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PRODUCTION OF SOUND

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My invention relates to the production of sound, and has for its principal object the provision of an improved loud speaker or sound producing device of the electrostatic type.

It is known that an electrostatic loud speaker constitutes a capacity load on the output circuit of the amplifier with which it is used. The actual power supplied to the electrostatic speaker and converted into sound energy is small compared with the wattless volt-amperes required for charging the electrodes to the required varying potentials. This is especially true at high frequency when the capacity reactance of the loud speaker becomes so low in comparison with the impedance of the amplifier output circuit that the amplifier fails to produce adequate potential variations between the loud speaker electrodes. The result is a loss in high frequency sound output compared with the low frequency output. The response of a well designed electrostatic speaker of the usual type will be fairly uniform up to a certain frequency, and above this frequency the response, or sound output for a given voltage applied to the amplifier input, falls rapidly. The larger the mutual capacity of the loud speaker electrodes (for a given amplifier) the lower the frequency at which this falling off in response begins to appear. It is thus incompatible with high quality sound reproduction to load an amplifier with an electrostatic speaker having more than a certain capacity, and this factor sets the limit to the useful sound which can be obtained from an amplifier of a given volt-ampere output rating.

In accordance with my invention these difficulties are avoided by dividing the area into sections which have a comparatively small electrostatic capacity, and connecting these sections through inductance devices. The arrangement may be regarded as an artificial transmission line or wave filter one end of which is connected to a high voltage source. The other end should be provided with damping resistance as indicated in the accompanying drawing. By employing this construction I simultaneously avoid two of the difficulties described above. A much larger total capacity may be employed without overloading the amplifier, and the impedance of the device, or in other words the load on the amplifier, is now the same at all frequencies within the essential audio range.

The reason that this is possible is that it is now no longer necessary to charge all parts of the electrode area to full potential simultaneously, but the several sections receive their charges in

progression, the charges being passed on from one section to the next. In fact by carrying the principle far enough, using a large number of sections and low loss inductances, it is possible to build an electrostatic speaker with which the amplifier has only to supply the energy losses, which are in large measure due to sound radiation. In practice however it will frequently be desirable to stop short of this point, not employing a sufficient number of sections to dissipate all of the energy supplied by the amplifier. The terminating resistance previously mentioned then serves to dissipate the residual energy and prevent wave reflections. Without such resistance, electrical resonance is likely to occur, with resulting irregularities in response.

Since the device has the structure of a low pass filter there will be an upper frequency limit above which it will practically cease to radiate. This cut off frequency may be made as high as necessary by properly proportioning the individual inductances and capacities. The cut off frequency is that at which the inductive reactance of one coil is four times the capacity reactance of one section of the speaker. The system operates with substantially unity power factor for the frequencies below that at which it acts as a filter. The impedance of the device is practically independent of frequency and is now very much higher than previously, being now equal to twice the capacity reactance of a single unit area, said capacity reactance being calculated for the highest frequency in the essential range, namely the cut off frequency. With the proper arrangement of units no loss in quality is involved in the employment of my invention and practically an improvement in quality will in general be experienced, on account of the reduced tendency to overwork amplifiers.

A further object of my invention is to utilize the phase differences between the several sections of the diaphragm to produce a desirable distribution of sound in the auditorium or room where the loud speaker is used. For this purpose the overall dimensions of the radiating surface must be of the order of a wave length of the lowest frequency sound which is to be closely directed. In practice it is not feasible to give accurate direction control to the lowest frequency components of sound radiated, since this would entail very large structures, but very useful directivity effects may be obtained if components of 250 cycle frequency and above are well directed. This would call for an area of the order of four feet square. It may prove desirable, where the

expense of a larger structure is warranted, to carry the direction control to considerably lower frequencies, while in other cases, smaller structures may be employed, and still much benefit secured from proper control of the directive properties of the speaker.

Considering then only the sounds of high enough frequency to be controlled, the directions they will take may be predicted by estimating the shape of the wave front of a sound wave leaving the speaker, and by utilizing the principle that sound is propagated normal to the wave front. The phase difference between the vibrations of successive sections of the diaphragm can be calculated from the well known characteristics of low pass filter circuits. It is simpler however to make the calculation in terms of the time difference, which is

$$\sqrt{LC}$$

seconds, except near and above the cut off frequency, L being the inductance of one coil and C the capacity of one section. Thus if the crest of a voltage wave reaches section n at a given time, it will reach section $n+1$ later by

$$\sqrt{LC}$$

seconds. During this time sound can travel

$$V\sqrt{LC}$$

centimeters if V is the velocity of sound in air or approximately 33000 cms. per sec. The shape of the wave front may then be determined graphically by laying out a series of arcs, each having its center at the middle of one of the diaphragm sections and having radii which differ successively in length by

$$V\sqrt{LC} \text{ cm.}$$

This is similar to the well known Huygen's construction used especially in optical problems.

