A Method of Measuring the Total Output of Speakers

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Routine measurements of speaker output are usually made in a single direction on the axis extending out in front of a speaker. However, the total acoustic output is sometimes desired. Indeed, were it not so hard to obtain, the total output would in most cases be the proper information to publish. In speaker efficiency measurements the total output is required, and in actual practice the listener is seldom in open air, where he would receive the output in a particular direction alone, but he is inside a room, where, by reflection, he is subjected to the total speaker radiation field.

There are several methods for finding this total output. The speaker may be measured out-of-doors by taking the average of a number of measurements on the surface of an imaginary sphere of which the speaker is the center (1). In the reverberation chamber method the speaker is located in a highly reverberant room, and its total output calculated by a single measurement with a microphone placed anywhere in the room on the theory that the acoustic pressure becomes constant regardless of frequency and location in the room (2, 3). Another method is to simulate outdoor conditions by making measurements in a highly absorbing room treated with acoustic materials (4). Bell Telephone laboratories have rotated the microphone at a speed sufficient to eliminate standing waves while making measurements (5). A multiple microphone method employs several microphones placed about the speaker so as to obtain at a single measurement sufficient data to calculate the total output.

In the motional impedance method, the free and blocked impedance of the speaker are found electrically, and the efficiency calculated from these constants (6).

There can be no objection to the outdoor method except its inconvenience. Our experience with the reverberation chamber method shows the presence of standing waves in all enclosures, which shift with changing frequency, rendering the results of no value for showing speaker characteristics. As to sound absorbing rooms, it is very difficult to eliminate reflection even with a foot of hair-felt lining the room. In working with the multiple microphone method, the writer has found that all types of microphones have polarity, so that when connected together they will measure the vector sum of the effective values of the acoustic pressure or velocity at their respective locations and thus give maxima and minima as the frequency is varied, showing a pattern which does not belong to the speaker at all (7). The motional impedance method avoids accoustical measurements but neglects mechanical losses of motion and rates the speaker optimistically.

This paper describes a method of measuring the total output of a speaker which is analogous to the method of measuring the total luminous flux from a lamp by means of a globe photometer. The speaker is placed at the center of a 3-foot globe photometer. A microphone is placed at the small window of the globe and shielded from direct radiation from the speaker so that it receives only sound which has been reflected one or more times from the wall of the globe. A single measurement of the intensity at the window gives a figure which is proportional to the total sound flux emitted by the speaker. The theory may be found in textbooks on illumination (8). The method used to eliminate standing waves in the globe was to wobble the frequency of the oscillator used to drive the speaker, above and below the frequency at which it is set. An analysis was made to determine what variation in frequency was desirable to eliminate the standing waves and yet not be so great as to mask the frequency characteristics of the speaker. The frequency variation necessary to move one loop past the microphone and back was calculated, as this requires the microphone to read the average intensity from loop to loop and should smooth out the pattern.

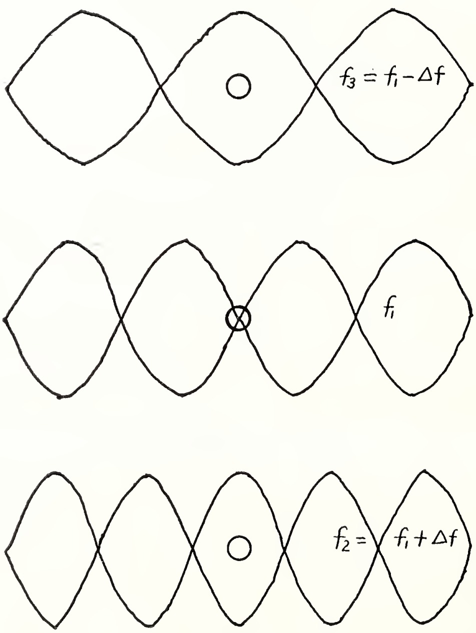

Fig. 1.

