Nov. 7, 1939. H. J. VON BRAUNMÜHL ET AL 2,179,361

CONDENSER MICROPHONE

Filed March 30, 1936 2 Sheets-Sheet 1

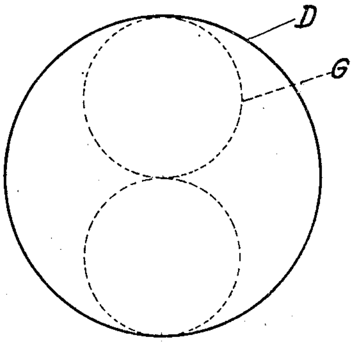

Fig. 1

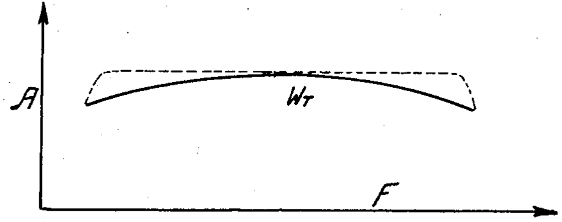

Fig. 2

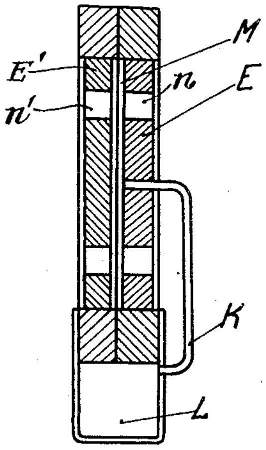

Fig. 3a.

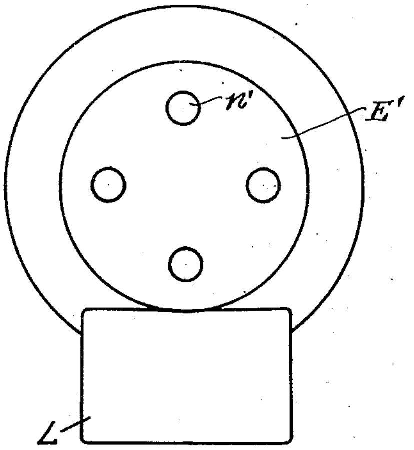

Fig. 3.b.

Inventors

Hans Joachim von Braunmühl &
Walter Weber
By Knight Bros.
Their Attorneys

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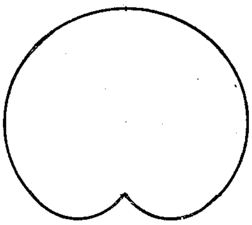

Fig. 8

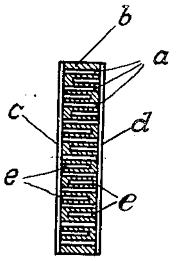

Fig. 4

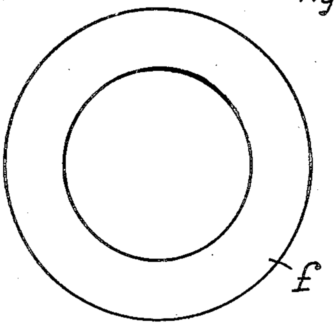

Fig. 9

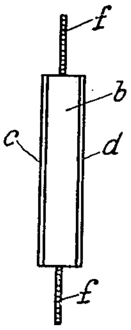

Fig. 10

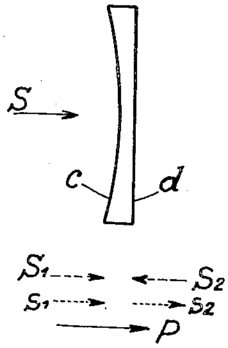

Fig. 5

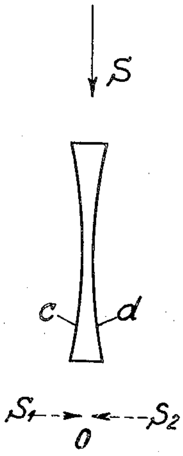

Fig. 6

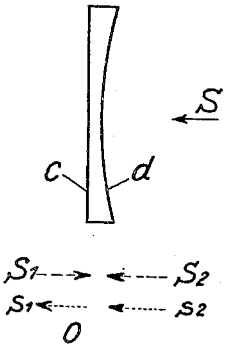

Fig. 7

Inventors

Hans Joachim von Braunmühl +
Walter Weber
By Knight Bros
Their attorneys

UNITED STATES PATENT OFFICE

2,179,361

CONDENSER MICROPHONE

Hans Joachim von Braunmühl, Berlin-Ruhleben, and Walter Weber, Berlin-Charlottenburg, Germany

Application March 30, 1936, Serial No. 71,792
In Germany April 4, 1935

7 Claims. (Cl. 179—111)

This invention relates to improvements in or relating to microphones, and more particularly to electrostatic or condenser microphones.

