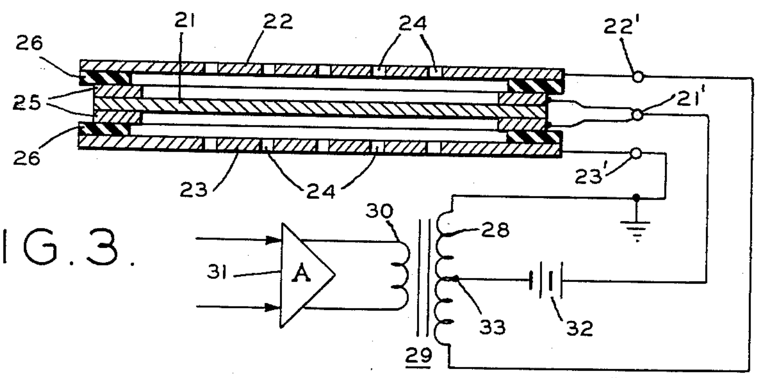


FIG. 4.

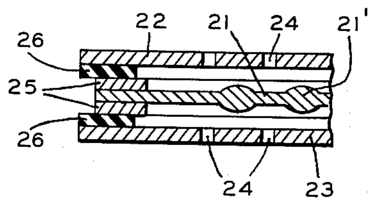


FIG. 5.

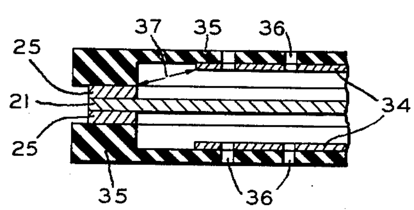


FIG. 6.

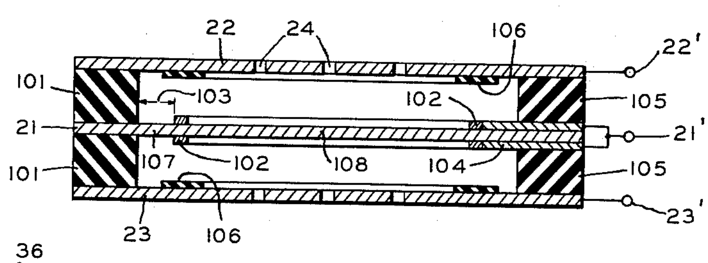
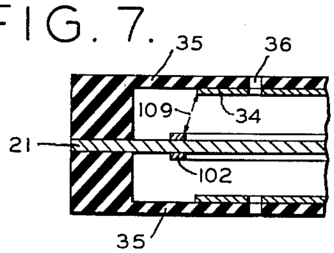


FIG. 7.



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Nov. 7, 1961 D. T. N. WILLIAMSON ET AL 3,008,014

ELECTROSTATIC LOUDSPEAKERS

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FIG. 10.

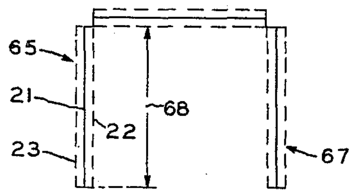


FIG. 12.

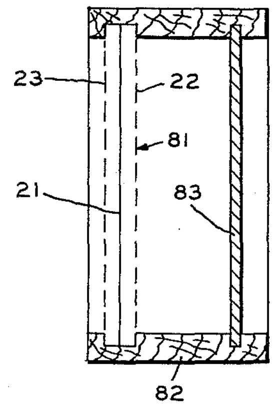


FIG. 11.

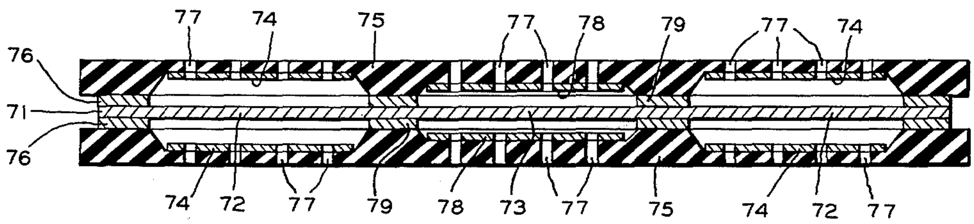


FIG. 8.