In Figure 1 suppose at the middle frequency f_1 there are n_1 half waves in the enclosure. The wavelength $\lambda_1 = \frac{2L}{N_1}$ where L is the length of the enclosure.

$$f_1 = \frac{V}{\lambda_1} \text{ where } V \text{ is the sound velocity, or } f_1 = \frac{Vn_1}{2L}$$

For one more half wave within the globe, $n_2 = n_1 + 1$

$$\lambda_2 = \frac{2L}{n_2} = \frac{2L}{n_1+1}$$

$$f_2 = \frac{V(n_1+1)}{2L}$$

$$\frac{f_2}{f_1} = \frac{2V(n_1+1)L}{2LVn_1} = \frac{n_1+1}{n_1} = 1 + \frac{1}{n_1}$$

$$f_2 = f_1 + \frac{f_1}{n_1} \text{ or } \triangle f = \frac{f_1}{n_1} \text{ but } n_1 = \frac{2f_1L}{V} \text{ hence } \triangle f = \frac{f_1V}{2f_1L} = \frac{V}{2L} \text{ a constant.}$$

This shows that to shift the pattern from a node to an antinode in front of the microphone requires a constant frequency increment independent of the original frequency.

Now to see what happens to the pattern when the frequency is decreased by the same increment—

$$f_2 = f_1 + \frac{V}{2L} \text{ and } f_3 = f_1 - \frac{V}{2L}$$

$$\lambda_1 = \frac{V}{f_1},\ \lambda_2 = \frac{V}{f_1 + \frac{V}{2L}} = \frac{2LV}{2Lf_1+V}$$

$$\lambda_3 = \frac{V}{f_1 - \frac{V}{2L}} = \frac{2LV}{2Lf_1-V},\ n_1 = \frac{2L}{\lambda_1} = \frac{2Lf_1}{V}$$

$$n_2 = \frac{2L}{\lambda_2} = \frac{2Lf_1+V}{V} = n_1+1 \quad \text{as was calculated}$$

and $$n_3 = \frac{2L}{\lambda_3} = \frac{2Lf_1-V}{V} = n_1-1 \quad \text{as we hoped.}$$

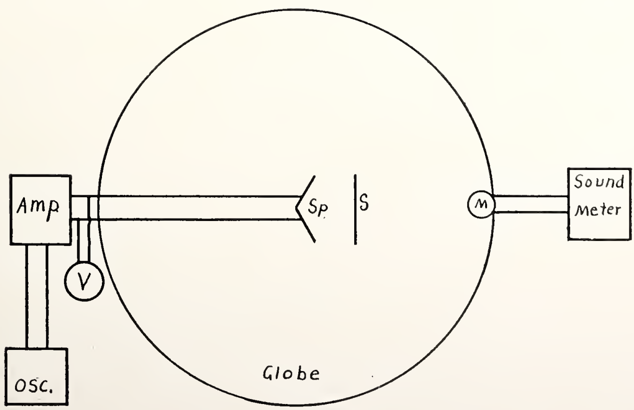

Fig. 2.

So a constant frequency variation moves the node at the lower frequency to a loop at the high frequency limit and back again. An ideal frequency wobbler would be a heterodyne, beat oscillator, for it can be shown that a constant variation in the condenser capacitance in the fixed frequency circuit will produce a constant variation in the output frequency regardless of the frequency at which the oscillator is set.

The experimental set up is shown in Figure 2. A Clough Brengle audio oscillator, variable from 50 to 16,000 cycles was used. The frequency was wobbled 460 cycles on each side of the set value by paralleling the condenser in the fixed frequency circuit of the oscillator with a small variable air condenser and rotating its rotor at 500 revolutions per minute by a small motor. Each frequency was set with the plates of the rotable condenser half meshed so that the capacitance, and hence the frequency, was varied equally above and below the set frequency.

The oscillator was connected through an amplifier to a Wright De Coster speaker placed in a globe photometer three feet in diameter. The microphone of a General Radio Sound Level meter was placed in the window of the globe. A shield was placed between the speaker and microphone to protect the microphone from direct radiation from the speaker.

