United States Patent [19]

Bobb

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[54] **SPEAKER SYSTEM AND ELECTROSTATIC SPEAKER**

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Related U.S. Application Data

[63] Continuation of Ser. No. 724,805, April 4, 1968, abandoned.

[52] **U.S. Cl.** ..... **179/111 R**

[51] **Int. Cl.** **H04r 19/02**

[58] **Field of Search** ..... 179/111 R, 111 E, 179/16, 115.5 PS, 1 G, 1 A, 1 E

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[57] **ABSTRACT**

A speaker system incorporating an electrostatic speaker and a dynamic speaker in which a cross-over network is employed providing for operation of the dynamic speaker only up to the frequency at which it will function as a piston. Also, a flat push-pull electrostatic speaker incorporating a pair of planar single ended electrostatic speakers so constructed as to maintain omni-directional tensioning of their respective electrically conductive membranes and electrical contact therewith and to provide controlled spacing between each membrane and its associated conductive perforated backing plate and constructed to provide acoustic coupling of the pair of speakers by means of a thin air film of controlled thickness at ambient pressure.

15 Claims, 5 Drawing Figures

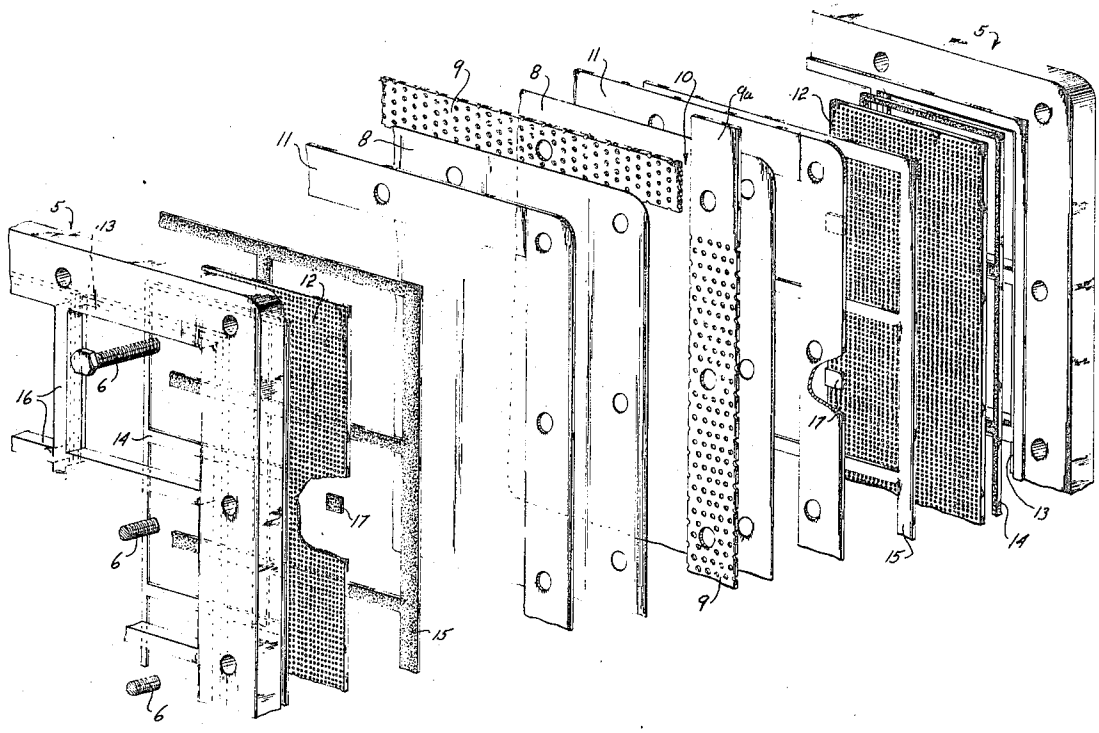


Fig. 1

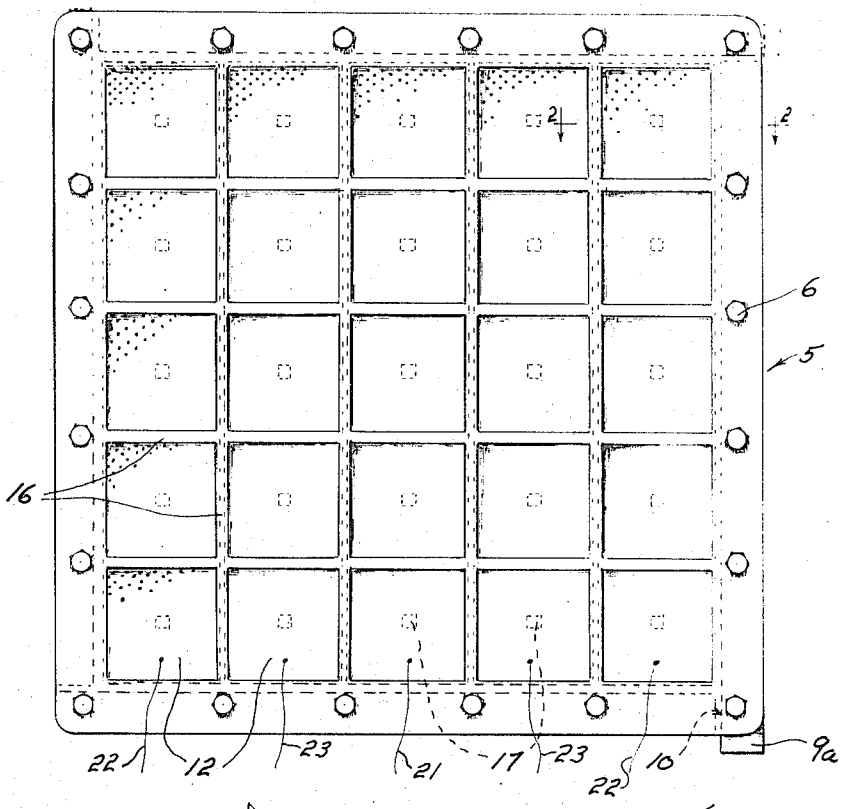


Fig. 5

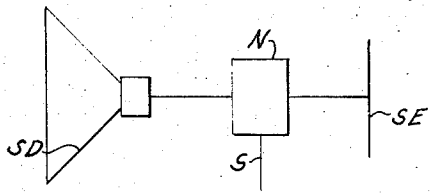
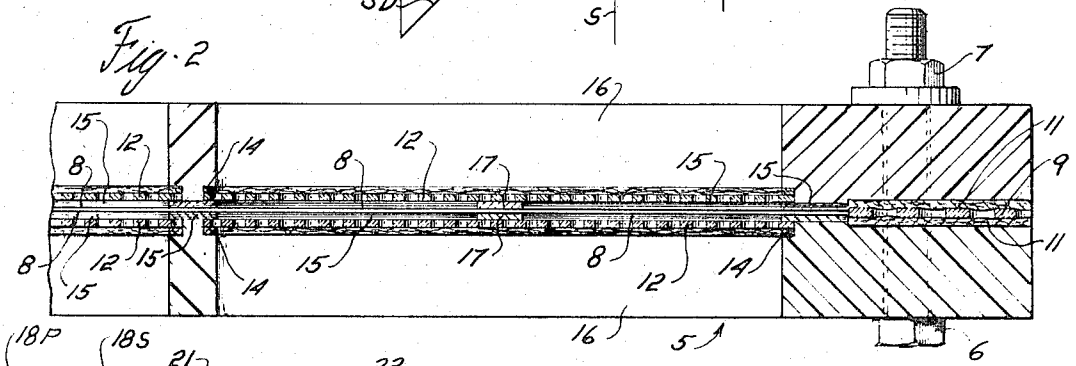