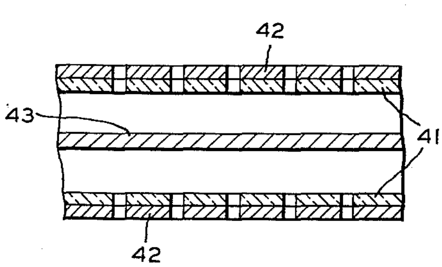
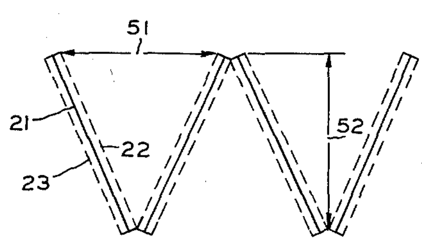


FIG. 9.



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ELECTROSTATIC LOUDSPEAKERS

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Claims priority, application Great Britain, July 20, 1954
17 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.

This application is a continuation-in-part of each of copending applications Serial Nos. 522,354 and 616,856, now abandoned filed July 15, 1955 and October 18, 1956, respectively.

To reduce non-linear distortion in electrostatic loudspeakers it is usual to locate the diaphragm between two 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 FIG. 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.

Another object is to provide a loudspeaker unit of the character described wherein a minimum of high-grade insulating material is required.

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 are fragmentary sectional views of two modifications of the construction of FIGURE 3.

FIGURES 6 and 7 are sectional views of further modifications of the loudspeaker units shown in FIGURES 3 and 5, respectively.

FIGURE 8 shows a section through a part of a loudspeaker unit in accordance with another embodiment.

FIGURES 9, 10 and 11 are sectional views of various arrays of loudspeaker units in accordance with the invention, and

FIGURE 12 is a sectional view of still another embodiment of the invention.

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″x6″ 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 drawings, 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'** is 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 adopted, 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 and must be low enough to allow sufficient current to flow to maintain the electrostatic charge despite leakage from the central part of the diaphragm through the air by ionization. A resistance value of 1000 megohms per unit square has been found to satisfy all these requirements in loudspeakers of normal size; however, resistance values ranging from several hundred megohms to several thousand megohms per unit square may 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 audio-frequency 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 audio-frequency 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 were 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 trebel 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 contributing 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 the modified form of the invention shown in FIG. 6, the loudspeaker unit includes a diaphragm electrode **21** of resistive sheet material secured by being clamped between parallel-plate electrodes **22** and **23**, with strips **101** of comparatively low-grade insulation interposed, similar to the arrangement disclosed in FIG. 3. In the present arrangement, however, the conductve strips **25** of FIG. 3 are omitted and the insulation **101** is of a comparatively low grade instead of being of a comparatively high grade.

In place of the conductive strips **25** of FIG. 3, there are provided conductive strips **102**, which are adherently in contact with a free part of the diaphragm **21** adjacent to the peripheral part where the diaphragm is secured between strips 101. Strips 102 may be "printed" on the diaphragm or may be in the form of graphite-pencilled tracks. Each strip should extend, parallel to the adjacent fixed periphery of the diaphragm and displaced inwardly from it by a distance 103 of the order of one eighth of an inch (shown much exaggerated in the drawing), throughout the peripheral region of the diaphragm. It is not essential that there should be two such strips, one on each side of the diaphragm, since a single strip on one side only of the diaphragm may be sufficient.

The polarizing voltage is applied to strips 102 by way of metallized strips or lines 104 extending outwards through high-grade portions of insulation 105 at some convenient point.