My invention will be better understood from the following description when considered in connection with the accompanying drawing, and its scope will be pointed out in the appended claims.

Referring to the drawing, Fig. 1 illustrates an embodiment of my invention wherein the inductance units are interposed between the different sections of the vibratable member of the speaker, this member being interposed between a pair of stationary members maintained at potentials different from that of the vibratable member.

Fig. 2 illustrates a similar embodiment wherein only one stationary member is employed, mounted on one side of the vibratable member.

Fig. 3 illustrates an arrangement wherein the inductance elements are connected between the different sections of stationary members located on opposite sides of the vibratable member, and Fig. 4 illustrates the sequence of connections designed to secure a certain directive characteristic.

The apparatus illustrated by Fig. 1 includes a plurality of vibratable members or diaphragm sections 10 which are electrically conducting and are connected to the output circuit of the amplifier 11 through a plurality of inductance devices or reactors 13 connected between the different sections 10. On one side of the vibratable members 10 are mounted a plurality of stationary members 14 which are shown as perforated metal plates, interconnected through conductors 15, and connected to one of the amplifier circuits which for convenience I shall designate as the grounded terminal, through a source of

steady potential shown as a battery 16. It is obvious that a single continuous perforated plate might equally well be employed so far as the principle of operation is concerned. On the other side of the vibratable members 10 are mounted a plurality of similar stationary members 17 interconnected through connections 18 and connected to the grounded side of the amplifier circuit through a source of potential 19. It will be observed that the potential applied to the members 14 by the source 16 is positive and that the potential applied to the member 17 by the source 19 is negative. Under these conditions an electrostatic stress is produced between the vibratable members 10 and the stationary members 14 and 17, and the resulting forces acting upon the vibratable members or diaphragm sections 10 are substantially equal and opposite. If now a voltage is produced in the output circuit of the amplifier, the potential of the members 10 is altered, and this reduces the electrostatic force on one side and increases it on the other side, causing a movement of the diaphragm or vibratable member. This is in accordance with the principle of operation of the well known bilateral or "push-pull" electrostatic sound producer. At 12 is shown the resistance already referred to for preventing reflection of electric waves. This resistance should have a value approximately equal to

$$\sqrt{L/C}.$$

Any means such as series resistances which produces high electrical losses in the inductances or capacities at and near the end 12 of the circuit, will produce substantially the same effect as the resistance 12.

The arrangement illustrated by Fig. 2 is similar to that illustrated by Fig. 1 except that it is of the single acting or unilateral type, employing stationary electrodes on one side only of the diaphragm. The amplifier output circuit also differs from that shown in Fig. 1, in that it employs a reactor 20 instead of a transformer, this being a common form of amplifier output affording an especially simple arrangement when employed in connection with a unilateral electrostatic speaker.

In the arrangement illustrated by Fig. 3 the vibratable members or diaphragm sections are connected to a source of steady potential which is indicated here as the same as that which supplies power to the plate circuit of the amplifier. The diaphragm may be one continuous conducting sheet or separate sections with interconnecting conductors 21. The stationary members 14 and 17 are interconnected through inductance elements 22 and 23, and are connected to the output circuit of the amplifier through a transformer 24 in such a manner that the audio frequency potentials applied to the members 14 are opposite in phase to the potentials applied to the members 17. This arrangement gives the same result as that shown in Fig. 1, but has some advantage on the score of simplicity. It is important that the inductances and capacities on the two sides be closely equal, since otherwise the rate of propagation of electrical impulses will be unequal on the two sides of the diaphragm and the desired phase opposition may be lost toward the end of the chain. As a further insurance of maintenance of phase opposition it may be desirable in a structure such as shown in Fig. 3 to connect one or more auto-transformers 25 across between the elements 14 and 17 at intervals, the mid-points of the windings being connected to 154

conductor 27 which is at stationary potential. The final sections of the stationary members 14-17 are connected through damping resistors 26 to the return lead 27 which is connected both to the cathode of the amplifier 11 and to a mid-terminal on the secondary circuit of the transformer 24. This arrangement gives the same results as Fig. 1, but requires no extra sources of high potential and is safer in that the exposed outside members are at ground potential except for the modulating voltage.