Fig. 2



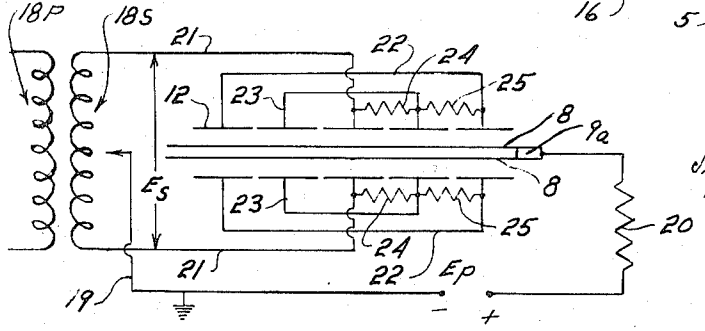


Fig. 4

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SHEET 2 OF 2

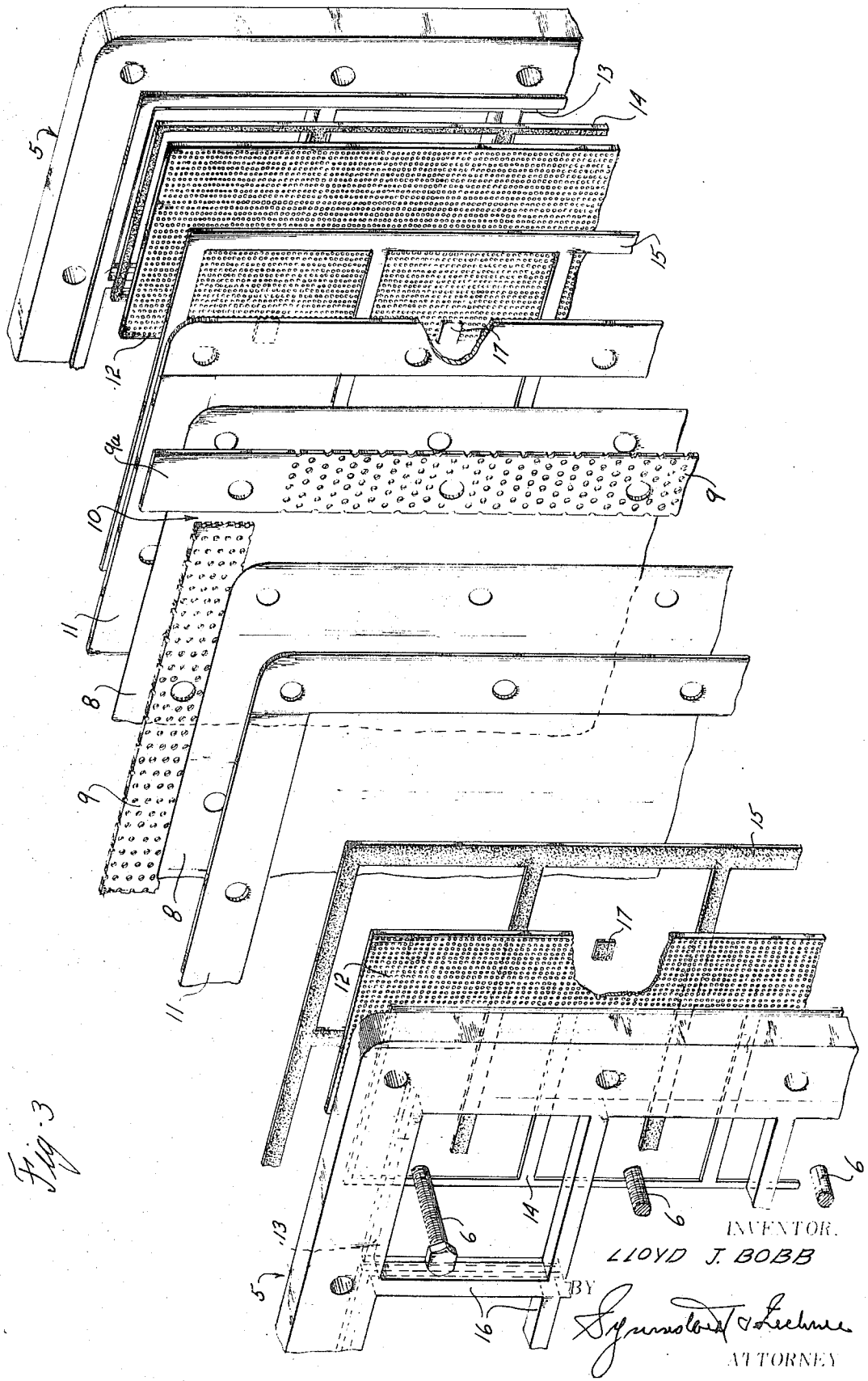


Fig. 3

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SPEAKER SYSTEM AND ELECTROSTATIC SPEAKER

The present application is a continuation of my prior application Ser. No. 724,805, filed Apr. 4, 1968, now abandoned.

This invention relates to sound reproducing speaker systems and is concerned with several important aspects of conjoint use of both electrostatic and dynamic speakers, as well as with several important aspects of electrostatic speaker construction, all of which aspects have a bearing on the quality of the sound reproduction obtainable from such speaker systems and from electrostatic speakers.

One of the important objects of the invention is to provide a speaker system incorporating both electrostatic and dynamic speakers, characterized by exceptionally low transient distortion throughout the audio frequency range. The system of the invention also maximizes the power handling capability of the system, especially when considered in relation to the cost and size of the components employed.

In explaining the manner in which the foregoing objectives in the system as a whole are achieved, attention is first directed to the fact that the dynamic type of speaker, especially in the common cone form, operates as a piston over a small portion of the audio frequency range at the lower end, usually up to approximately 500 cycles per second, depending somewhat upon the size of the speaker. Above the frequency at which the cone functions as a piston, the cone type of speaker is characterized by transient distortions many of which originate in resonances of the cone. On the other hand, electrostatic speakers are not practical to employ at very low frequencies because to use them in the low frequency range would require inordinately large speaker elements, if any satisfactory degree of efficiency is to be obtained. With these two factors in mind, the present invention contemplates the conjoint use of a dynamic speaker, such as a cone speaker, and an electrostatic speaker, together with a cross-over network operating to cut off the dynamic speaker operation at or below the frequency at which it ceases to function as a piston. In this way the speaker system of the present invention maximizes the power handling capability while at the same time substantially eliminates transient distortions of the system, and accomplishes these objectives in an economical manner.