To prevent flashover between strips 102 and those portions of the inner surfaces of plates 22 and 23 in register with them, shielding strips 106 of insulation are interposed, being secured to the inner surface of the plates.

Except that the potential for the diaphragm electrode is applied by way of strips 102 instead of by way of strips 25 as in FIG. 3, the loudspeaker operates in a similar manner to that above described.

The necessary high-grade insulation between the diaphragm electrode 21 and plates 22 and 23 is provided to a large extent by that portion 107 of the diaphragm material between the free part to which strips 102 adhere and the part secured between strips 101. The strips 101 therefore serve mainly to insulate the plates 22 and 23 from one another and may therefore, as already stated, be of low-grade insulation except where at 105 the high voltage conductors 104 pass through. A considerable saving of high-grade insulating material is thereby effected.

That portion 108 of the diaphragm material enclosed within strips 102 may be treated to render it slightly more conductive than the portion 107 outside the strips which acts largely as insulation for the diaphragm. It should however be understood that it is not essential to treat the diaphragm in this way, for the diaphragm material may be of uniform conductivity throughout. Any slight leakage across the portion 107 acts merely as a small extra load in the high-tension supply and does not seriously reduce the diaphragm potential.

Shields 106 are not required where the loudspeaker is of the type disclosed in FIG. 5, so long as strips 102 are spaced sufficiently outwardly from the metallized areas 34 to prevent flashover. This arrangement is shown in FIG. 7 wherein the rigid sheets of insulation are shown at 35, the metallized areas at 34, the perforations through 34 and 35 at 36, and the diaphragm at 21 as in FIG. 5. Strips 102 again replace strips 25 of FIG. 5, the distances 109 between strips 102 and the nearest points on areas 34 being sufficient to prevent flashover. A low-grade insulation may again be used for the main insulation 35 between the plate electrodes, thereby again economizing in high-grade insulation.

It should be understood that the term "diaphragm electrode" or "diaphragm," as used above and in the claims in connection with the embodiments of FIGS. 6 and 7, refers not merely to that part of the diaphragm within the strips 102 but to the entire sheet of flexible material extending inwards from, and including, the clamped peripheral portion.

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. 8) 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 folded or zig-zag formation, as shown in FIG. 9. 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 thereby 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.

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 just 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. 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 diaphragm 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.

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 mass of the membrane are thus effectively added to the mass of the diaphragm and so reduced the bass resonance frequency.

It will be understood that the loudspeaker units of the folded arrays of FIGS. 9 and 10 and that of the box arrangement of FIG. 12 may correspond in structure to any of the embodiments of FIGS. 3–8.

What we claim is:

1. An electrostatic loudspeaker unit comprising two rigid outer plate electrodes in close parallel relationship, a vibratable diaphragm electrode of flexible sheet material having a high electrical surface resistance located between and spaced from said plate electrodes, means for insulating said diaphragm electrode from said plate electrodes, means for applying audio-frequency signals to said plate electrodes, and means for continuously applying a polarizing voltage to said diaphragm electrode with respect to said plate electrodes, the electrical surface resistance of said diaphragm electrode 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 unit as claimed in claim 1 wherein portions of the diaphragm electrode are loaded in such manner as to improve the bass response.

3. A loudspeaker unit as claimed in claim 1 wherein the plate electrodes are perforated for the emission of sound waves.

4. A loudspeaker unit as claimed in claim 3 including a perforated dielectric shield interposed between the diaphragm electrode and each plate electrode of sufficient conductivity to prevent the build-up of a charge thereon, said shield being in electrical contact with the adjacent plate electrode.

5. A loudspeaker unit as claimed in claim 1 wherein said voltage applying means includes a source of potential and a conductive member connected to said source and adherently in contact with a free part of the diaphragm electrode adjacent to a secured part thereof, the portion of the diaphragm material between said parts serving as at least some of the insulation between the diaphragm electrode and the plate electrodes.