The method of utilizing the phase difference between successive diaphragm sections, to secure a desired directive characteristic, is illustrated in connection with Fig. 4. For auditoriums it is often desirable to provide for considerable spreading of the sound to the right and left of the source in order to reach all of the listeners, but to permit a comparatively small degree of spreading in the vertical plane. In other words, it is desired to produce a beam of sound which spreads horizontally like a fan. This is especially the case in single floor auditoriums. The prevention of avoidable radiation toward the ceiling is helpful in reducing echoes and reverberation. In order to cause the sound to spread horizontally while being confined within narrow limits vertically, the wave front as the sound leaves the speaker should have a cylindrical form with vertical axis.

If the diaphragm sections consist of vertical strips a wave length or more high, the wave front axis will be parallel to these strips. To give it the desired cylindrical form, the radiation from the center strip must be ahead in phase compared with that from the strips to either side. This is brought about by using the sequence shown in Fig. 4. In this drawing the stationary electrodes are not shown, and it is to be understood that they would be connected as shown in Fig. 1. An electrical wave from the amplifier acts first on the section marked *a*, then on the adjacent section *b* on the right, then on section *c* on the left, then on *d* which is next outside on the right, and finally on *e* on the extreme left. This will not give a perfectly symmetrical wave, but probably a close enough approximation. If a more nearly perfect symmetry is desired, it can be obtained by arranging the strips in pairs, each pair being connected together and replacing a single section in the circuit. Thus the circuit sequence would be from amplifier through coil to section *a*, through the second coil to sections *b* and *c*, through a third coil and to sections *d* and *e*, through a fourth coil and to ground through the damping resistance 12. In such an arrangement the pairs should have the same capacity as the single sections which they replace in the circuit. This would in general involve dividing the total area into a larger total number of sections.

It is obvious that the principle herein outlined may be employed to produce a wave front of other shape than that used for illustration. It is also obvious that this method of controlling wave shape or directivity is alternative to or may be supplementary to the method which depends upon disposing the radiating elements over a curved instead of a plane surface. If all parts of the diaphragm moved in phase, as in the case of the ordinary electrostatic loud speaker, for example, directivity can be controlled by shaping the entire radiating area to the same shape as the desired wave front. Thus the radiating area might be given a cylindrical form. An illustration of supplementary action of the two methods would be the case where in addition to the horizontal divergence, a small amount of vertical

divergence is desired. Here the horizontal divergence might be secured by means of the phase difference between successive sections, while the vertical divergence might be obtained by curving the strips, so that the total surface formed a cylindrical surface with horizontal axis. This gives a structure much easier to construct than one having a double curvature, while the divergence in the two directions can be independently controlled.

As is well known in the art of designing electrical filters or artificial lines, there are two terminal arrangements either one of which may be used. If the line consists of a number of series inductances *L* henrys alternated with shunt capacities *C* farads the termination of the structure at both ends may be either capacities of *C*/2 farads or inductances of *L*/2 henrys. The former gives what is called a π line and the latter a *T* line. Thus for example a π line might consist of five capacities *C* and two capacities *C*/2 at the ends and with six coils of *L* henry between, while a corresponding *T* line would have six capacities of *C* farads, five coils between of *L* henrys each, and two terminating coils of *L*/2 henrys each.

If the device produces a convex wave front, the sound will seem to emanate from a small source behind the screen. The sound may be caused to seem to emanate from a small source in front of the screen by producing a concave wave front. This can be brought about by reversing the connections from those shown in Fig. 4 so that section *c* is connected to the amplifier and section *a* which is at the center is connected to the damping resistance 12, in each through a coil of *L*/2 henrys as before.

An incidental advantage of my invention over the usual type of electrostatic loud speaker is that the reduced capacity per section reduces the destructiveness of a spark should a spark occur between electrodes. With a large capacity charged to high potential, a spark may readily be hot enough to burn a hole through the diaphragm which must be of very light material. With the small sections a much less intense spark occurs for the same voltage. The adjacent sections may discharge through the arc but to do so must build up currents through the intervening coils, and this slows down the discharge and permits the energy to be largely dissipated in the coils instead of in the spark.