In addition to the foregoing objectives relating to the sound reproduction system as a whole, the present invention also has a number of important objectives in relation to the electrostatic speaker construction, various of which are of special advantage in an overall system of the kind above referred to.

It is an object of the invention to provide an electrostatic speaker having strikingly improved sound reproduction fidelity.

It is also an important object of the invention to make possible the use of electrostatic speakers over a broader audio frequency range, than has been practical heretofore, especially at the lower end of the audio range covered by the electrostatic speaker. This is of special advantage when the electrostatic speaker is used in a system of the kind above referred to in which the operation of the dynamic speaker is cut off at the upper end of the frequency range in which the dynamic speaker operates as a piston.

Still another object of the invention is the provision of an electrostatic speaker incorporating one or more metal coated sound generating membranes and having a novel and improved electrical connection means, i.e., the means of connection with the metal coating, this connection means being characterized by extensive surface area contact between the metal coating and a contact element. With such extended area of surface contact, notwithstanding the fact that the membranes are very thin and delicate, and are placed and maintained under tension, the contact with the membranes has much greater life than in prior speakers of this type, and the membranes themselves are not subject to damage or rupture.

In considering certain additional objects and advantages, it is first pointed out that in a typical speaker constructed according to the present invention a pair of sound generating membranes are employed, being mounted under tension in spaced but closely adjacent parallel planes, with their metal coated surfaces presented toward each other and with contact strips lying and clamped between the perimeters of the membranes. The typical preferred speaker according to the invention further incorporates acoustically transparent electrodes or backing plates at the outer faces of the membranes, in spaced relation to the membranes, these backing plates being electrically conductive, for instance formed of metal, and being electrically connected in push-pull fashion to the output transformer of the driving amplifier, with the two conductive coatings on the membranes connected to receive the signal voltage from the "center tap" of the transformer.

The cooperating membranes and backing plates of each speaker are uniformly spaced from each other substantially throughout the cooperating areas of the membranes and backing plates, so that the membrane of each speaker "conforms" with irregularities in the surface of its associated backing plate. With the two membranes acoustically coupled together, the construction referred to above, in effect, comprises a pair of "single ended" congruent speakers acoustically coupled to each other in push-pull relationship. By this arrangement, certain distortions heretofore present in sound reproduction generated by electrostatic speakers are greatly diminished or eliminated, it being a major objective of the invention to provide extensive increase in fidelity of reproduction by virtue of use of acoustic push-pull coupling of a pair of electrostatically actuated sound generating membranes.

Still another objective of the invention is to improve the frequency response characteristics or curve of the speaker, this being achieved in part by sectionalizing the backing plates and by separately connecting the backing plates in groups, with different impedance in the signal connections to the several groups, in the manner which will be described more fully hereinafter.

The invention also provides for improvement in the dispersal or distribution of the sound generated by an electrostatic speaker.

It is also an object of the invention to improve the uniformity of response and power handling ability of the speaker by employment of membranes and other speaker elements in planar form, i.e., in the form of flat membranes and backing plates, and still further by placing the membranes under substantially uniform tension applied in substantially all directions in the plane of each membrane.

How the foregoing objects and advantages are attained, together with others which will occur to those skilled in the art will appear more fully from the following description referring to the accompanying drawings, in which:

FIG. 1 is an elevational view of an electrostatic speaker constructed according to the present invention;

FIG. 2 is an enlarged fragmentary sectional view taken as indicated by the section line 2—2 on FIG. 1;

FIG. 3 is an isometric fragmentary view illustrating on an enlarged scale one corner of the speaker shown in FIG. 1 but with the various components of the speaker separated from each other, in the manner of an exploded view;

FIG. 4 is a schematic diagram of the electrostatic speaker and of certain typical operating connections adapted to be employed; and

FIG. 5 is a schematic diagram of a speaker system incorporating both an electrostatic speaker and a dynamic speaker, together with a cross-over network.

Herebelow the structure of the preferred electrostatic speaker of the present invention is first described and thereafter reference will be made to the speaker system of the present invention incorporating not only an electrostatic speaker but also a dynamic speaker, with an interconnecting cross-over network.

Referring now to FIGS. 1, 2 and 3, it is first to be noted that while various features of the invention are applicable to a speaker incorporating only a single membrane and backing plate, in the embodiment shown a "double ended" speaker is illustrated, having two membranes and two sets of backing plates arranged in push-pull relationship as above mentioned.

In the embodiment illustrated, a pair of clamping frames 5—5 are employed at the outer face of the speaker, and a stack or sandwich of components is positioned between these two frames, some of them being clamped together by the frames, as will further appear. The frames are fastened together by nuts and bolts such as shown at 6 and 7, the clamping frames and certain of the intervening components being apertured to pass the clamping bolts.

The two sound generating membranes appear in FIG. 3 at 8—8. These membranes are advantageously formed of polyester resin, one form of which is readily available under the tradename Mylar (E. I. DuPont de Nemours and Co.). The resin film employed for the membranes is advantageously quite thin, for instance of the order of ¼ to ½ mil, this being of importance in minimizing inertia of the membrane and thereby enhancing the sensitivity of the membrane especially at high frequencies. The membranes are provided with metallic coatings, applied, for instance, by well-known vacuum evaporation techniques. Aluminum is an effective metal for coating purposes and the coating is preferably very thin. An appropriate aluminum coating will have a resistance of the order of 3 to 5 ohms as measured across a square of the coated membrane. This is believed to represent a coating of thickness of the order of 100 angstroms. Even coatings having some considerable resistance are entirely satisfactory since the conductivity of the coating on the membrane will function properly even if it is much lower than the conductivity of the associated backing plates.

Preferably, the membranes 8—8 are metal coated on their sides presented toward each other and the electrical contact means is interposed between the pair of conductive coatings on the membranes. The contact means may take a variety of forms, but should provide not only for electrical contact with the conductive coatings of the membranes but also for a mechanical gripping for maintaining the tension under which the membranes are placed. As seen particularly in FIGS. 2 and 3, the contact means comprises perforated strips 9. The contact strips should have some form of recesses for engaging and interlocking with the coated surface of the membranes. For example, the strips may have indentations or a roughened surface for mechanical gripping of the membranes, or, as in the embodiment illustrated, the interlocking recesses may be provided by perforations. Moreover, although a contact strip may be provided adjacent to only one edge of the adjoining membranes, preferably a plurality of contact strips is used, and in the case of a rectangular speaker construction such as herein illustrated by way of example, a contact strip is desirably extended along each of the four edges of the adjacent membranes. By using a contact strip at each edge of the membranes, the contact strips themselves serve also as the spacer means between the two membranes. Where a contact strip is employed at one edge only, other spacer strips at the other edges of the membranes will be required in order to establish the desired spacing between the two membranes. The several contact strips may be electrically interconnected, if desired, but this is not necessary. In any event, one of the contact strips is provided with a projecting end or tab 9a for the purpose of facilitating the making of an electrical connection to the contact strip and thus to the metal coatings of the membranes.

