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RECENT SOUND-TRANSMISSION MEASUREMENTS AT THE NATIONAL BUREAU OF STANDARDS

By Vivian L. Chrisler and Wilbert F. Snyder

ABSTRACT

This paper gives a description of the equipment and method now used in making sound-transmission measurements at the National Bureau of Standards. Measurements are made at nine frequency-bands covering a range from 128 to 4,096 cycles per second.

The results of measurements on a number of floor and wall panels are given. In the case of floor panels the transmission of impact noises was also studied. Specifications for the construction of the various panels are appended.

CONTENTS

I. INTRODUCTION

The problem of obtaining a proper degree of sound insulation is still an important one, although considerable information has been acquired on this subject during the past ten years. Unfortunately, however, all of the data are not comparable, because different methods of measurement were used in different laboratories.

When measurements of sound transmission [1] were first started at the National Bureau of Standards it was decided to make the measurements entirely by instrumental methods. Since that time there has been great improvement in microphones, loud speakers, vacuum tubes, vacuum tube circuits, etc., with the result that equipment which was of the latest type at the time when the first work was done, became obsolete in a very short time. From time to time the equipment for measuring sound transmission at the National Bureau of Standards has been modified to keep up with these improvements, but a description of these changes has never been published.

This paper outlines the method now in use, giving some description of the equipment, and some of the measurements made during the past three years.

[1] BS Sci. Pap. 21, 37 (1926–27) S526.

II. SOUND CHAMBER

The sound chamber is a laboratory specially constructed for sound-transmission measurements. Figure 1 shows a vertical section of the chamber. S is the source or transmitting room. It communicates through the panel window in the ceiling with the receiving room R_1 above and through the panel window at the right with the receiving room R_2. The section of the opening where the test panel is inserted is 7 ft 6 in. by 6 ft, and the panel window is 6 ft 6 in. by 5 ft. In the figure a test panel is in the window at the opening into receiving room R_2. The panel forms the only mechanical tie between the transmitting and receiving rooms. The walls are 6 inches or more in thickness and are constructed of reinforced concrete. Any sound not transmitted by the panel has an alternative path through the two

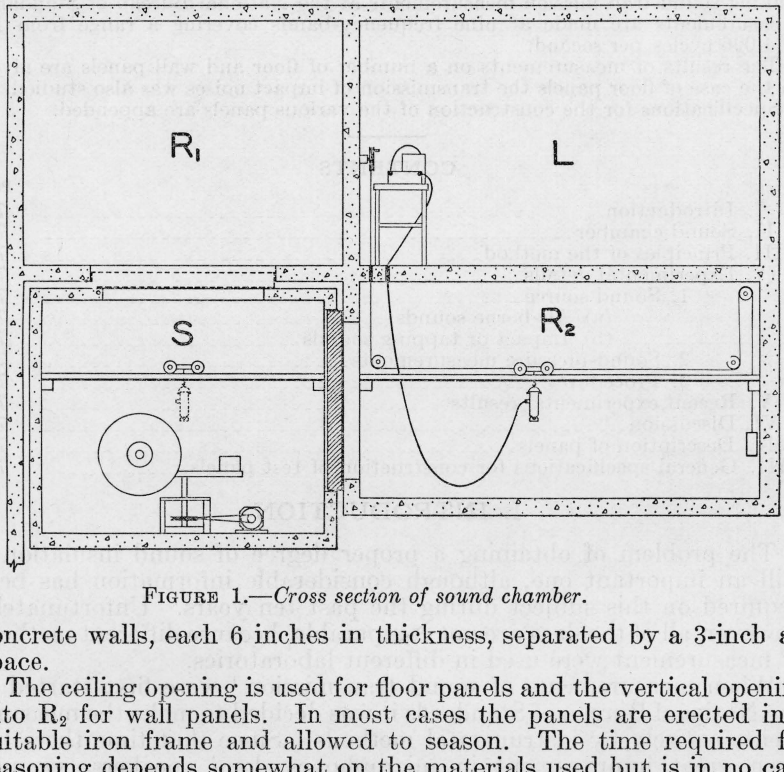

FIGURE 1.—*Cross section of sound chamber.*

concrete walls, each 6 inches in thickness, separated by a 3-inch air space.

The ceiling opening is used for floor panels and the vertical opening into R_2 for wall panels. In most cases the panels are erected in a suitable iron frame and allowed to season. The time required for seasoning depends somewhat on the materials used but is in no case less than two weeks and as a rule not less than one month. When thoroughly seasoned, the panels are moved into position and sealed into the opening with plaster. This procedure permits the seasoning of the panel to be carried on elsewhere and permits the prompt removal and replacement of a panel after completion of a test. Maximum availability of the panel opening for testing purposes is thus provided.

