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## (54) IMPROVEMENTS IN OR RELATING TO ELECTROSTATIC LOUDSPEAKERS


(71) We, BOWERS & WILKINS ELECTRONICS LIMITED, a British Company of 34 Ship Street, Brighton, Sussex, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:


This invention relates to electrostatic loudspeakers and it is an object of the invention to provide an electrostatic loudspeaker which may be simply constructed and which is designed to have good acoustical properties.

The invention consists in an electrostatic loudspeaker including two perforated plates of substantially rigid electrically insulating material secured together in spaced relationship and each including a conductive surface on the side facing away from the other plate, a diaphragm of flexible insulating material coated with electrically resistive material being secured between said plates, and each of said conductive surfaces being perforated to correspond to the respective perforated plate but the diameter of each hole in each conductive surface being greater than the diameter, or the minimum diameter, of the corresponding hole in the respective plate.

It is to be understood that it will normally be desirable to combine a number of electrostatic loudspeaker elements in accordance with the invention to form a single unit, since it is difficult to design a single electrostatic loudspeaker element to provide a sufficient power output for normal requirements and, at the same time, to have good acoustical properties. Accordingly, each of the perforated plates will normally include a number of perforated areas separated by solid areas, the arrangement being such that the diaphragm is held stationary in the region of the solid areas of the plates but is free to move perpendicularly to its surface in the vicinity of the perforated areas.

This arrangement may be effected, for example, by increasing the thickness of the plates in the solid areas or by the provision of spacer strips in these areas. In either case it will be understood that a plurality of loudspeaker elements are formed each comprising a portion of diaphragm gripped between two plates at its edges but free to move at its centre. Furthermore, the central part of each portion of diaphragm corresponds to a perforated area of each plate so that the diaphragm is able to cause air movements and thus reproduce sounds.

Furthermore, it is difficult to design an electrostatic loudspeaker unit so that it is efficient over the entire audio frequency range and, accordingly, it will be usual to divide the frequency range into at least two, and preferably three, bands and allocate a separate loudspeaker to each band. Each of these loudspeakers may be constituted by a group of electrostatic loudspeaker elements in accordance with the invention but, if desired, one or more of these frequency bands may be reproduced by a conventional moving coil or other type of loudspeaker.

Preferably, the perforated plates with their conductive surfaces are produced by a printed circuit technique. For example, each plate may be manufactured from a sheet of copper bonded to an epoxy glass laminate, portions of the copper being etched away to produce a series of spaced metallic areas separated by non-metallic strips. Lines of metal are, however, left to provide electrical connections between the conductive areas and these lines lead to a connecting terminal point on each plate. After etching, the plates are drilled to provide a plurality of holes in each metallic area. Thereafter, metal is removed from a small area around each hole

so as to increase the arcing path between each metallic area and the diaphragm when the unit has been assembled. This removal of metal also has the effect of improving the acoustic properties of the element and controlling the behaviour of the diaphragm, particularly at high frequencies.

If desired, the metallic portions may be covered with insulating material, for example, by an encapsulating or dipping process, or merely by means of varnish spray.

The diaphragm preferably consists of a flexible sheet material of the order of 0.0004 inch thick. Polyvinyl chloride or polyvinylidene chloride in practice have been found suitable. It is required to render this diaphragm conductive and this resistance may be produced by application of various conductive materials or solutions containing the necessary agents which, when in a stable state, provide the desired degree of conductivity. Permanence of conductivity may be achieved by the method of application such as bonding with additional substances or by burnishing or by application of a partial solvent of the base material or by a combination of any of these processes. It is preferred that the conductivity lies within the range of $1\times10^{7}$ to $5\times10^{8}$ ohms per square inch.

Connection to the diaphragm may be made at more than one position to cover the situation whereby it is desired to increase the number of points at which the polarisation voltage is fed to this diaphragm.

Since electrostatic loudspeakers tend to be highly directional, it is preferred that the complete electrostatic loudspeaker in accordance with the invention should be curved in at least one plane. For example, a mid-range and/or high frequency range electrostatic loudspeaker may consist of a number of separate and suitable sized elements arranged vertically, the curved configuration being achieved by screwing the individual units to a wood or similar frame made to a required chord. Alternatively, the required number of separate units may be embodied in a single frame and secured to a support of the desired curvature.