It is of importance that at least some one point around the perimeter of the membranes the contact or spacer strips be spaced from each other in order to provide a gap such as indicated at 10 in FIGS. 1 and 3. This provides for equalization of the air pressure between membranes with the surrounding atmosphere, and thus prevents adverse influences upon the positioning of the membranes under the influence of application of the polarizing DC voltage and also under the influence of changes in barometric pressure, or under other pressure conditions, for instance if the speaker is employed in the pressurized cabin of an airliner.

At the outer sides of each of the membranes 8—8 gaskets 11—11 are provided, running around the perimeter of the membranes and serving, when the parts are clamped together, to press localized areas of the membranes into the perforations of the contact strips 9, in the manner clearly indicated in FIG. 2. The gaskets 11—11 are desirably formed of a yielding material in order to serve the function just referred to, an example of such a material being blotting paper or any other material having the ability to yield under compression, along with minimum lateral "cold flow."

In connection with the metal coating on the membranes and the contact strips employed it is to be noted that preferably the metal of the contact strips (or at least the surface thereof which actually contacts the coating on the membranes) should be the same as that of the coating. Thus, with an aluminum coating, which is a preferred embodiment, the contact strips should also be of aluminum. One reason for this is that employment of the same metal eliminates electrochemical action or corrosion which might occur if two

different metals were used, especially if they were considerably separated in the electromotive series.

The membranes **8—8** are advantageously placed under tension, and the flat or planar form of the membranes is of importance in this connection because, in contrast with various prior art devices in which curved membranes are employed, each membrane in the construction according to the invention is placed under tension in all directions in the plane thereof, rather than only arcuately of a curved membrane, as in various prior art devices. The mounting and clamping of the membranes under tension in all directions is an important feature of the present invention, because this eliminates the source or origin of certain distortions resulting from irregularities in the motion of membranes which are mounted under a condition of tension applied in only one direction. With prior art arrangements having a membrane placed under tension arcuately of a curved support, it is exceedingly difficult to establish a condition of uniform tension thorughout the membrane, and I have found that this non-uniformity can be eliminated by employing membranes in planar form and placing them under omni-directional tension.

The employment of perforated contact strips to serve not only for electrical contact purposes, but also as the spacer means between the membranes, with the resultant pressing of the membranes into the perforations of the strips, is not only of advantage in establishing effective electrical contact between the contact strips and the metal coatings of the membranes, but also in providing a tight grip or clamping action in cooperation with the gaskets **11—11** adapted to retain the tension under which the membranes are placed. This tension is readily maintained by this clamping action over long periods of time and is accomplished without damage even to exceedingly thin membranes or to the conductive coatings thereon.

At each side of the assembly of membranes, perforated metal plates **12—12** are provided, these plates serving as backing plates or stationary electrodes in combination with the metal coating on the membranes. Although a single plate **12** at each side of the membranes could be extended throughout the entire area of the speaker, i.e., of the membranes, it is preferred to sectionalize each of the backing plates and, in the embodiment illustrated, each one of the backing plates is in effect made up of five sections or strips arranged in edge to edge relationship with their long dimensions paralleling each other, the several sections of each plate being separated or insulated from each other to enable use of electrical connections of the kind described hereinafter.

To accommodate the several backing plate strips, each of the frame members **5** is provided with rabbeted edges **13** which receive the damping gaskets **14** and also the edges of the plate sections **12.** Damping gaskets **15** are positioned over the plate sections **12,** the outer peripheral portion of the gaskets **15** being located in part over the edges of the plates **12** and in part over the adjoining portions of the frame members **5.** These gaskets **15** have outside dimensions fitting inside of the gaskets **11** associated with the contact strips **9.**

As will be seen in the drawings, the illustrative speaker shown incorporates frame members which, in effect, are windowed, the overall area of the frame being subdivided by mullions **16.** The damping gaskets **14** and **15** are also similarly and correspondingly subdivided by mullions, so that when the frames, plate sections **12** and gaskets **14** and **15** are assembled, the mullions of the gaskets **14** and **15** register with those of the frame members.

The gaskets **14** and **15** are not necessarily built up as separate gasket elements, but may be applied to the plate sections at the edges thereof and also in strips extended across the plates at spaced points intermediate the ends thereof. Such strips may take the form of adhesive tape, for instance masking tape. In any event, whether built up in the form of complete gaskets, or whether applied in tape form, the damping gaskets **14** and **15** are desirably formed of a damping type of material, i.e., a material of viscous type, with high mechanical hysteresis, although it is preferable that the material does not have any appreciable cold flow. The damping material applied to the plates **12** desirably has an adhesive coating, for instance the pressure sensitive adhesive of masking tape, so that the damping material will adhere to the plates and thus properly perform its damping function in relation to vibrations of the plates.

The damping gaskets serve several purposes. First, they serve the purpose or function of damping out undesired vibrations of the backing plate sections **12.** This arrangement of damping means is especially effective because the damping material is applied to the plates at the edges thereof where it is particularly effective in eliminating vibrations of the plates, especially vibrations at various resonant or harmonic frequencies of the plates. The damping gaskets **15** further serve as spacing elements between the backing plates and the membranes.

Additional damping and spacing action is desirably provided by applying damping material **17** in a limited area centrally of each of the windows, as is clearly shown in the drawings. The damping material employed for the spots indicated at **17** is desirably of the same type and thickness as that described above.

With respect to the damping **17** provided in the center of each of the window areas, it is to be noted that this damping is of greater importance in the peripheral ring of **16** outermost window areas than in the inner window areas, and this is especially true where little if any baffling is employed surrounding the speaker. If no baffle area is employed surrounding the speaker, as is preferred because the baffling is both space consuming and expensive, the "circuiting" path for the sound waves between opposite faces of the speaker is quite short because such path extends only radially around the marginal frame of the speaker. However, I have found that even with no baffling surrounding the speaker frame, if the damping elements **17** are provided in the peripheral ring of windowed areas, the speaker will nevertheless perform satisfactorily, both from the standpoint of frequency response and power output. The use of the damping elements **17** in the inner windowed areas are of less importance but are also desirably provided.