III. PRINCIPLES OF THE METHOD

In practice, any material to be subjected to measurement of sound transmission is made to fill a window between two rooms. A source of sound is operated in one room (the transmitting room) and, by means of a microphone, relative sound pressure [2] measurements are made on both sides of the panel, in the transmitting room and in the receiving room.

It is the problem of experimental work to realize as nearly as possible the ideal condition of a uniform distribution of sound energy, free from interference patterns. In general, it will be impossible to obtain this condition near the source, and for this reason, measurements are not made in this region. In a closed room there is always an interference pattern, but the effect of the interference pattern can be minimized if the pattern is caused to shift continually from one position to another and the time-average of the sound pressure at the different points measured.

The following experimental devices are used to approximate the ideal condition:

1. The source is not of a single frequency, but varies cyclically through a frequency band, the width of which is under experimental control.

2. The position of the source in the transmitting room is varied cyclically by revolving the source at the end of a rotating arm.

3. The device measuring the relative sound pressure involves a thermoelement which provides a time-average of sound pressure for any position of the sound receiver.

The frequency variation and the motion of the source keep the interference pattern in motion, constantly stirring up the sound, and the measuring device gives a time-average of the resulting sound pressure.

With the panel in position, a series of measurements is made with the microphone at different places along a line perpendicular to the middle point of the opening. An average is taken of these values in the transmitting room and also of those in the receiving room. Let these values be $K\rho_T$ and $K\rho_R$, respectively, where K is a constant, ρ_T the sound-energy density in the transmitting room, and ρ_R the sound-energy density in the receiving room.

Making use of the formulas derived by Buckingham,[3] we have

$$\frac{T}{A}=\frac{\rho_R}{\rho_T}, \tag{1}$$

where T is the transmittance of the panel, and A the total sound absorption of the receiving room. The fraction of the energy falling on the panel which is transmitted will be called the transmissivity of the panel or coefficient of sound transmission, and is denoted by τ.

The transmittance

$$T=\tau S, \tag{2}$$

[2] In most publications in the past, the term "sound intensity" has been used. The quantity which is measured under these conditions is probably proportional to the sound energy density, as defined by the committee on Terminology of the American Standards Association.

[3] BS Sci. Pap. **20,** 193 (1922-23) S506.

where S is the area of the panel window. From equations 1 and 2 we have

$$\tau=\frac{\rho_R}{\rho_T}\frac{A}{S}. \tag{3}$$

It is a well-recognized fact that the response of the ear is not proportional to the energy density ρ. The ear has a regulating or protective mechanism whose nature is not fully understood, which, like the well-known mechanism of the eye, protects the organ against excessive stimulation. This response of the nerves in the ear is connected to the energy density of the sound by the following empirical relationship. According to the Weber-Fechner law, the impression of loudness, except at low frequencies, is approximately proportional [4] to the logarithm of the sound energy producing it.

Since sound insulation is concerned with the sensation received by the ear, the transmission results are most naturally expressed in numbers which are approximately proportional to the impression received by the ear. This is done by expressing the results in decibels.

As τ is a fraction it is not convenient to express it as a logarithm, hence results are generally expressed in terms of $\frac{1}{\tau}$. The quantity $10 \log_{10} \frac{1}{\tau}$ has been called the transmission loss in decibels.

Expressing this quantity in terms of quantities which can be measured, we have from equation 3

$$10 \log_{10} \frac{1}{\tau}=10 \log_{10} \frac{\rho_T}{\rho_R}+10 \log_{10} S-10 \log_{10} A.$$

The sound-energy density is a quantity which is not easily determined, but fortunately only the ratio of two energy densities is required. All that one has to do then is to measure something proportional to the sound-energy density, such as the sound pressure, and the proportionality factor drops out in the ratio. S is simply the area of the panel window, and A can be determined by the usual reverberation method.[5]

IV. EXPERIMENTAL DETAILS

1. SOUND SOURCE

(a) AIR-BORNE SOUNDS

The source of sound is a dynamic-type loudspeaker, capable of delivering a high acoustical output, which is supplied with alternating current from a suitable amplifier and beat-frequency oscillator.[6] The speaker unit is mounted on a rotating arm so that it moves in a circle approximately 5 feet in diameter. The rotating

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[4] Harvey Fletcher and W. A. Munson, *Loudness, its definition, measurement, and calculation*, J. Acoustical Soc. Am. **5**, 82 (1933); *Proposed standards of noise measurement*, J. Acoustical Soc. Am. **5**, 109 (1933). Harvey Fletcher, *Loudness, pitch, and the timbre of musical tones and their relation to the intensity, the frequency, and the overtone structure*, J. Acoustical Soc. Am. **6**, 59 (1934).

[5] A description of the equipment used will be found in *An automatic reverberation meter for the measurement of sound absorption*, BS J. Research **9**, 47 (1932) RP457.