The best known microphones, particularly the condenser microphones previously introduced into practice, are so-called sound pressure receivers, since only one side of the membrane or diaphragm is exposed to the sound field. Since the sound pressure is a scalar quantity all sound pressure receivers possess the property that their sensitivity is not dependent on the direction of incidence of the sound but is the same for sound waves coming from different directions, at least for the low and middle frequencies. This can be shown by the fact that if the sensitivity of the microphone or the effect of the sound pressure on the microphone, relative to the direction of incidence of the sound, is platted for a single plane, the curve obtained is a circle at the centre of which the membrane of the microphone is located. This means, therefore, that the pressure microphone shows a characteristic, which represents the sensitivity according to the direction of the sound (known in short as the directional response characteristic) which is in the form of a circle.

Such pressure microphones are certainly advantageous for many purposes, e. g., for picking up conversations of a plurality of speakers gathered around the microphone. For many other purposes, however, where the selective picking up a single sound source from a particular direction is desired with the suppression as far as possible of sound waves from other directions, a microphone having the best possible directional response characteristic, i. e., having a decided maximum sensitivity for one particular direction, is required. It is certainly possible, by employing complicated auxiliary devices of large dimensions, e. g., reflectors, to impart to pressure microphones also a certain directional action. The employment of such devices is, however, possible only to a limited extent.

A microphone which is sensitive for a particular direction of sound can, however, be constructed if, instead of using the scalar property of the sound pressure, the vectorial quantity of the difference in pressure for two neighbouring points of the sound field is used for actuating the microphone. In this case the quantity of the effect of the sound on the membrane or a corresponding member of the microphone is represented by the sound pressure gradient. This principle has been realised for an electrodynamic microphone by the ribbon microphone exposed on both sides to the action of the sound.

The object of the present invention is, however, to provide a pressure difference microphone operating on the capacitative principle. This can be effected according to the invention by arranging the diaphragm or membrane to be struck by the sound waves not only on one side but on both sides.

According to the present invention, therefore, there is provided a condenser microphone in which the membrane acting as the movable plate or electrode of the condenser is exposed on both sides to the sound by the provision of perforations in the fixed plate. Further, the distance between the membrane and the perforated plate is arranged to be small in proportion to the size of the perforations and the spacing thereof, in order to obtain high frictional damping of the membrane for a purpose which will be hereinafter described.

Condenser microphones of this kind have the property of converting into electrical oscillations only those sound waves which come from a particular directions, whilst sound waves from certain other directions are transmitted electrically to a considerably lesser extent or not at all.

In order that the invention may be well understood it will now be described by way of example only with reference to the accompanying drawings, in which

Figure 1 shows diagrammatically the directional response characteristic of the pressure difference microphone which may also be termed a pressure gradient microphone, compared with that of the pressure microphone,

Figure 2 is a curve illustrating the dependence on frequency of the response of the pressure difference microphone,

Figures 3*a* and 3*b* illustrate in side sectional elevation and rear plan view respectively a microphone according to the invention,

Figure 4 illustrates a microphone according to another embodiment of the invention,

Figures 5, 6 and 7 illustrate diagrammatically the membrane displacements of a microphone according to the invention under the action of the sound pressure and sound pressure difference for different directions of sound incidence.

Figure 8 shows the directional response characteristic of a microphone according to the invention, and

Figures 9 and 10 illustrate in front and side view respectively a microphone provided with means for increasing the sound pressure difference.

Referring first to Figure 1, the circle D represents the directional response characteristic of the pressure microphone and shows that the sound, which acts on a microphone located at the centre of the circle, influences the membrane to an equal extent from all directions. If, however, the microphone is of the above-mentioned construction such that the membrane is influenced on both sides by the sound, the directional response characteristic obtained consists of two circles G, which touch at the line in which the microphone can be regarded as located. The directional response characteristic of the pressure gradient microphone has, therefore, the form of figure 8. This characteristic of the pressure gradient microphone shows that the membrance is most strongly influenced by sound incident in a direction at right angles to its plane., i. e., at right angles to the horizontal line of the diagram, that is to say from the front or rear, whilst the membrane is not influenced by sound incident in a direction parallel to the membrane.