Although the plates or plate sections **12** may be formed in a number of different ways, for instance by being built up of interwoven or interconnected wires in the form of a grid or grill, it is preferred to employ a perforated metal strip or sheet type of material, as is illustrated in the drawings. Because the sound waves radiated from the membranes which lie between the perforated plates must pass through the perforated plates in the operation of the speaker, in order that the radia-

tion will pervade the area surrounding the speaker, it is desirable that the backing plates be acoustically transparent, and for this purpose, where perforated plates are used, a substantial percentage of the area of those plates should be represented by the perforations, for instance it is preferred that the total cross sectional area of the apertures constitute at least 10 percent of the total area of the plates. The plates are also advantageously made of metal because it is necessary in this type of speaker to provide electrical connections to the plates, so that they will serve their intended function as stationary electrodes, thereby providing the desired electrostatic action with reference to the metal coatings on the membranes. Any suitable metal will serve the purpose, but aluminum is advantageous in being readily punched and worked. Sheet aluminum of about 0.034 inch thickness is appropriate, it being pointed out that it is preferred to use metal of some appreciable thickness for these plates, because of the importance of having them as rigid as possible and further because of the desirability of having some reasonable mass in the plates in order to resist tendency for the plates to flutter or vibrate during operation of the speaker.

Preferably the size or diameter of the apertures in the backing plates should not be so large in relation to the spacing between the membrane and its associated backing plate that the area of the membrane opposite the aperture is not acted upon by the electrostatic field. In typical constructions according to the present invention the apertures are of diameter ranging from about 1 to 10 times the spacing between the membrane and its associated backing plate.

In a typical speaker according to the invention the spacing between each membrane and its associated backing plate is desirably from about 15 to 30 mils.

The frame members **5** which serve for clamping and mounting the membranes in tensioned condition, and which also serve to maintain the backing plates and associated damping elements, desirably have considerable rigidity, since they serve as the backbone or skeleton of the structure. These clamping frames may be built up of wood or may be molded of certain plastics or resins, for example epoxy resins. Molding is desirable because it is capable of providing accurately flat inside surfaces or grooves with which the membranes and plates cooperate.

The various parts of the speaker, as illustrated in FIG. **3** in exploded relation to each other, are brought together and the frames are suitably fastened together, as by means of the bolts **6** and nuts **7**, the latter being illustrated only in FIG. **2.** For the purpose of assembly, a jig may be used in which one of the frame members is first inserted and then all of the other parts are stacked on the first frame member in the positions and sequence as indicated in FIG. **3.** The membrane sheets are preferably initially introduced in a size greater than the size indicated in the drawings, to provide gripping areas outside of the areas to be incorporated and clamped within the speaker. Before the parts above the two membranes are put in place, the membranes are desirably tensioned, and in doing this it is preferred to grip each membrane at a multiplicity of localized areas outside of the perimeter of the areas to be incorporated in the speaker. The clamped areas are then pulled in a multiplicity of directions radiating from the center point of the membranes, so that the tension is established in the membranes in substantially all directions (not merely in directions paralleling the sides of the square frame).

Although the various parts of the speaker may be assembled in a variety of different ways, it is preferred to progressively assemble the speaker parts, beginning with those at one side of the sandwich, for which purpose the clamping bolts **6** are positioned in the bolt holes in the frame member **5**, for instance the frame member at the left of FIG. **3**, and then additional components of the speaker sandwich are brought to their proper position. When it is time for assembly of the first of the two membranes **8**, it is positioned against the ends of the bolts **6** and the omni-directional tensioning is established in the membrane. The membrane is then punctured as by a sharp scribe point directly over the end of each bolt, and the omni-directional tensioning results in development of apertures which open to accept and pass over the end portions of the bolts. Thereafter the perforated contact and spacing strips **9** are applied over the bolts. The second membrane **8** is then applied in the manner described above for the first membrane, and this is followed by assembly of the remaining components of the speaker sandwich, including the second of the two frame members **5**, after which nuts are applied to the bolts and the parts are clamped together as illustrated in FIG. **2.** In this clamped condition the edges of the membranes are gripped so that the omni-directional tension therein is "captured" and maintained. The edge portions of the membrane films projecting beyond the frame members may then be trimmed off.

With respect to the "omni-directional" tensioning of the membranes referred to herein, it should be noted that appropriate tensioning may be achieved by applying tension, for instance by means of clamps, pulling in a multiplicity of radial directions radiating from a common central point or area of the membrane. To accomplish this it is preferred to use pieces of the membrane material slightly larger than the area to be incorporated in the speaker itself. This provides room for engagement of the clamps without undue waste of membrane material. With such pieces of membrane material, preferably the total number of pulling directions should be upwards of about 10, for instance of the order of 20 to 40. The theoretical ideal would of course be achieved by pulling in an infinite number of directions from the common central point or area, but tensioning in the number of directions indicated provides substantially omni-directional tensioning in the membrane and is effective for the purposes of the invention. The amount of tension may also vary somewhat, but I have found that tension, in each of the directions in which it is applied, of the order of 1¼ to 1½ pounds, serves the purpose.

Turning now to FIG. **4** which illustrates one appropriate circuit in which the speaker described above may be connected. The membranes **8** and the backing plates **12** are indicated diagrammatically in this figure. Numeral **18***s* indicates the secondary of an audio output transformer serving to deliver signal voltages Es to the speaker. The center tap connection **19** of the transformer winding **18***s* is provided with terminals for the introduction of the polarizing voltage employed, as indicated at Ep. This line **19** is then connected through resistors **20** to the contact tab **9***a* and thus to the metal coatings of the two membranes **8.** Resistor **20,** for in-

stance of the order of 2 megohms, functions to keep the polarizing charge substantially constant.

The two ends of the transformer winding 18*s* are connected by wires 21—21 with the backing plates 12, there being interconnections extended between these plates in groups at each side of the speaker. Wires 22—22 interconnect the outermost pairs of plate sections 12 at each side of the speaker, and wires 23—23 interconnect the adjacent pairs of backing plates at each side of the speaker. All of the grouped pairs of plate sections are connected in parallel. Certain resistors are introduced into each parallel branch. Thus resistors 24—24 interconnect the wires 21—21 and 23—23, and resistors 25—25 interconnect the wires 23—23 and 22—22.

By the network described above the single pair of plate sections 12 in the center of the speaker are directly connected with the wires 21—21, and the additional groups of plates are connected to the wires 21—21 only through the resistors 24—24 and 25—25, all of these resistors being effective for the signal delivered to the outermost pairs of plate sections.

The connections to the backing plates may be made by soldering a connection directly to the plate element, for instance along one edge of the speaker as is illustrated in FIG. 1 where the connections 21, 22 and 23 are shown, corresponding to the connections described above with reference to FIG. 4.

With the circuit illustrated in FIG. 4, a direct current or polarizing voltage Ep is applied as a bias voltage between the membranes and the backing plates. The signal Es is delivered in push-pull to the backing plates at the opposite sides of the pair of membranes 8—8, and in consequence of these connections the signal voltage decreases the polarizing voltage at one side of the speaker at the same time that the signal voltage increases the polarizing voltage at the other side of the speaker.

