

THE SENSITIVITY AND PRECISION OF THE ELECTRO-
STATIC TRANSMITTER FOR MEASURING SOUND
INTENSITIES.

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SYNOPSIS.

Electrostatic Transmitter of Constant Sensitivity.—(1) *Characteristics.* This instrument is the same in principle as that described in 1917, but certain changes have been made which, as proved by actual tests, render the sensitivity independent of changes of temperature, pressure and humidity. The sensitivity is also found to be constant over a long period of time. By means of a piston-phone and a thermophone, for which corrected formulæ are available, both the absolute sensitivity and phase lag were determined for frequencies of from 10 to 12,000 cycles. Eight transmitters similarly constructed give the same curves within 20 per cent. With a steel diaphragm 0.0051 cm. thick having a natural frequency of 7,000 cycles, and with an air gap of 0.0025 cm., the mean sensitivity is about 0.35 millivolt/dyne. (2) *Use with an amplifier for measurement of sound intensity.* Combined with an amplifier of ordinary design the instrument has an over-all sensitivity which is practically uniform from 25 to 8,000 cycles. It is therefore remarkably well adapted for the measurement of the intensities of complex tones and tones of changing pitch and for use with an oscillograph for recording sound waves. On the other hand, if sounds of a definite pitch are to be measured, the apparatus can be made highly selective and almost any desired sensitivity can be obtained by using a tuned amplifier in connection with a vibration galvanometer.

THE writer some years ago published a paper¹ in this journal on the use of an electrostatic transmitter for the absolute measurement of sound intensities. The transmitter, as there described, consisted essentially of a thin metal diaphragm under tension separated by a small distance from a plane metal plate, the plate and the diaphragm forming the two electrodes of an air condenser. Data were given which showed that the instrument had a uniform sensitivity over a wide range of frequencies and so was especially adapted for the measurement of intensities of sounds of various frequencies.

The relation between sensitivity and frequency was determined by means of a thermophone and also, at the lower frequencies, by means of a piston-phone. But, as the two methods did not yield the same absolute values, doubts were cast upon the accuracy of the results. Since then the theory of the thermophone has been further developed and corrected formulæ for its acoustic efficiency have been obtained.² The pressures calculated by these new formulæ have been found to agree with those

¹ Vol. X., No. 1, p. 39, July, 1917.

² E. C. Wente, *PHYS. REV.* (2), XIX, p. 666.

given by a piston-phone, so that an absolute calibration of a transmitter may now be made with the thermophone which is dependable over a wide frequency range.

The particular electrostatic transmitter described previously had a natural frequency of nearly 17,000 cycles per second. As this frequency is considerably beyond the region which is covered in most acoustic measurements, it is desirable to construct an instrument with a lower natural frequency and thereby obtain greater sensitivity. Dr. I. B. Crandall¹ has shown theoretically how the natural frequency and damping of an electrostatic transmitter may be given almost any desired values by cutting grooves of the proper size in the back plate.

The transmitter which is here described has a natural frequency slightly over 10,000 cycles per second and a damping constant of 14,000. The sensitivity-frequency characteristic is such that an amplifier may readily be constructed so that the sensitivity of the amplifier and transmitter combined shall be nearly the same from 25 to 8,000 cycles per second. Tests have shown that the sensitivity of the transmitter is closely maintained under various atmospheric conditions for a long period of time.

CONSTRUCTION OF THE TRANSMITTER.

A sectional drawing of the transmitter is shown in Fig. 1. The transmitter differs from the instrument previously described in several essential respects. The diaphragm, *A*, is made of 0.002 inch (0.0051 cm.) steel and is stretched so that its natural frequency in free air is 7,000 cycles per second. Annular grooves are cut into the face of the back-plate, *B*, to give the diaphragm the desired natural frequency and damping. The length of the air-gap is 0.001 inch (0.0025 cm.). To keep out moisture, the space surrounding the back-plate is sealed off completely from the outside air. A thin rubber diaphragm, *C*, is provided to keep the pressure on the two sides of the steel diaphragm substantially equal under all conditions of temperature and atmospheric pressure.

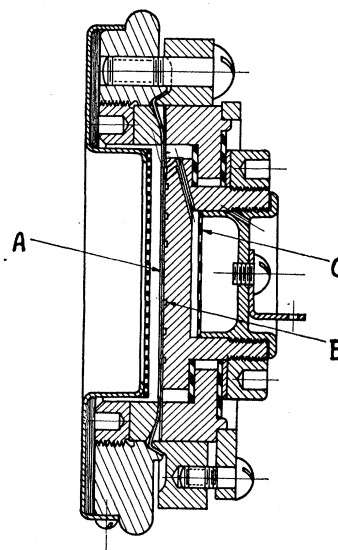


Fig. 1.

