DIAPHRAGMLESS MICROPHONES

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Introduction. The passage of a sound wave through a fluid will cause periodic disturbances in the pressure, density, temperature, and particle velocity at any given point. A microphone is a device which can convert the variations in one of these properties into periodic electrical potential differences. If a microphone is to be used as a laboratory device of a dependable nature, it must have the following characteristics: high sensitivity, constant response, and linear response. The first means that an appreciable voltage output must be obtained from even a barely audible sound; the second, that readings taken under identical conditions must be reproducible day after day; the last means that the voltage produced must be strictly proportional to the excess pressure in the sound wave and that this relation must be independent of frequency. The required range of this linear response depends on the use to which the instrument is put. If it is for a loud-speaking system, the range is from about 50 to 10,000 cycles per sec.; for measurements throughout the audible range, it must extend from about 20 to 25,000 cycles per sec. It is quite probable that, before many years, an instrument may be required that will produce ultra-sonic disturbances as well.

Most modern microphones consist of a diaphragm, usually stretched, which is agitated by sound waves impinging upon it. It is a well known fact that all supported bodies possess natural frequencies which are determined by the construction of the body and its supports. Resonance results in such a microphone if one of the frequencies of the impinging sound wave train is equal to one of the natural frequencies of the diaphragm. A deviation from linear response, commonly called "frequency distortion," is the result. This frequency distortion can be corrected in three ways: by designing the diaphragm to have no resonant frequencies in the usable range; by compensating for distortion in some other electrical network; or by designing a microphone to have no vibrating parts—a "diaphragmless microphone." Much work has been done in the laboratories of the Physics Department of Indiana University on the last of these possibilities (1).

This paper is a report concerning four devices which were built and tried at Indiana University as possible diaphragmless microphones. In all cases the models were connected to an amplifier which was in turn connected to a dynamic speaker. The amplifier used in this investigation was built by Mr. Conrad and had a maximum voltage amplification of 50,000. There was built also a single stage push-pull amplifier so designed that it could be coupled ahead of the main amplifier, thus allowing a push-pull input to the amplifying system. Since the voltage amplification was two orders greater than that commonly used in practice, it was assumed that any model was not usable if ordinary audible sounds could not be reproduced by the system, so as to give an audible output.

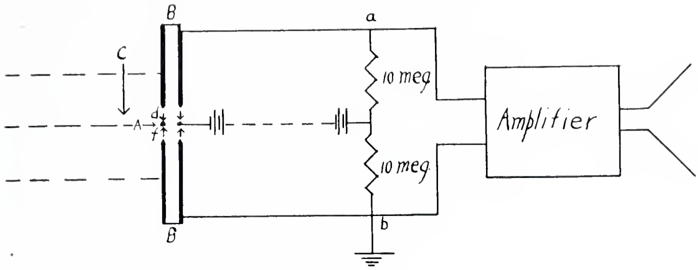

Fig. 1.

First model. The first model consisted of twenty identical parallel elements, two of which are shown in cross-section in Fig. 1. Each element consisted of three parts: two were metal strips each having one sharp edge as shown by the parts labelled *B*, the third was a wire placed midway between and parallel to the two edges. The wire is labelled *A* in the diagram. The twenty elements were connected in parallel forming three units; two units of twenty edges each, the third a unit of twenty wires. The negative terminal of a set of batteries was connected to the set of wires while the positive terminal was connected to the two sets of edges through two ten megohm resistors. Since ions are usually produced at surfaces of greatest curvature, the edges were sources of positive ions which were neutralized at the surfaces of the wires. The point *b* was grounded and the points *a* and and *b* were connected to the input of the amplifier-loudspeaker system.

Theory and results. Positive ions moved along paths indicated by the small arrows *d* and *f*. When a condensation was made to pass in the direction of the arrow *c*, ions indicated by the arrow *d* were speeded up, while ions indicated by the arrow *f* were retarded. It was first thought that the small currents in the two resistors would be varied in opposite directions so that a difference of potential would be produced between points *a* and *b*. Voltages up to 700 were tried on the model without any detectable response. At this voltage, sparking set in, which stopped any further increase in applied potential. The real failure of the model was due to the inability of the edges to produce ions faster than the wire could neutralize them. Thus, any increase or decrease in the velocity of the ions did not appreciably affect the total number of ions neutralized per second. If an appreciable cloud of ions could have been formed about the wires in any manner, a positive response would probably have been noted.