An electrostatic loudspeaker in accordance with the invention may be connected to the output of an amplifier in accordance with the normal practice for electrostatic loudspeakers. However, it is desirable that the polarising voltage which is applied between the diaphragm and the conducting surfaces of the two plates should be derived from the acoustic output of the amplifier. In this connection, it has been found that it is unnecessary to provide a smoothed direct-current polarising voltage, since the capacitor constituted by the diaphragm and the plates can be charged rapidly and decays very slowly. Accordingly, if desired, the polarising voltage may be a pulse voltage or a voltage of irregular wave-form provided it is uni-directional.

Methods of performing the invention will now be described with reference to the accompanying diagrammatic drawings, in which:—

Figure 1 is a perspective view of a loudspeaker unit comprising a plurality of electrostatic loudspeaker elements in accordance with the invention, parts of the unit being broken away to show the interior of the unit;

Figure 2 is a front view of a part of the unit illustrated in Figure 1 on an enlarged scale, parts of the unit again being broken away to indicate details not visible from the front of the unit;

Figure 3 is a rear view of the unit illustrated in Figure 1, looking in the direction of the arrow 3;

Figure 4 is a magnified, sectional view of a part of the unit illustrated in Figure 2, taken on the line 4-4 looking in the direction of the arrows;

Figure 5 is a front view of a very small part of one of the perforated plates used in a loudspeaker element in accordance with the invention;

Figure 6 is a sectional view of the part shown in Figure 5;

Figure 7 is a sectional view of a modified form of the part shown in Figure 5; and

Figure 8 is a magnified view of a part of the plate illustrated in Figure 6 after encapsulation.

Referring now particularly to Figures 1 to 4 of the drawings, it will be seen that the unit illustrated includes eleven electrostatic loudspeaker elements. The unit is made up from a rear perforated plate 11, a front perforated plate 12, a rear spacer member 13, a front spacer member 14 and a diaphragm 15. Each of the two perforated plates includes eleven metallised perforated areas such as that shown at 16, the metallised areas of the front plate 12 being electrically interconnected by metal strips such as that shown at 17 so that they are all in electrical contact with a terminal member 18. Similarly, the metallised areas 29 of the rear plate 11 are electrically interconnected by metal strips 19 so that they are all in electrical contact with a terminal member 20. It is to be understood that, when the plates are assembled, the metallised areas on each plate are located on the side facing away from the other plate so that the unmetallised sides are adjacent.

The plates with their conductive surfaces may be produced by a printed circuit technique. For example, each plate may be manufactured from a sheet of copper bonded to an epoxy glass laminate, portions of the copper being etched away to produce

the eleven spaced metallic areas, the interconnecting metallic strips and the terminal members. After etching, the plates may be drilled to provide seventy-five holes in each metallic area. Thereafter, each hole may be counterbored to remove the metal from an annular ring around each hole, as shown at 21. These rings are particularly clearly visible in Figures 5 and 6. Alternatively, the holes may be countersunk instead of counterbored, to produce a flared arrangement of the kind shown in Figure 7 at 22. In yet another process, the rings 21 are produced by etching in the initial printed circuit process. Each of these processes has the effect of removing metal from an area around each hole so as to increase the arcing path between each metallic area and the diaphragm when the unit has been assembled. The arrangement illustrated in Figure 7 also has a particularly favourable effect on the acoustic properties of the element by controlling the behaviour of the diaphragm at high frequencies.

After each plate has been produced in the manner described, the whole plate, or at least the metallic portions thereof, may be covered with insulating material, for example, by an encapsulating or dipping process, or by means of a varnish spray. The varnish coating is illustrated particularly in Figure 8 at 23 in the case of an arrangement of the kind illustrated in Figure 6. It will be seen that the encapsulation produces a slight flaring of each hole, similar to that produced by counter-sinking, and accordingly improves the acoustic properties of the unit, as well as protecting the metallised areas.