On grounds of symmetry it may be advantageous to arrange on the second side of the membrane a plate similar to the fixed condenser plate. With an unsymmetrical arrangement the circles G (Figure 1) would be of unequal size.

Such a microphone is diagrammatically illustrated in Figures 3^a and 3^b. The fixed condenser plate E has a plurality of openings *n*, and at the other side of the membrane M is located a plate E′ similar in shape and arrangement to the fixed plate E. This plate either does not take part electrically in the operation of the microphone, or is connected in a particular manner known in connection with differential microphones. The function of the parts K and L will be referred to later.

In order that a capacitive microphone may possess a horizontal frequency curve, it is necessary that the amplitude of the membrane be constant over the audible range. Since the membrane of the microphone is exposed to the sound field on both sides, the difference in sound pressures at the front and rear sides is proportional to the drive of the membrane. This sound pressure difference has, however, a rising frequency characteristic up to that frequency at which the half wave length corresponds to the difference in path between the front and rear sides of the microphone button.

During the movement of the membrane the quantity of air located between the membrane and the fixed electrode is displaced. The force necessary for this displacement increases with increasing frequency. An increasing force having this dependence on frequency is available, however, in the operative pressure difference, so that the membrane executes oscillations of the same amplitude over the whole range of frequencies.

Since, according to the invention, the distance between the membrane and the perforated plate is small in proportion to the diameter of the perforations and the spacing thereof, with the effect that the membrane would suffer a high damping by friction of air, therefore, a completely horizontal frequency curve over the whole range of sounds would only be obtained if the friction control widely exceeds the mass control and the elastic control of the membrane. Since this is not technically desirable on grounds of sensitivity, and the employment of a not too great friction is advantageous, there is obtained in practical constructions a dependence on frequency having the characteristic of a highly damped resonance curve, as shown in Figure 2.

The frequency is plotted as abscissae F and the amplitude of the membrane as ordinates A. The resonance curve is shown by a full line. Its flat course with a weak maximum at the point W_r shows the high degree of damping. The damped natural frequency of the membrane is arranged to lie in the middle range of frequencies by a proper selection of its mass and its elasticity. This curve can, by the following measures, be improved so that the frequency curve, shown in dash-lines and having for the most part a horizontal course, is obtained.

For the high frequencies the arrangement of a flat air cavity in front of the membrane brings about an increase in the driving force. By suitable dimensioning of the air cavity the position and the degree of this increase can be suited to the falling characteristic of the frequency curve (right hand part of the curve, Figure 2).

For the lower range of sounds the fall of the frequency curve (left hand part of the curve, Figure 2) can be compensated by coupling one or more closed air cavities with parts of the membrane. Figure 3 shows such a construction by way of example. A completely closed cavity L is coupled by means of a tube K with the space between the membrane M and the fixed electrode E. By suitable shaping and dimensioning this coupled closed air cavity the strength and progress with frequency of the desired compensating increase can be dimensioned for the fall at lower frequencies.

If a microphone constructed in accordance with the invention is of such dimensions that its diameter is not greater than the wave length of the highest frequency to be transmitted, there is obtained a microphone which is extremely satisfactory in operation, since the satisfactory properties of directional response are further supplemented by a good frequency curve. The upper limit of the diameter lies at about 3 cms. corresponding to a wave length of 10.000 Hertz (cycles per second). For the lower limit the consideration arises in connection with the construction that with reduction of the diameter the sensitivity of the microphone is reduced. It follows from this that the most satisfactory dimension of the microphone described is such that even having regard to the lower limit of sensitivity the diameter is approximately 3 cms.

The basic form of the pressure gradient microphone, which as above described possesses a fixed perforated plate, can be altered by mounting a second membrane on the rear side of this fixed plate. The action obtained thereby will be explained more detailed in the following.

For a large number of purposes of employment a condenser microphone would be required which, whilst retaining its otherwise good transmitting properties accepts sounds from a particular direction selectively and is less sensitive for the remaining directions of incidence. This property can be achieved by the arrangement constructed as described in the following and illustrated by way of example in Figure 4 in cross-section.