Second model. A second model was built using again a discharge from an edge, but at the same time, taking advantage of the fact that the ions were produced at a constant rate. A schematic drawing of the assembly is shown in Fig. 2. The ions traveled from the edge along the two dotted paths to two like conductors *A* and *B*, between which was placed a sheet of mica *c*. The surfaces next to the mica were polished to mirror-like smoothness so that the mica could be as thin as possible. The conductors *A* and *B* were connected through two resistors to the negative terminal of a battery, the positive terminal being connected to

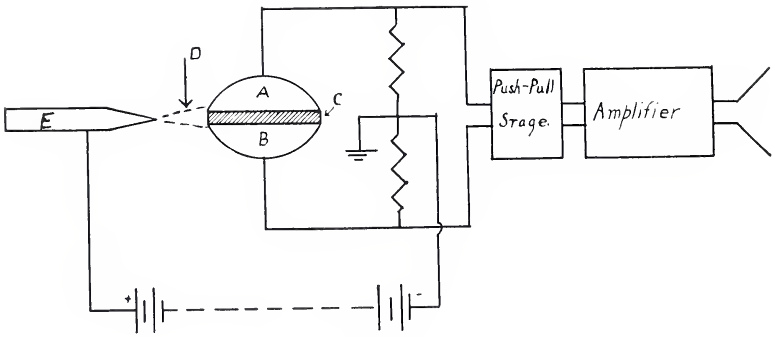

Fig. 2.

the edge *E*. The ends of the two resistors were connected to the push-pull unit, which was in turn connected to the amplifier-speaker system as shown.

Theory and results. When a condensation was made to pass in the direction as shown by the arrow *D*, some of the ions from the upper path might have been driven to the lower path, thus decreasing the current through the upper resistor and increasing it through the lower. The model, however, gave no detectable response. This was due in all probability to the thickness of the mica being large compared to the displacement of an air molecule by the passage of a sound wave. The thickness used was about .001 cm. What was actually needed was a non-conducting film about .000001 cm. in thickness. Several attempts were made to produce a suitable film, but none proved successful.

Third model. A third model was tried depending on the variation of the index of refraction of air as a sound wave passes. Calculations indicate that in such cases any bending of a beam of light would be extremely small. Consequently, this model was based instead on the variation of intensity of transmitted light with the variation of the angle of incidence when the latter is near the critical angle. This set-up can be understood by reference to Fig. 3. Four prisms with plate glass sides were built together as shown. Prisms *A* and *C* were air-filled and completely enclosed so as to have constant air density. Prism *D* was filled

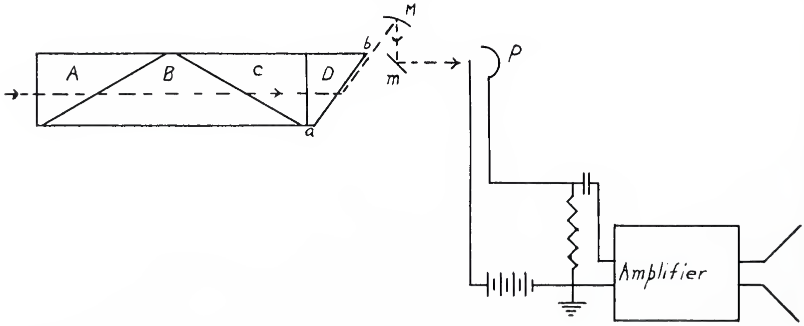

Fig. 3.

with water and so designed that light would emerge almost parallel to the surface as shown by the path of the ray of light passing from left to right. Prism *B* was air filled and had its two ends open to the air. Sound was made to travel normally to the plane of the drawing through the prism *B*, thus varying the density within it. The light was collected by a concave mirror *M*, and reflected by a plane mirror *m*, and focused on a photo-electric cell *P*. The output of the cell was amplified in the usual manner.

Theory and results. The variable density in prism b caused a variation in the index of refraction, which in turn caused a slight variation in the angle of incidence on the surface *ab*. The index of refraction of air is given by the following formula, due to Ayrton and Perry (2).

$$n=\sqrt{1+.000586p/76}.$$

By differentiation,

$$dn=.000586p/76\times dp/2\sqrt{1+.000586p/76}.$$

Since for ordinary sounds, dp = .0000075 cm. of Hg, and if we use very small finite numbers for the infinitesimals,

$$dn=2.2\times10^{-9}.$$

If a beam of light goes through a prism whose angle is A, the angle of incidence, i, and the angle of emergence, r, the following relation is true.

$$\frac{\sin(i+r-A)\sqrt{n^2-\sin^2 i}+\dfrac{\cos(i+r-A)\sin i}{n}}{\sin r}=n.$$

Allowing the angle of incidence to remain constant, and differentiating, the following equation is obtained.

$$dr=\frac{\sin r+\dfrac{n\sin(i+r-A)n}{\sqrt{n^2-\sin^2 i}}+\dfrac{\sin i}{n^2}\cos(i+r-A)}{\sin(i+r-A)\dfrac{\sin i}{n}-\sqrt{n^2-\sin^2 i}\cos(i+r-A)-n\cos r.}dn$$

In the case under consideration, $n=1$, $i=60^0$, $r=60^0$, and $A=120^0$. With the value of dn given above, $dr=3.8\times10^{-9}$ radians.