Turning now to the overall operation of the electrostatic speaker as above described, attention is first called to the fact that the two membranes 8—8 are mounted under tension with a small space therebetween, for instance a space of the order of from 1/64 to 1/16 inch. Because of the application of the polarizing voltage to the metal coating on each membrane and to the cooperating backing plates, each membrane is electrostatically attracted to its backing plates. The spacers 15 and 17 provided between each membrane and its backing plates act to maintain the spacing between each membrane and its backing plates notwithstanding the electrostatic attraction.

Because the signal voltage applied to the backing plates at one side of the speaker is 180° out of phase with that applied to the backing plates at the other side of the speaker, the two membranes are caused to move or vibrate in the same direction as a unit toward and away from the backing plates at the two sides of the speaker, and this action results in radiation of the sound waves corresponding to the signal voltage. In this conjoint vibration of the two membranes together the film of air lying between the membranes becomes, in effect, a part of the radiator. It is to be noted in connection with the air space between the membranes that there is communication or venting established between that space and the surrounding air, for instance through the channel 10 shown in FIG. 3, and this assures equalization of pressure within the chamber of the membranes with respect to the surrounding atmosphere.

Although the metal coatings on the membranes might be provided on the outer sides thereof, instead of on the sides presented toward each other, the latter arrangement (which is shown herein) is preferred for several reasons. In the first place the positioning of the metal coatings on the adjacent sides of the membranes makes possible the use of common contact strips for both metal coatings. Still further the positioning of the metal coatings on the adjacent sides of the membranes is also of advantage because the metal coatings are delicate and subject to corrosive influences, especially in certain types of urban and sea coast atmospheres. With the coatings presented toward each other only very minor air circulation occurs, because the space between the membranes is almost completely closed, it being necessary to provide only a very small opening or vent for the purpose of the pressure equilization referred to above. Corrosion is therefore minimized.

The positioning of the conductive coatings facing each other also eliminates the necessity for applying a protective overcoating on top of the conductive coating, an expedient which has heretofore been adopted in an effort to protect the conductive coating from corrosive influences. The absence of a protective overcoating also minimizes the mass and inertia of the membrane, resulting in further improved frequency response.

Positioning the membranes with the conductive surfaces presented toward each other and with the nonconductive or dielectric membrane at the outer sides is desirable from another standpoint, namely the fact that presenting the dielectric material toward and backing plates increases the power handling capability of the speaker, because the dielectric strength of the resin film, for a given thickness, is many times that of air.

The omni-directional tensioning of the membranes aids in maintaining uniformity of spacing between each membrane and its backing plate or plates, and this in turn increases the power handling capacity of the speaker, especially at low frequencies, which is of importance when using the electrostatic speaker of a given size in an overall system of the kind described in which the electrostatic speaker is relied upon down to a lower frequency than has been common practice.

The use of flat or planar membranes in the speaker is of importance because this permits uniform acoustic coupling of the two membranes throughout the area thereof, and thus makes possible fully effective acoustic push-pull coupling of the membranes of a pair of counterpart single ended speakers.

In considering the operation of the speaker it should also be kept in mind that the employment of a pair of membranes connected in push-pull fashion and acoustically coupled to each other is of advantage for a number of reasons. One source of distortion arising in certain electrostatic speakers results from the fact that the backing plates cannot be made with great accuracy, because of manufacturing tolerances. In consequence of this the backing plates will not be accurately planar. The electrostatic attraction between any given backing plate and its cooperating membrane, because of the spacers, will result in the membrane assuming a position in which it is substantially uniformly spaced from its backing plate, notwithstanding deviations in the surface of the backing plate from an accurate flat plane.

Employment of two acoustically coupled pairs of membranes and backing plates, permits each membrane to assume a configuration mating with its own backing plate and thus assume a somewhat irregular shape instead of lying exactly in a flat plane. At the same time the fact that the two membranes are acoustically coupled by an air film (having high impedance with respect to the membranes at the highest frequency of interest) and the fact that the two membranes vibrate together as a unit with a constant volume of air between them, eliminates the distortions which occur when using a single membrane speaker as a result of the force versus displacement relationship, which is Square Law. The fact that the volume of air between the two membranes may be of different thickness in different areas does not have any appreciable adverse influence on the fidelity of reproduction, because the two membranes, together with the volume of air therebetween, are moving together as a unit in generating the sound waves corresponding to the signal voltages.

Another source of distortion arising in certain prior electrostatic speakers and which is eliminated by the use of a pair of acoustically coupled membranes is the second harmonic distortion which is present in the operation of a single ended electrostatic speaker having only one membrane. Since the two membranes of the present invention are subjected to signal voltages 180° out of phase with each other, the inherent harmonic distortions of the two mutually cancel each other.

The dual membrane push-pull arrangement of the electrostatic speaker makes possible the handling of more power at low frequencies, in view of which the speaker may be more effectively used at lower frequencies than prior electrostatic speakers. This is of special importance in the overall speaker system contemplated by the invention in which the electrostatic speaker is relied upon for reproduction down to the upper end of the range (usually about 500 cycles) at which the dynamic speaker operates as a piston.

The foregoing advantages resulting from the acoustic coupling of a pair of membranes in accordance with the present invention are obtainable whether the backing plates for the two membranes are co-extensive with the membranes or whether the backing plates are subdivided, as in the preferred embodiment herein disclosed. The subdivision or sectionalizing of the backing plates also has a number of distinctive advantages which can best be understood by first considering certain factors of importance in connection with the radiation of sound from a sound radiator such as a membrane. In general, the efficiency of a radiator depends upon the dimensions of the radiator (or of the portion thereof vibrating at a given frequency) in relation to the frequency of the sound being generated, the most efficient generator having its smallest dimension equal to approximately two-thirds of the wave length of the frequency to be generated. Moreover, the lateral spread or dispersal of the sound wave of a given frequency is greater where the radiator has a small dimension in relation to the wave length or frequency.

With the foregoing factors in mind, the invention provides for the subdivision of the backing plates, for instance into five strips as illustrated in the accompanying drawings, and for purposes of this illustration it is assumed that the overall size of the speaker approximates 12 inches, each backing strip being of the order of 2¼ inches in width. The sectionalizing of the backing plates results in electrostatic action with reference to corresponding localized areas of the associated spaced membrane, so that in effect the membrane may radiate sound waves in a sectionalized manner.

Each section of the backing plates, being approximately 12 inches long and 2¼ inches wide will thus be capable of producing vibrations in the associated membrane and of generating resultant sound waves, with different dispersal characteristics in one plane as compared with other planes. In other words, and for example, in the generation of a high frequency sound wave, the dispersal of the sound will be broadened in a direction crosswise of the strip, as compared with the dispersal in the lengthwise direction of the strip.

It should also be kept in mind that if the dimension of the radiator approaches and exceeds the dimension corresponding to one complete wave length at the frequency being radiated, the dispersal diminishes until the sound wave generated is substantially beamed in a single direction pernendicular to the plane of the radiator.