6. A loudspeaker unit as claimed in claim 5 wherein said conductive member extends throughout the peripheral region of the diaphragm.

7. A loudspeaker unit as claimed in claim 6 wherein the diaphragm material enclosed within said conductive member is more conductive than that portion of the diaphragm material between the free and secured parts thereof.

8. A loudspeaker unit as claimed in claim 5 wherein a portion of the inner surface of at least one of said plate electrodes is in register with said conductive member, and including a shield of insulation interposed between said portion of the inner surface and said conductive member to prevent flashover.

9. A loudspeaker unit as claimed in claim 1 including a shallow box having the unit so mounted as to form the front closure member of said box, and a back closure member comprising a stretched membrane of thicker material than the diaphragm electrode of the unit, whereby lower bass resonance is attained.

10. An electrostatic loudspeaker unit comprising two rigid outer plate electrodes in close parallel relationship, a diaphragm electrode of nylon located between and spaced from said plate electrodes, means for insulating said diaphragm electrode from said plate electrodes, means for applying audio-frequency signals to said plate electrodes, and means for continuously applying a polarizing voltage to said diaphragm electrode with respect to said plate electrodes.

11. An electrostatic loudspeaker unit comprising a pair of rigid sheets of insulating material disposed in spaced parallel relationship, a diaphragm electrode of flexible material located between said rigid sheets and having its periphery clamped between the peripheral portions of said sheets, the central portion of said diaphragm electrode being spaced from the inner surfaces of the central portions of said sheets, a pair of outer plate electrodes carried by the inner surfaces of said sheets in spaced relationship to said diaphragm electrode, and at least one strip of conductive material in contact with and extending around the peripheral portion of said diaphragm electrode through which a polarizing voltage may be applied to said diaphragm electrode.

12. A loudspeaker unit as claimed in claim 11 wherein the peripheries of said plate electrodes are smaller than the peripheral portion of said diaphragm electrode with which said conductive strip is in contact, whereby no portions of said plate electrodes are in register with said conductive strip.

13. A loudspeaker unit as claimed in claim 11 wherein the peripheries of said plate electrodes are smaller than the clamped periphery of said diaphragm electrode, and said conductive strip is interposed between the clamped periphery of said diaphragm electrode and the peripheral portion of one of said sheets of insulating material.

14. An electrostatic loudspeaker unit comprising two rigid outer plate electrodes disposed in spaced parallel relationship, a vibratable diaphragm electrode of flexible sheet material located between and spaced from said plate electrodes, means for insulating said diaphragm electrode from said plate electrodes, means for applying audio-frequency signals to said plate electrodes, and means for continuously applying a polarizing voltage to said diaphragm electrode with respect to said plate electrodes, said last-named means including at least one member of good electrical conductivity in contact with and extending parallel to the periphery of said diaphragm electrode and insulated from both of said plate electrodes, the electrical surface resistance of said diaphragm electrode 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.

15. A loudspeaker unit as claimed in claim 14 wherein no portions of the plate electrodes are in register with said member of good electrical conductivity, whereby capacitive loss is reduced in areas not usefully contributing to sound output.

16. An electrostatic loudspeaker unit comprising a pair of rigid perforated sheets of dielectric material disposed

in spaced parallel relationship, a diaphragm electrode of flexible material located between said sheets and having its periphery clamped between the peripheral portions of said sheets, the central portion of said diaphragm electrode being spaced from the central portions of said sheets, a pair of perforated outer plate electrodes carried by said sheets in spaced relationship to said diaphragm electrode, and at least one strip of conductive material in contact with and extending around the peripheral portion of said diaphragm electrode through which a polarizing voltage may be applied to said diaphragm electrode.

17. A loudspeaker unit as claimed in claim 16 wherein said plate electrodes are carried by and in electrical contact with the outer surfaces of said rigid sheets, and said sheets are of sufficient conductivity to prevent the build-up of a polarizing charge thereon.

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