The Fresnel theory yields the following equation for the intensity of light transmitted through a surface;

$$I=\frac{1}{2}\,\frac{a^2\sin 2i\sin 2r}{\sin^2(i+r)}+\frac{\sin 2i\sin 2r}{\sin^2(i+r)\cos^2(i+r)}$$

where a is the amplitude of the incident light, i, the angle of incidence, and r, the angle of refraction. N can be eliminated by the use of Snell's law. If the relation between I and i be difierentiated graphically, we find that when i is near the critical angle,

$$\frac{dI}{di}=9610\text{ per cent per radian.}$$

It was hoped that this rapid variation would be sufficient to cause an audible response. Such was not the case. The cause of the failure was due to the small value of dn occurring in practice. The per cent change in I is given by,

$$\frac{9610 \times 2.2 \times 10^{-9}}{1.33} = 1.587 \times 10^{-5} \text{ per cent.}$$

This variation was too small to be detected with the apparatus used.

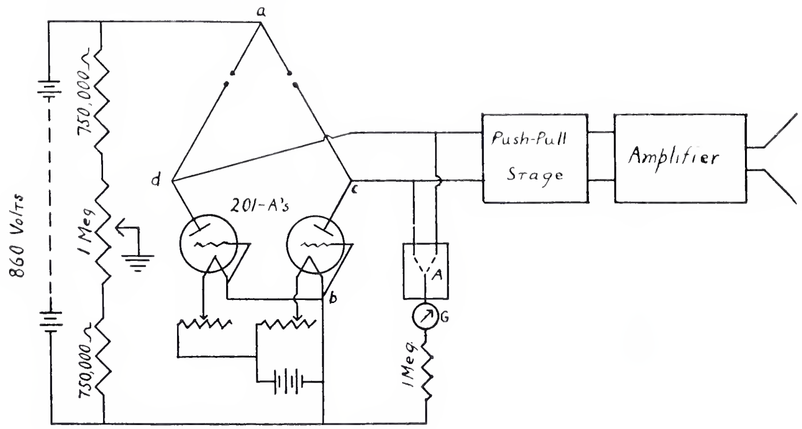

Fig. 4.

Fourth model. The last model tried used a luminous discharge in air, maintained by a constant current device which kept the current low (about 25 milliamperes). Under these conditions, the discharge was a miniature of the well known discharge under a partial vacuum, having a cathode glow, a Crook's dark space, negative column, Faraday's dark space, and positive column. A microphone using a single discharge has been described by Thomas (3). This device was very sensitive to slow periodic pressure changes. The present model was designed to be free from such features. The microphone proper consisted of two gaps mounted so that one gap was open to the sound disturbance, the second partially shielded from the sound disturbance but still open to the air. As a result, only one was appreciably affected by an audible disturbance, while both were equally affected by a slow aperiodic disturbance. The glow was established between copper electrodes, the best results being obtained by oval shaped ends. More work remains to be done on the proper design of the ends to prevent the glow playing over the ends of the copper electrodes. This action was the cause of most of the background noise in the instrument. The electrical connections are shown in Fig. 4. The two gaps were two arms of a bridge circuit, while two vacuum tubes were the other two arms. A voltage of about 860 was placed across the bridge at *a* and *b*, using dry batteries. The three resistors placed across the bridge constituted a Wagoner ground (false ground), which served to keep the discharges stable, by keeping the potential of points *c* and *d* near ground potential. A device, consisting of a switch, resistor, and galvanometer in series with the ground, was added at *A* to test the equality of these potentials with the ground. Points *c* and *d* were connected to the amplifier-loudspeaker system as shown.

Theory and results. The vacuum tubes were made to act as constant current devices by operating them at potential high enough to draw all thermions to the plates as fast as they were formed. A great deal of work has been done on the characteristics of sparks but practically none on glows, the latter getting their peculiar properties by keeping the current low. By using a calibrated electroscope to measure voltages across the gap, the following formula was found to give the relation between voltages across the gap and the gap length in millimeters, the relation being valid up to 4.3 mm.; $V = 119.1\,d + 292.3$. The constants were determined from experimental data by the method of least squares. A relation was also found between the resistance of the gap and its length. It was: $R = 247.53\,d^2 + 5052.67\,d + 10828.98$. These relations were determined while using a constant potential across the bridge. According to Thomas (loc. cit.), any small increase in pressure gives an increase in resistance which is very closely proportional to the increase in pressure. A sound wave gives such an increase which causes a change in the potential difference across the glow. The circuit was designed to amplify the differences between the effects on the two glows. As a result, audible sounds should have been reproduced while slow aperiodic disturbances should not. Experimentally, the system reproduced speech with fair intensity and with good quality. There remained, however, a lot of ground noise due mainly to two causes; the first was a movement of the glow over the ends of the electrodes; the second was a slow disintegration of the electrodes causing small bits of metal to pass from electrode to anode.

Many points remain to be investigated, but the positive results so far obtained lead one to believe that the method might profitably be investigated farther.

Acknowledgments. In conclusion, I wish to express my thanks and appreciation to Dr. Foley for permitting me to work on the problem, for advice, and for apparatus, to Dr. Ramsey for very valuable suggestions as to desired circuits, to Mr. Payne for the care taken in making the various models used in the investigation, and to other members of the Physics Department staff of Indiana University, who have made helpful suggestions from time to time.

References

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