The two spacer members may be identical stampings having windows coresponding to the metallised areas, and the spacer member 14 is preferably secured to the front plate 12 by means of adhesive or by use of the encapsulating varnish. In the case of the rear spacer member, however, the diaphragm 15 is secured thereto before assembly. The diaphragm preferably consists of a flexible sheet material having a thickness of the order of 0.0004 inch. The material may be, for example, polyvinyl chloride or polyvinylidene chloride. This material is given an electrical resistive coating on both sides. This coating may be produced by the application of an electrically resistive material such as graphite in powder form or by the use of a solution containing conductive material, the quantity of material in the solution being sufficient to produce the desired resistivity when the solvent has evaporated. Permanence of conductivity may be achieved by bonding the material with additional substances or by burnishing or by the application of a partial solvent of the base material or by a combination of any of these processes. In any case, the final surface resistivity of the coating should be between $1 \times 10^7$ and $5 \times 10^9$ ohms per square inch.

During the coating process, the diaphragm material is preferably secured to an outer frame, the dimensions of which are greater than the final dimensions of the diaphragm. The material is shrunk by the application of heat and the rear spacer member is thereafter secured to the stretched material by means of a suitable cement. When the cement has set, the portion of the material secured to the rear spacer member is cut out of the remainder of the material and the rear spacer member is placed on the rear perforated plate with the diaphragm facing away from the rear plate. Thus, when the two plates are assembled, the diaphragm will be secured between the two spacer members. Thus, a portion of diaphragm material will be gripped between the two spacer members all round the periphery of each of the loudspeaker elements.

To enable an electrical connection to be made to the coatings on the diaphragm, three thin sheet metal members such as that shown at 24 are wrapped round the diaphragm. When the unit is assembled, contact is made to these three metal members by means of terminal members 25, 26 and 27, formed on the front plate 12 during the printing process, said terminal members being interconnected by a metal strip 28.

The various parts of the loudspeaker as described are assembled on a curved frame so that they adopt the shape shown in Figure 1. In this connection it is, of course, to be understood that the spacing between the holes of the rear plate 11 is slightly greater than the spacing between the holes of the front plate 12 so that the holes are aligned when the two plates are curved as shown in Figure 1. This curvature improves the directional characteristics of the loudspeaker.

WHAT WE CLAIM IS:—

1. An electrostatic loudspeaker element including two perforated plates of substantially rigid electrically insulating material secured together in spaced relationship and each including a conductive surface on the side facing away from the other plate, a diaphragm of flexible insulating material coated with electrically resistive material being secured between said plates, and each of said conductive surfaces being perforated to correspond to the respective perforated plate but the diameter of each hole in each conductive surface being greater than the diameter, or the minimum diameter, of the corresponding hole in the respective plate.

2. An element as claimed in Claim 1, wherein each of the plates with its conduc-

tive surface is produced by a printed circuit technique.

3. An element as claimed in Claim 2, wherein each plate is manufactured from a sheet of copper bonded to an epoxy glass laminate.

4. An element as claimed in any of the preceding Claims, wherein an annular ring of conductive material is removed around each hole in each plate.

5. An element as claimed in any of Claims 1 to 3, wherein each hole in each plate is tapered so that its diameter on the side provided with the conductive surface is greater than its diameter on the other side.

6. An element as claimed in any of the preceding Claims, wherein a varnish layer is provided on each plate, said layer penetrating through each of said holes.

7. An electrostatic loudspeaker unit comprising a plurality of loudspeaker elements as claimed in any of the preceding Claims, and including two perforated plates, each provided with a series of spaced metallised perforated areas electrically interconnected by metallic strips.

8. A unit as claimed in Claim 7, wherein the two plates are separated by spacer members between which the diaphragm is located, said spacer members being shaped to grip the diaphragm around the periphery of each perforated metallised area.

9. An electrostatic loudspeaker unit substantially as hereinbefore described with reference to, and as illustrated in, Figures 1 to 4 of the accompanying diagrammatic drawings.

10. An electrostatic loudspeaker element including two metallised perforated plates and a diaphragm secured therebetween, wherein the arcing path between the metallising of each plate and the diaphragm is increased at each perforation by a method substantially as hereinbefore described with reference to any of Figures 5 to 7 of the accompanying diagrammatic drawings.