On both sides of a metallic plate *b* provided with bores *a* extending through it, which plate constitutes the fixed plate of the condenser, are mounted two membranes *c* and *d* having similar mechanical properties. One membrane *c* is electrically conducting and is used as the counterplate or electrode for the perforated plate or electrode *b*; the other membrane *d* is electrically operative. Under influence of the sound waves such a system of two membranes executes two principal movements. On the one hand the sound pressure causes a movement with respect to one another of the two membranes with compression of the enclosed volume of air. On the other hand there occurs, owing to the difference in the sound pressures acting on the two sides a parallel displacement of both membranes, the enclosed volume of air being carried along with them. The manner of operation for sound incidence from various directions is shown in Figures 5 to 7. In the case of incidence of sound normally to the electrically operative membrane (Figure 5) the sound pressure represented by the arrow S, causes a membrane movement of the sense and magnitude of the arrows S_1, S_2, and the sound pressure difference causes a movement of the sense and magnitude of the arrows s_1, s_2. The resultant movement of the electrically operative membrane *c* is proportional to the sum of the two sound pressures acting on it, that is S_1+s_1. It is represented in Figure 5 in direction and magnitude by the arrow P. In the case of lateral sound incidence, represented in Figure 6 by the arrows S, the arrows S_1, S_2 again represent the membrane movement under the influence of the sound pressure. Since they are equal but oppositely directed, there is no sound pressure difference (represented by "0"). The arrow P represents the small movement in this case of the membrane *c*. In the case of incidence of the sound from the rear on to the electrically inoperative membrane *d* (arrow S in Figure 7), the arrows S_1, S_2 as in the previous cases show the membrane movement under the influence of the pressure and the arrows s_1, s_2 represent the membrane movement under the influence of the pressure difference. The resultant movement of the operative membrane *c* is in this case zero, as S_1 and s_1 are oppositely directed. Movement of the electrically inoperative membrane *d* only occurs. Such a microphone possesses on this account a directional response characteristic in the form of the cardioid shown in Figure 8. In this case the microphone is to be regarded as being on the horizontal line parallel with the membrane, so that the vertical line in Figure 8 is perpendicular to the electrically operative membrane.

The condition for a decreasing or vanishing sensitivity for sounds from rearward directions is the equality of the membrane displacements under the influence of the sound pressure and under the influence of the sound pressure difference. The displacement of the membrane caused by the sound pressure difference is determined by the properties controlling the movement of the membrane and the magnitude of the sound pressure difference. The latter is determined by the length of path between the front and rear sides of the membrane, i. e. simply by the diameter of the microphone.

For the production of a straight line frequency curve the movement of the membrane must be principally determined by friction. Similarly for the production of a constant displacement of the friction controlled system independent of the frequency, the driving force must increase with the frequency, i. e., the pressure difference must increase as far as the upper limiting frequency of the transmission range. This requirement is fulfilled if the length of path between the front and rear sides of the membrane for the upper limiting frequency is smaller than a half wave length. Accordingly the diameter is preferably arranged to be about 3 cm., as above explained.

The electrode *b* possesses, according to Figure 4, besides the bores *a* extending through it a number of shorter bores *e* not extending through it. Their number, size and arrangement influences the membrane displacement caused by the action of the sound.

The requirement referred to above, that the cophase membrane movement shall be friction controlled, has the result that the sensitivity of the microphone is reduced in proportion. It is, however, possible to compensate for the falling-off in sensitivity in the case of reduced friction for the low frequencies due to the elastic properties, by increasing the pressure difference for these frequencies. This can, for example, be done by surrounding the microphone button, as shown in Figures 9 and 10, with an annular sheet *f* of a material such as possesses a sound permeability dependent on frequency in the sense that the outer ring or annules offers a greater resistance to the passage of sound at low frequencies than at middle and high frequencies. An arrangement such as is illustrated in Figures 9 and 10 acts for the low frequencies as if the diameter of the microphone had been increased. A suitable material for the sheet *f* is gauze.

The described microphone arrangement may also be so constructed that it can be used as a directional or non-directional microphone according to the manner in which it is connected. For this purpose it is only necessary to make both membranes electrically conducting. For a directional microphone one membrane remains unconnected, and for a non-directional microphone both membranes are used connected in parallel.

Having now particularly described and ascertained the nature of our said invention and in what manner the same is to be performed, we declare that what we claim is:

1. In a condenser microphone a fixed condenser plate having transverse perforations extending from side to side and also having recesses extending from each plate side only partway to the other side, a diaphragm constituting the movable condenser plate and being spaced from said fixed plate by a distance small compared with the diameter and spacing of said perforations and recesses and of a value which would render the frictional air damping on said diaphragm high as compared with its mass- and elasticity damping and a second diaphragm disposed on the other side of said fixed plate at a distance similar to the spacing of said first mentioned diaphragm.