[6] A description of this oscillator will be found in *The measurement of sound absorption*, BS J. Research **5**, 957 (1930) RP242.

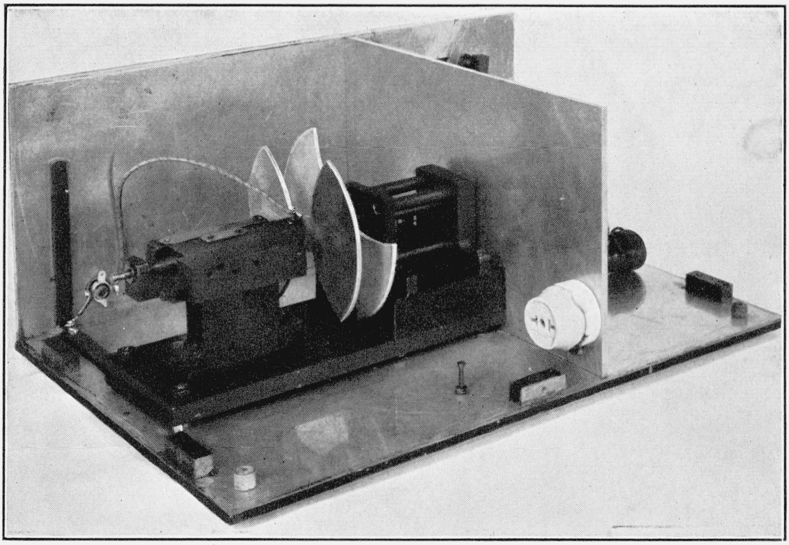

FIGURE 2.—*Rotating condenser for producing frequency bands.*

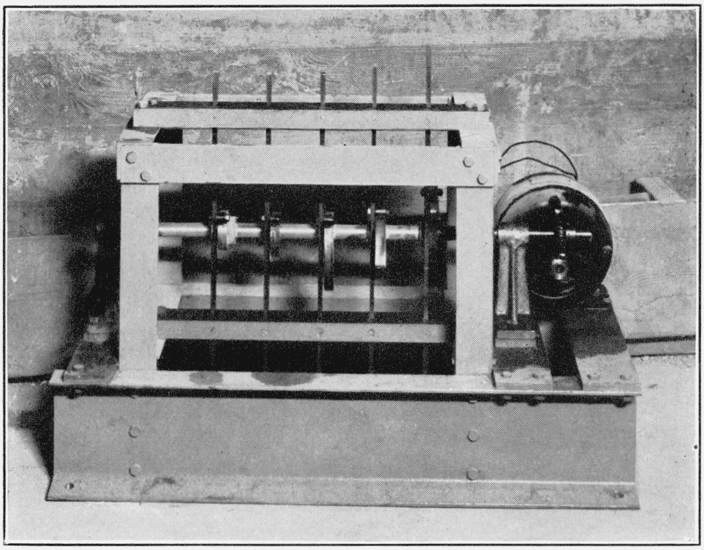

FIGURE 3.—*Machine for producing impact sounds.*

arm is driven by a motor the speed of rotation of which is adjusted by a rheostat in the armature circuit to about one revolution per second. The motor drive must, of course, be as quiet as possible.

The beat-frequency oscillator can be tuned to any desired audio-frequency by a small variable condenser. It is possible to calibrate the dial on this variable condenser, but our practice is to check the frequency by means of standard tuning forks.

The frequency band is obtained by means of a small rotating condenser, figure 2, the capacity of which can be varied by changing the distance between the fixed and rotating plates. This rotating condenser is connected in parallel (see footnote 6) with the tuning condenser of the oscillator and rotated so that the frequency shifts take place from 6 to 8 times per second. The band widths have been chosen so that they are approximately 10 percent of the middle frequency of the band. For instance, at 512 cycles per second the frequency band extends from 486 to 538, while at 4,096 cycles per second it extends from approximately 3,961 to 4,230 cycles per second. At the lower frequencies the band is a trifle over 10 percent in width. At 128 cycles per second the band extends from 118 to 138 cycles per second. In reporting the results the middle point of the band is given rather than the band limits.

An a-c voltmeter is connected across the input to the loudspeaker so that the energy input to the loudspeaker at a given frequency can be kept constant (by adjustment of the input control to the amplifier) during a set of measurements.

(b) IMPACT OR TAPPING SOUNDS

Another type of sound, much harder to control, is produced by vibration communicated directly to the structure. The vibration may be transferred from a machine or caused by impact, as when a chair is dropped, or when someone walks across the floor. In many cases a noise of this type is as loud on the side of the floor or partition away from the source as it is on the side of the source.