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1239658 COMPLETE SPECIFICATION

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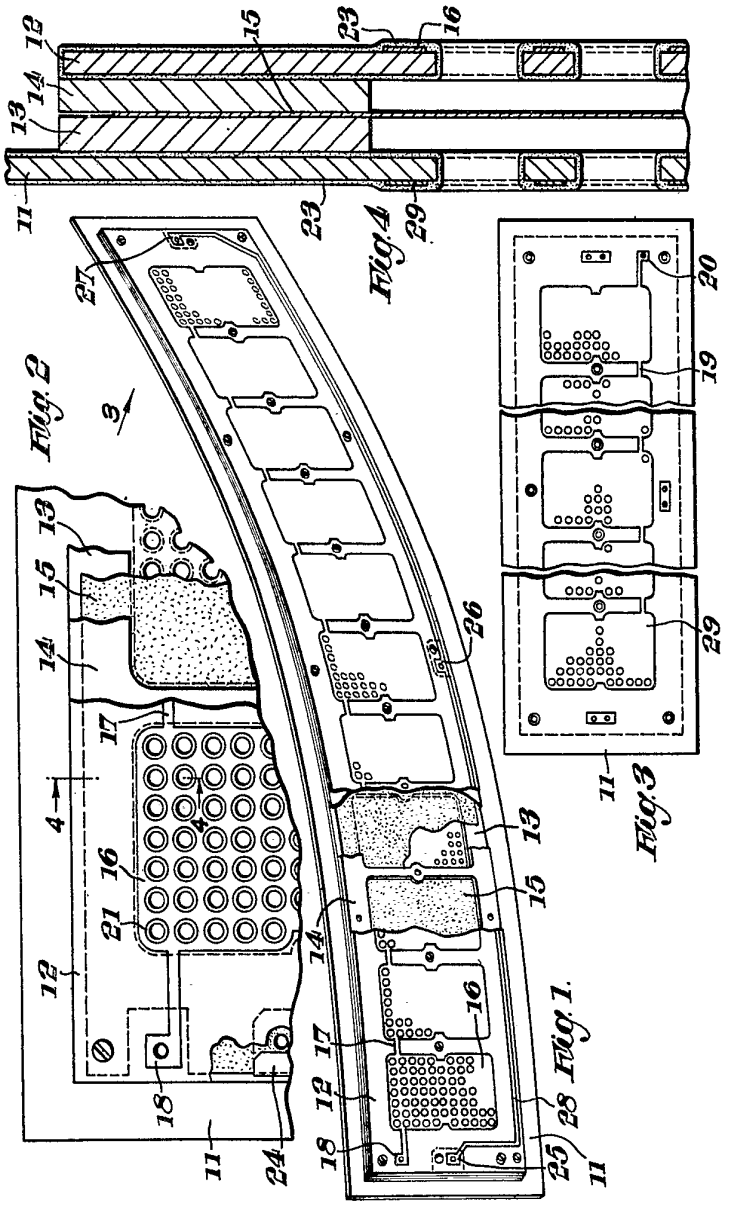

1239658 COMPLETE SPECIFICATION

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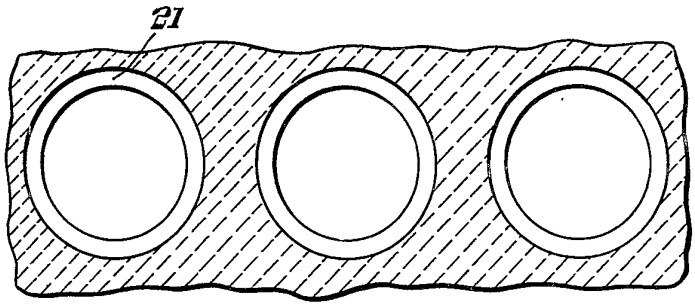


*Fig. 5.*

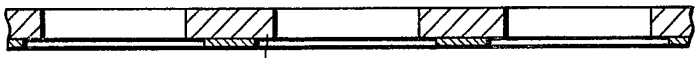


*Fig. 6.*

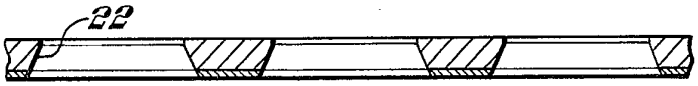


*Fig. 7.*

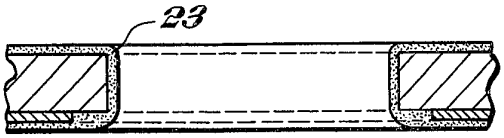


*Fig. 8.*