While as I have already pointed out the subdivision and introduction of inductances may be applied either to the vibratable element or diaphragm, or to the stationary electrodes, and in the latter case the diaphragm may be a continuous conducting sheet; it is practically necessary for best results that the parts of the diaphragm opposite the several sections of stationary electrode, shall be capable of substantially independent vibration. This is for the reason that the forces due to the electrostatic field differ in phase between the several sections and each part of the diaphragm should be capable of vibrating in phase with the force applied to it. This mechanical independence of the diaphragm panels may be secured by providing mechanical supports for the diaphragm at the edges of the panels. Thus, if the electrical subdivision is of the stationary electrodes, the diaphragm, while not necessarily electrically subdivided, is preferably mechanically subdivided.

What I claim as new and desire to secure by Letters Patent of the United States, is

- 1. The combination of a vibratable member, a stationary member mounted in juxtaposition to said vibratable member, at least one of said members being divided into sections in series with one
5 another, means for producing an electrostatic field between said members, and means including inductance elements connected between said sections for neutralizing the capacitance between said members. 80
- 10 2. A sound producer comprising a vibratable means arranged in sections interconnected through inductance elements, and stationary means mounted in juxtaposition to said vibratable means, said inductance elements neutralizing
15 the capacitance between said vibratable means and said stationary means. 85
- 3. A sound producer comprising a diaphragm divided into sections connected in series, stationary means arranged in juxtaposition to said diaphragm, and means including inductance elements
20 connected between said sections for neutralizing the capacitance between said diaphragm and said member. 90
- 4. A sound producer including a diaphragm divided into sections, stationary means mounted in juxtaposition to said diaphragm and divided into sections, and means connected between the sections of said diaphragm for neutralizing the capacitance between said diaphragm and said
25 stationary means. 95
- 5. A sound producer including stationary means, a vibratable member divided into sections connected in series and mounted in juxtaposition to said stationary means, and means connecting said sections arranged to cause the vibrations of successive sections to differ in phase, said sections being connected in such sequence that the resulting sound wave is given a predetermined degree of curvature.
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- 6. The combination of a vibratable member divided into sections, a stationary member divided into sections interconnected with one another in series and mounted in juxtaposition to the sections of said vibratable member, means to produce an electrostatic field between the sections of said stationary member and the sections of said vibratable member, inductance means comprising elements connected between the sections of said vibratable member for neutralizing the capacitance between said vibratable and stationary members, and means connected in circuit with said vibratable member for preventing the reflection of electrical waves propagated from section to section of said vibratable member.
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- 7. An electrostatic loud speaker including vibratable and stationary members mounted in juxtaposition to one another, one of said members being divided into sections, and means connected between said sections for neutralizing the capacitance between said members. 80
- 8. An electrostatic loud speaker including vibratable and stationary members mounted in juxtaposition to one another, one of said members being divided into sections, means connected between said sections for neutralizing the capacitance between said members, and means for preventing reflection of electrical waves propagated between said sections. 85
- 9. An electrostatic loud speaker including vibratable and stationary members mounted in juxtaposition to one another, one of said members being divided into sections, means for neutralizing the capacitance between said members and for causing a difference in phase of the sound waves emitted by different portions of said vibratable member, and means including said first-named means to connect said sections in such sequence as to produce a predetermined curvature of sound wave front. 90
- 10. A sound producer comprising a vibratable means arranged in sections interconnected in series through inductance elements, and stationary means mounted in juxtaposition to said vibratable means. 100
- 11. A sound producer including a diaphragm divided into sections connected in series, stationary means mounted in juxtaposition to said diaphragm and divided into sections, and means connected between the sections of said diaphragm for neutralizing the capacitance between said diaphragm and said stationary means. 105
- 12. An electrostatic loud speaker including vibratable and stationary members mounted in juxtaposition to one another, one of said members being divided into sections connected in series, means connected between said sections for neutralizing the capacitance between said members and resistance means connected in circuit with one of said members for preventing reflection of electrical waves propagated between said sections. 115
- 13. An electrostatic sound translating device comprising a plurality of members forming plates of condensers, certain of said members being capable of radiating sound energy, and impedance means connected between certain of said members for neutralizing the capacity of said condensers, said condensers and said means being proportioned and correlated to define an electro acoustic network adapted to translate sound energy with substantially negligible attenuation over a wide range of audio-frequencies. 120

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