With all of the foregoing in mind, the present invention contemplates positioning the speaker so that the long dimension of each of the sectionalized strips of the backing plate extends vertically, and so that the short dimension of each strip extends horizontally. In this way the dispersal characteristic of the speaker is improved in the horizontal plane, which is desired in normal use of the speaker, where the speaker is mounted in a vertical plane and where it is preferred to have the sound waves horizontally spread over a considerable arc in order to reach a plurality of listening positions in relation to the speaker.

It is because of various of the foregoing factors that the backing plate strips have been connected to the signal source in groups, in the manner illustrated in FIG. **4.** In a typical speaker of the kind shown having the dimensions and spacing of membranes and plates as described, the resistors **24** may be of the order of 47,000 ohms and the resistors **25** of the order of 67,000 ohms. The two outermost pairs of plates **12** are fed through the combined resistance of both the resistors **24** and **25,** in view of which the higher and intermediate frequencies are attenuated. Similarly, the two adjacent pairs of plates are fed only through the resistors **24** by which the high frequencies are attenuated. Finally the central pair of plate strips **12** are fed directly from the signal source and therefore do not have any of the frequencies attenuated. In consequence of the foregoing, from the standpoint of sound radiation, the total area of the membranes is effective as a radiator for the purpose of generating sound at the lowest frequencies being handled by the speaker; the area of the membranes adjacent the three intermediate pairs of the plate sections are effective to generate sound at the intermediate frequencies being handled by the speaker; and the area of the membranes adjacent the central pair of plate sections is effective to generate sound at the highest frequencies being handled by the speaker.

The arrangement of the speaker, including both the sectionalizing of the backing plates and also the signal feed system, provides a substantially flat frequency response, i.e., the volume of sound produced at various frequencies is substantially uniform. The arrangement also is of advantage in providing for production of a given overall volume level without resort to excessive power input.

Although as indicated above it is preferred to employ a pair of membranes and backing plates, it will be understood that many features of the arrangement disclosed are also applicable to a single ended speaker in which only a single membrane is used and is employed either with a single backing plate or with backing plates at both sides of the single membrane. For example the arrangement provided for securing intimate electrical contact with the metal coating on a membrane may be used with only a single membrane. Moreover, various of the damping arrangements applied to the backing plates may be used on any backing plates in a speaker of either single or multiple construction. The arrangement of the speaker to provide for the employment of a planar membrane and also the related omnidirectional tensioning of the membrane, may be employed wherever such membranes are utilized.

While the embodiment of the electrostatic speaker herein disclosed incorporates all of the elements of the dual speaker in a single mounting structure, it is to be understood that the invention also contemplates the acoustic and electrical push-pull coupling of two independently mounted electrostatic speakers each incorporating a flat membrane.

The electrostatic speaker constructed as above described and as illustrated in the drawings is particularly suitable for use in an overall speaker system of the kind contemplated by the present invention, because the electrostatic speaker is capable of effective reproduction at least down to a frequency of the order of 500 cycles per second. It is to be understood, however, that in an overall system of the kind contemplated by the present invention, including not only an electrostatic speaker, but also a dynamic speaker, other electrostatic speakers may be employed, although, as hereinabove indicated it is preferred that whatever electrostatic speaker is used, it should be capable of effective reproduction at least down to a frequency of the order of the highest frequency at which the dynamic speaker employed will operate in the manner of a piston.

The signal may be fed to the dynamic speaker in any of various well-known ways, for instance through an appropriate network connected with the primary 18*p* of the transformer shown to the left of FIG. 4. The network here employed may be of known type, but designed to provide for cut off of the dynamic speaker at a frequency in the neighborhood of the upper end of the frequency range in which the dynamic speaker operates as a piston, in a typical case at a frequency of the order of 500 cycles per second.

In FIG. 5 there is a "simplified" diagrammatic representation of an overall speaker system incorporating an electrostatic speaker SE and a dynamic speaker SD, for instance of the cone type, these two speakers being fed by a cross-over network indicated at N interposed in the signal supply S in advance of the speakers. The network N may include the network components shown for example in FIG. 4 for the electrostatic speaker and also a network such as described above adapted to cut off the operation of the dynamic speaker at the upper limit of its range of piston type operation. As already mentioned, the cross-over network should also establish the operation of the electrostatic speaker at a frequency at or about which the dynamic speaker is cut off. In a typical system incorporating a dynamic cone speaker, for instance of 8 to 12 inch size, a cross-over frequency of about 500 cycles per second has been found to be effective and to represent approximately the upper limit of piston type operation of the dynamic speaker. In a typical system this frequency also represents a practical lower limit for the frequency range of the electrostatic speaker without excessively increasing the size of the electrostatic speaker.

With an overall system incorporating both electrostatic and dynamic speakers as above described, the reproduction is substantially free of transients and other distortions throughout the entire frequency range covered by the combination.

While it is theoretically possible to construct an electrostatic speaker capable of response over the full audio frequency range, such a speaker would be inordinately large and impractical for ordinary use. On the other hand it is also theoretically possible to employ a multiplicity of dynamic speakers each designed to cover a small selected range of frequencies. In constrast with either of these theoretical possibilities, the present invention makes practical substantially transient free reproduction throughout the entire audio spectrum by the use of only two speakers, each of moderate size in an enclosure substantially smaller than conventional multi-unit speaker systems employing electrostatic speakers for all or a portion of the spectrum. In turn, this provides for distortion free reproduction throughout the audio spectrum by relatively simple and inexpensive components.

I claim:

1. An electrostatic speaker comprising a pair of windowed and opposed planar clamping frames, a pair of electrically conductive perforated plates overlying opposed frame windows, a sandwich of elements clamped between the frames including a pair of planar membranes having electrically conductive coatings on adjacent sides and spacer means between the membranes adjacent the perimeter thereof with the central area of the membranes unobstructed by the spacer means, the spacer means having a vent providing communication between the central space between the membranes and the surrounding atmosphere, and the spacer means being electrically conductive and being in electrical contact with the conductive coatings of the membranes, the elements of the sandwich being clamped between the clamping frames with the membranes under tension in substantially all directions in the planes of the membranes, and spacer strips between the outer sides of the membranes and the edges of the perforated plates.

2. An electrostatic speaker comprising a pair of opposed planar clamping frames, a pair of electrically conductive perforated plates mounted in the frames, a sandwich of elements clamped between the frames including a pair of planar membranes each having an electrically conductive coating on a side thereof and electrically insulated from the perforated plates, spacer means between the membranes adjacent the perimeter thereof with the central region of the membranes unobstructed by the spacer means, and the spacer means having a vent providing communication between the central space between the membranes and the surrounding atmosphere, and the elements of the sandwich being clamped between the clamping frames with the membranes under tension in the planes thereof, and other spacer means between the outer sides of the membranes and the perforated plates, at least a portion of the spacer means at the coated sides of the mem-

branes being electrically conductive and being in electrical contact with the conductive coatings of the membranes.