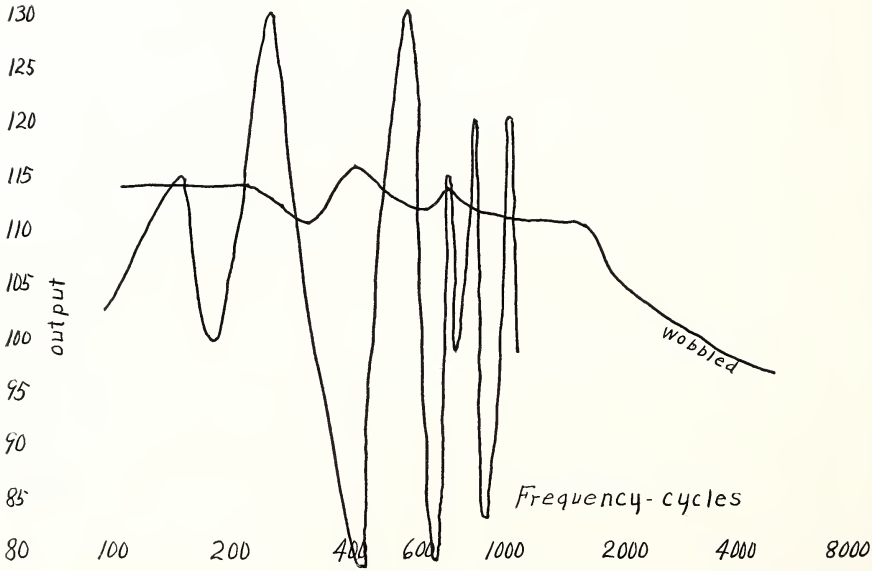

Fig. 3.

Figure 3 shows runs made with and without wobbling the frequency and is convincing proof that the sound intensity is not constant in an enclosure. The peaks occur at a fairly constant frequency increment and are, hence, due to standing waves in the globe. Due to the logarithmic scale of frequencies, the separate peaks cannot be shown beyond 1000 cycles. Hence the curve in this region is the individual readings at each even 100 or 1000 cycles.

Next the frequency was wobbled above and below the set frequency and the curve superposed on the first curve in Figure 3 to show the smoothing effect.

Figure 4 shows the frequency characteristic of the same speaker taken out of doors. The speaker was mounted on a turntable arranged to be turned on two axes at right angles to each other, and the microphone was left at a fixed position. Twenty-one frequencies were used from 50 to 8000 cycles and twenty-one different angles of the speaker. The averages of these readings were taken as proportional to the total

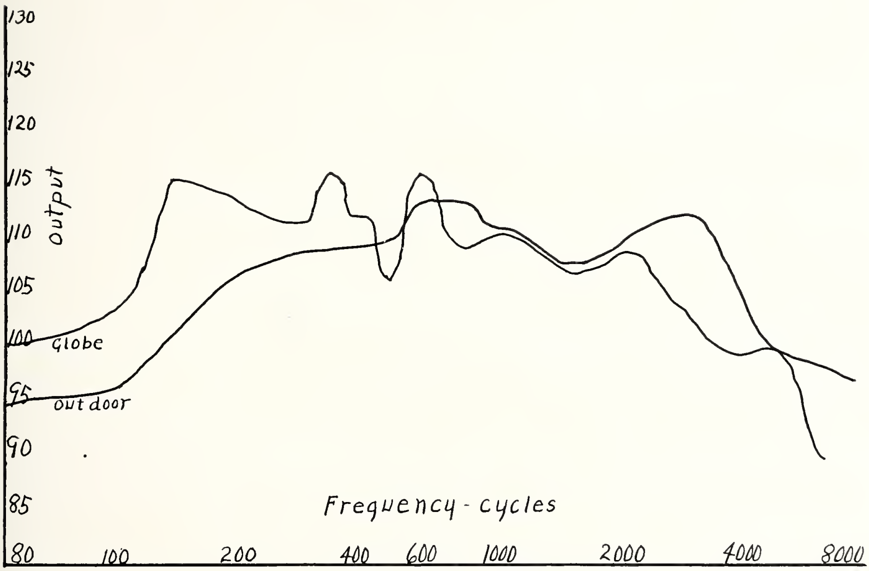

Fig. 4.

output of the speaker at any particular frequency. The readings were not reduced to an absolute level, as relative values only were needed. All output readings are the decibel readings of the sound level meter. The open air and globe-wobbled frequency curves are superposed to show the correlation between the two.

It is felt that the globe method of measuring the total output of speakers offers a considerable advantage over the rather cumbersome methods used heretofore.

This experiment was conducted in the physics laboratory of Indiana University and the electrical engineering laboratory of Ohio University under the direction of Professor R. R. Ramsey of the Indiana department of Physics.

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