Sectional view of the electrostatic transmitter.

¹ E. C. Wentz, *PHYS. REV.*, (2) XI., 450 (1918).

CALIBRATION OF THE TRANSMITTER.

The open-circuit voltage of the transmitter per unit of pressure has been measured with the piston-phone for the frequency range of 10 to 200 cycles per second and with a thermophone for the frequency range of 60 to 12,000 cycles per second. Both of these instruments have been described in another paper.¹ The method of measurement was virtually the same as previously described,² except that an a.c. potentiometer³ was used in place of a thermo-couple and galvanometer. The polarizing voltage in all cases was 200.

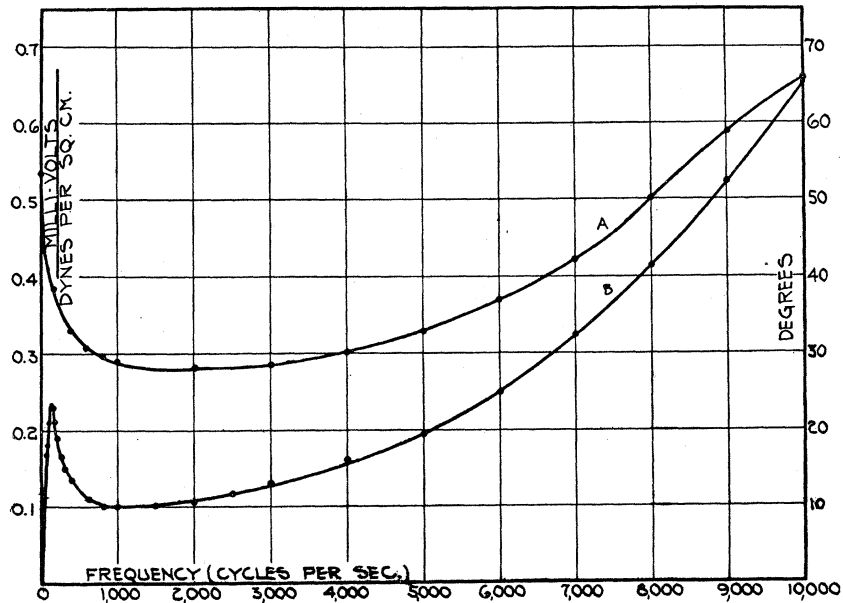


Fig. 2.

Sensitivity-frequency characteristic of the electrostatic transmitter. A. Volts per unit of pressure. B. Phase lag of e.m.f. behind pressure.

Fig. 2 gives the calibration curve obtained by averaging the results for eight transmitters. Between 25 and 8,000 cycles the calibration curve of none of the individual transmitters differs from this average curve by more than 20 per cent. To make all the transmitters exactly alike would require extreme precautions in construction, which would add considerably to their cost. However, even if there is a considerable variation in the mechanical constants of the individual instruments, we

¹ E. C. Wente, *The Thermophone*, loc. cit.

² E. C. Wente, *PHYS. REV.*, (2) X., 51 (1917).

³ E. C. Wente, *Journal A. I. E. E.*, XL, p. 900, 1921.

may obtain a very nearly correct value of the calibration curve of any particular instrument by measuring the sensitivity at 200 cycles with the piston-phone and multiplying the ordinates of the curve given in Fig. 2 by the ratio of the value so obtained to the value of the ordinate of this curve at 200 cycles. For the eight calibrated transmitters the difference between the true calibration and the values obtained by this latter method was at no point greater than 12 per cent. for frequencies lying between 20 and 8,000 cycles per second, and for most of the transmitters the difference was nowhere greater than 5 per cent. This difference is small enough to be neglected in practically all acoustic measurements. Unless a precision greater than five per cent. is required it is therefore unnecessary to make any other measurements on transmitters of this type than that of the determination of the sensitivity at 200 cycles by means of the piston-phone, a measurement which may be made in a few minutes.

Fig. 2 shows that the sensitivity of the transmitter is not independent of frequency. However, since the transmitter is generally used with an amplifier, the sensitivity varies with the frequency in a desirable way. An amplifier as normally constructed has an amplification characteristic which is nearly proportional to the reciprocal of the efficiency characteristic of the transmitter. At any rate, an amplifier can readily be designed so that the sensitivity of the transmitter and amplifier combined is practically uniform from 25 to 8,000 cycles.