2. A condenser microphone having a fixed electrode and a movable diaphragm electrode fixed only at its periphery and spaced from said fixed electrode, said fixed electrode having a relatively small number of wide-spaced transverse perforations through which the side of the diaphragm electrode facing the fixed electrode is exposed to the effect of the sound waves, the distance between the diaphragm and said fixed electrode being small with respect to the diameter and the spacing of said perforations and of a value which would render the frictional air damping on the diaphragm high as compared with its mass- and elasticity damping and a plane sheet of material surrounding said fixed electrode in its plane, said material having a sound transmission which decreases with increasing frequency.

3. A condenser microphone having a fixed elec-

trode and a movable diaphragm electrode fixed only at its periphery and spaced from said fixed electrode, said fixed electrode having a relatively small number of wide-spaced transverse perforations, the distance between the diaphragm and said fixed electrode being small with respect to the diameter and the spacing of said perforations and of a value which would render the frictional air damping on the diaphragm high as compared with its mass- and elasticity damping, a second diaphragm disposed on the other side of said fixed electrode at a distance similar to the spacing of said first-mentioned diaphragh and adapted to transmit the sound waves through said perforations to said first diaphragm, and a plane sheet of material surrounding said fixed electrode in its plane, said material having a sound transmission which decreases with increasing frequency.

4. In a condenser microphone a fixed condenser plate having a relatively small number of transverse perforations uniformly spaced over its area, and having a diameter not greater than the wave length of sound at the highest frequency to be transmitted, and a movable condenser plate of similar diameter and being spaced from one side of said fixed plate a distance small with respect to the diameter and spacing of said perforations and of a value which would render the frictional air damping on the diaphragm high as compared with its mass- and elasticity damping, and whereby the sound acts upon both sides of said diaphragm, and a plane sheet of material surrounding said fixed electrode in its plane, said material having a sound transmission which decreases with increasing frequency.

5. In a condenser microphone a fixed condenser plate having transverse perforations extending from side to side and also having recesses extending from each plate side only partway to the other side, a diaphragm constituting the movable condenser plate and being spaced from said fixed plate by a distance small compared with the diameter and spacing of said perforations and recesses and of a value which would render the frictional air damping on said diaphragm high as compared with its mass- and elasticity damping, and a second diaphragm disposed on the other side of said fixed plate at a distance similar to the spacing of said first mentioned diaphragm, the diameter of said fixed condenser plate and of said diaphragms being not greater than the wave length of sound at the highest frequency to be transmitted.

6. In a condenser microphone a fixed condenser plate having transverse perforations extending from side to side and also having recesses extending from each plate side only partway to the other side, a diaphragm constituting the movable condenser plate and being spaced from said fixed plate by a distance small compared with the diameter and spacing of said perforations and recesses and of a value which would render the frictional air damping on said diaphragm high as compared with its mass- and elasticity damping, and a second diaphragm disposed on the other side of said fixed plate at a distance similar to the spacing of said first mentioned diaphragm, the diameter of said fixed condenser plate and of said diaphragms being not greater than the wave length of sound at the highest frequency to be transmitted, and a plane sheet of material surrounding said fixed electrode in its plane, said material having a sound transmission which decreases with increasing frequency.

7. A condenser microphone having a fixed electrode and a movable diaphragm electrode fixed only at its periphery and spaced from said fixed electrode, said fixed electrode having a relatively small number of wide-spaced transverse perforations through which the side of the diaphragm electrode facing the fixed electrode is exposed to the effect of the sound waves, the distance between the diaphragm and said fixed electrode being small with respect to the diameter and the spacing of said perforations and of a value which would render the frictional air damping on the diaphragm high as compared with its mass- and elasticity damping, a second diaphragm disposed on the other side of said fixed electrode at a distance similar to the spacing of said first-mentioned diaphragm, and a plane sheet of material surrounding said fixed electrode in its plane, said material having a sound transmission which decreases with increasing frequency, the diameter of said fixed condenser plate and of said diaphragm being not greater than the wave length of sound at the highest frequency to be transmitted.

HANS JOACHIM VON BRAUNMÜHL.
WALTER WEBER.