3. An electrostatic speaker according to claim 2 in which the membranes are provided with electrically conductive coatings on their adjacent sides and further in which the spacer means between the membranes comprise an electrically conductive element in electric contact with the adjacent coatings of both membranes.

4. An electrostatic speaker according to claim 2 in which the perforated plates are sectionalized and comprise plate sections arranged in opposed pairs at opposite sides of the membranes and in which the membranes each extend throughout the area of a plurality of pairs of opposed plate sections.

5. An electrostatic speaker comprising a pair of opposed planar clamping frames, a planar membrane having an electrically conductive coating on a side thereof, a strip of yielding material in contact with the opposite side of the membrane adjacent the perimeter thereof, an electrically conductive element in electrical contact with the conductive coating of the membrane, said element comprising a perforated strip adjacent the perimeter of the membrane opposite to the strip of yielding material, the membrane being under tension and the yielding material and the perforated strip being clamped between the clamping frames to thereby press the coated side of the membrane into the perforations of the perforated conductive strip, and a perforated electrically conductive plate electrically insulated from the membrane coating and mounted in a plane spaced and parallel to the plane of the membrane.

6. An electrostatic speaker comprising a pair of opposed planar clamping frames with a sandwich of elements clamped therebetween including a pair of spaced planar membranes each having an electrically conductive coating on a side thereof, yielding material at the opposite side of each membrane adjacent the perimeter thereof, electric contact means for the conductive coatings of the membranes comprising at least one perforated strip adjacent the perimeter of the membranes opposite to the yielding material, the membranes being under tension in the planes thereof and the yielding material and the contact means being clamped between the clamping frames to thereby press the coated side of the membranes against the contact means, the yielding material and the electrical contact means being arranged to leave the central area of the membranes unobstructed, and the central space between the membranes being vented, and a pair of perforated electrically conductive plates electrically insulated from the membrane coatings and mounted in planes spaced at opposite sides of the pair of membranes and parallel to the planes thereof.

7. An electrostatic speaker comprising a pair of electrically conductive planar perforated plates mounted in spaced parallel planes, a pair of planar membranes spaced from each other in planes between the planes of the perforated plates and each having an electrically conductive coating on a side thereof and electrically insulated from the perforated plates, spacer means between the membranes adjacent the perimeter thereof, other spacer means between the outer sides of the membranes and the perforated plates, the spacer means between the membranes being arranged to leave the central area of the membranes substantially unobstructed and to provide a vent between the central space between the membranes and the atmosphere, at least a portion of the spacer means at the coated sides of the membranes being electrically conductive and being in electrical contact with the conductive coatings of the membranes, and means mounting the membranes under tension in substantially all directions in the planes thereof.

8. An electrostatic speaker comprising a pair of opposed planar clamping frames with a sandwich of elements clamped therebetween including a pair of planar membranes each having an electrically conductive coating on a side thereof, spacer means between the membranes adjacent the perimeter thereof arranged to leave the central area of the membranes substantially unobstructed and arranged to provide a vent between the central space between the membranes and the atmosphere, the membranes and said spacer means being clamped between the clamping frames with the membranes under tension in the planes thereof, a pair of electrically conductive perforated plates at opposite sides of the pair of membranes and electrically insulated from the conductive coatings of the membranes, and other spacer means between the outer sides of the membranes and the perforated plates, at least a portion of said spacer means at the coated sides of the membranes being electrically conductive and being in electrical contact with the conductive coatings of the membranes.

9. An electrostatic speaker comprising a plurality of electrically conductive planar perforated plates mounted in spaced parallel planes, each plate being formed of a plurality of perforated plate sections electrically insulated from each other, and the plate sections of each plate being mounted in opposed spaced pairs, a pair of planar membranes spaced from each other in planes between the planes of the perforated plates and each having an electrically conductive coating on a side thereof and electrically insulated from the perforated plates, the membranes each being extended throughout the area of a plurality of pairs of perforated plate sections, spacer means between the membranes adjacent the perimeter thereof, other spacer means between the outer sides of the membranes and the perforated plate sections, at least a portion of the spacer means at the coated sides of the membranes being electrically conductive and being in electrical contact with the conductive coatings of the membranes, and means mounting the membranes under tension in substantially all directions in the planes thereof.

10. An electrostatic speaker according to claim 9 in which the membranes are substantially rectangular and in which the pairs of plate sections are elongated in one direction with respect to the rectangular membranes and are positioned with their long edges adjacent each other, and electrical signal connections for the plate sections at each side of the speaker providing for connection of the plate sections at that side in a plurality of groups, the connections for one group having an impedance different from the impedance of the connection for another group.

11. An electrostatic speaker according to claim 10 in which there are at least three pairs of plate sections and in which one of the groups of plate sections includes the two outermost plate sections and in which another group comprises an intermediate plate section.

12. An electrostatic speaker comprising a plurality of electrically conductive planar perforated plates

mounted in spaced parallel planes, each plate being formed of a plurality of perforated plate sections electrically insulated from each other, and the plate sections of each plate being mounted in opposed spaced pairs, a pair of planar membranes spaced from each other in planes between the planes of the perforated plates and each having an electrically conductive coating on a side thereof and electrically insulated from the perforated plates, the membranes each being extended throughout the area of a plurality of pairs of perforated plate sections, spacer means between the membranes adjacent the perimeter thereof, other spacer means between the outer sides of the membranes and the perforated plate sections, and damping material in contact with edge portions of the several plate sections.

13. An electrostatic speaker assembly comprising two counterpart single ended electrostatic speakers each incorporating a planar membrane with the membranes parallel to each other, spacer means maintaining the membranes out of contact with each other, the membranes of the two speakers being congruent and the spacer means establishing substantially uniform spacing of the membranes from each other with an air film of substantially uniform thickness therebetween throughout the effective area of the membranes and the membranes being acoustically coupled with each other substantially uniformly throughout the effective area thereof to provide for vibration of the membranes together as a unit with said air film therebetween.

14. An electrostatic speaker assembly as defined in claim 13 in which each of the two counterpart single ended electrostatic speakers incorporate an electrically conductive perforated plate spaced from the speaker membrane, with the two perforated plates positioned at the outer sides of the acoustically coupled membranes of the two speakers.

15. An electrostatic speaker assembly comprising a pair of opposed planar clamping frames, a pair of parallel planar membranes having electrically conductive coatings on their sides presented toward each other, strips of yielding material in contact with the outer sides of the membranes adjacent the perimeter thereof, an electrically conductive element between and in electrical contact with the conductive coatings of the membranes, said element comprising a perforated strip adjacent the perimeter of the members opposite to the strips of yielding material, the membranes being under tension and the strips of yielding material and the perforated strip being clamped together between the clamping frames to thereby press the coated sides of the membranes into the perforations of the perforated conductive strip, and a pair of perforated electrically conductive plates at the outer sides of the membranes electrically insulated from the membrane coatings, and mounted in planes spaced from and parallel to the planes of the membranes.

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