For the frequency range of 60 to 10,000 cycles a determination was also made of the phase relation between the pressure exerted on the diaphragm and the voltages generated by the transmitter. The values that were obtained are also plotted in Fig. 2. The maximum in the curve at 200 cycles is due to the fact that the damping of the diaphragm by the air in the gap increases with decrease in frequency.¹

VARIATION OF SENSITIVITY WITH TIME.

To determine the change in sensitivity of the transmitter with time under ordinary conditions of use it would be necessary to make measurements extending over a long period. The more practical method of subjecting the transmitter to a higher temperature for a shorter period of time was therefore adopted. A transmitter was heated daily for five or six hours to about 45° C. and then allowed to cool to room temperature. No change in efficiency was observable even after this process had been continued for more than two weeks. The precision of the measurements was about 2 per cent. The transmitter was then heated

¹ I. B. Crandall, loc. cit.

to 100° C. for several hours. After being allowed to cool it was again tested but no change in sensitivity was observable. It is thus reasonable to assume that under ordinary conditions the sensitivity will not change appreciably during the course of several years.

EFFECT OF TEMPERATURE AND PRESSURE ON SENSITIVITY.

When a rigid plate was used in place of the flexible rubber diaphragm, *C*, and equalization of the static pressure on the two sides of the diaphragm thereby prevented, measurements with the piston-phone and electrostatic voltmeter showed that the sensitivity of the transmitter changed about 2 per cent. per degree Centigrade at 200 cycles. With the rubber diaphragm, however, within the temperature range of 20 to 40 degrees C. the total change in sensitivity was less than 2 per cent., which is negligible for all practical purposes. The principal reason for this small temperature coefficient lies in the fact that the instrument is constructed almost entirely of the same material. The clamping rings and the diaphragm have nearly the same temperature coefficient of expansion, so that any change in temperature will produce but little change in the tension of the diaphragm. The diaphragm, although thin, cannot assume a temperature very different from that of the frame, for it is separated by such a small distance from the back plate that heat can flow from one to the other nearly as readily as if they were in contact.

If there were no displacement of the rubber diaphragm a change in temperature of 20° C. would produce a difference in pressure on the two sides of the diaphragm equal to 7 per cent. of one atmosphere. It follows, therefore, that a change in atmospheric pressure as great as this will not change the sensitivity of the transmitter by an appreciable amount.

COMPARATIVE SENSITIVITY OF THE TRANSMITTER.

The mean value of the sensitivity of the transmitter given above is approximately 0.35 millivolt per dyne. A more comprehensible idea of this sensitivity may be obtained from the fact that the male voice in ordinary conversation exerts a pressure of about 10 dynes per sq. cm. at a distance of 3 cm. from the mouth of the speaker.¹ With a three-stage amplifier, thermocouple and galvanometer pressures as low as 0.01 dyne per sq. cm. may be measured. If the tone is produced by some electrical device such as a telephone receiver and the source of current is supplied by an oscillator, an a.c. potentiometer may be used. In this case pressures may be measured which are barely perceptible to the ear.

¹ I. B. Crandall and D. Mac Kenzie, *PHYS. REV.* (2), XIX, p. 221.

CONCLUDING REMARKS.

Little has been said about amplifiers in this paper although the electrostatic transmitter has little practical value unless it is used with an amplifier. Experiments have shown that the transmitter changes but little with time and atmospheric conditions. The amplifier, when properly designed and if the vacuum tubes are carefully chosen, will maintain the same value of amplification for a long period, provided the plate voltage and the filament current are kept at a constant value. An amplifier used in most of the experiments described above did not vary by more than a few per cent. during the course of several months. A combination of electrostatic transmitter and amplifier can thus be used as an absolute phonometer, the readings of which are dependable from day to day.

In the preceding discussion it has already been pointed out that one of the chief merits of the electrostatic transmitter is the fact that it has a very uniform response and so is especially adapted for measuring sounds of complex wave form or for comparing the intensities of tones of different frequencies. However, in some classes of problems it is desirable to have an instrument which is sharply tuned so that it will respond to a tone of one frequency and be unaffected by any other tones that may be present at the same time. If an electrostatic transmitter is connected to a tuned amplifier the output of which goes to a vibration galvanometer, selectivity of a very high order may be obtained and an amplifier of sufficient amplification may be used to give the combination almost any desired sensitivity.

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