To study this type of sound, a special machine was built (see fig. 3), consisting essentially of five rods, which can be raised by separate cams and then allowed to fall. The cams are driven by a motor at such a speed that a rod falls approximately every fifth of a second. The noise thus produced can be measured in the same manner as the sound from the loudspeaker. The results, expressed as transmission loss in decibels, are recorded in the column headed "tapping" in table 1.

TABLE 1

Panel	Transmission loss (in decibels) at frequencies (cycles per second)—										Tapping	Weight per square foot
	128	192	256	384	512	768	1,024	2,048	4,096	Average		
FLOOR PANELS												
129a	35.9	------	37.7	------	38.6	------	46.8	53.8	55.1	44.7	22.6	------
129b	37.0	------	46.6	------	58.3	------	68.5	73.2	([a])	60.6	33.0	------
129c	42.6	------	49.5	------	60.9	------	71.3	76.7	([a])	63.5	38.5	------
129d	------	------	51.4	------	------	------	------	------	------	------	37.4	------
130	23.2	------	23.5	------	33.9	------	40.6	47.6	59.7	38.1	11.1	17.1
131	22.4	------	35.9	------	45.2	------	47.7	56.4	64.7	45.4	11.6	18.8
132a	31.8	------	35.4	------	48.7	------	56.6	67.5	80	53.3	19.4	------
132b	26.4	------	31.1	------	50.4	------	61.7	64.0	80	52.3	------	------
132c	25.5	------	35.9	------	48.1	------	56.1	70.1	80	52.6	17.1	------
133a	23.6	------	33.5	------	47.5	------	55.8	67.1	81.8	51.6	15.3	15.0
133b	23.1	------	34.8	------	51.2	------	60.3	72.8	80	53.7	20.2	------
134	22.5	31.0	32.8	29.1	25.3	30.9	22.3	32.9	28.3	28.3	−2.4	13.9
135	19.1	29.7	31.4	27.1	23.7	23.8	31.2	29.6	26.0	26.8	−2.9	13.0
136a	34.0	43.9	43.2	50.8	51.7	57.0	59.2	64.6	71.9	52.9	6.5	------
136b	41.9	48.9	52.4	56.3	60.0	64.2	66.7	77.3	83.0	61.2	21.1	------
137	30.6	51.0	43.7	46.1	51.9	55.2	58.2	64.5	74.2	52.8	11.7	------
WALL PANELS												
138	45.4	------	44.4	------	54.7	------	59.1	61.9	80	57.6	------	------
139	29.8	------	30.2	------	37.7	------	47.9	52.7	59.1	42.9	------	29.7
140	31.2	------	31.0	------	35.9	------	46.6	50.2	57.7	42.1	------	27.5
141	30.0	------	35.4	------	43.5	------	51.5	55.7	65.1	46.9	------	37.5
142	33.3	------	32.8	------	42.1	------	46.2	49.4	61.8	44.3	------	33.4
143a	17.7	------	20.6	------	27.2	------	42.7	39.2	57.8	34.2	------	17.6
143b	25.7	------	24.0	------	36.8	------	46.7	49.8	69.1	42.0	------	------
144	35.5	36.6	36.9	41.2	44.4	46.7	50.9	55.4	62.4	45.6	------	35.8
145	33.8	36.4	36.5	40.5	41.9	44.7	51.2	56.9	64.3	45.1	------	32.2
146	25.8	32.0	32.0	32.2	33.3	35.3	32.4	37.5	52.9	34.8	------	------
147a	33.4	33.1	35.9	36.0	37.6	43.7	45.2	47.1	62.9	41.7	------	23.5
147b	32.1	40.1	40.5	43.9	46.3	50.2	51.2	52.1	70.5	47.4	------	------

[a] Sound inaudible.

2. SOUND-PRESSURE MEASUREMENTS

The sound-pressure measurements are made by means of a condenser or dynamic microphone and a suitable amplifier and attenuator. The output of the amplifier is indicated by a thermoelement and galvanometer. As thermoelements will not stand an appreciable overload, it was felt desirable that some kind of a protective device should be built into this equipment to prevent surges or sudden overloads from burning out the thermoelement.

Figure 4 shows a diagram of the complete circuit which, in connection with a calibrated microphone, is also used as a sound meter for the measurement of sound levels in absolute units. The amplifier consists of three stages with transformer coupling and one stage with resistance-capacitance coupling. An external 200-ohm constant input and output impedance attenuator can be inserted between the microphone circuit and the amplifier. An attenuator of the potentiometer type is built into the circuit between the resistance-capacitance coupled stage and the last stage. The second stage in the amplifier can be switched in and out of the circuit.

A phone connection is provided whereby one can listen to the sound being measured and yet not disturb the measuring circuit. This is accomplished by adding a separate amplifier-tube circuit which does not draw an appreciable current from the main amplifier.

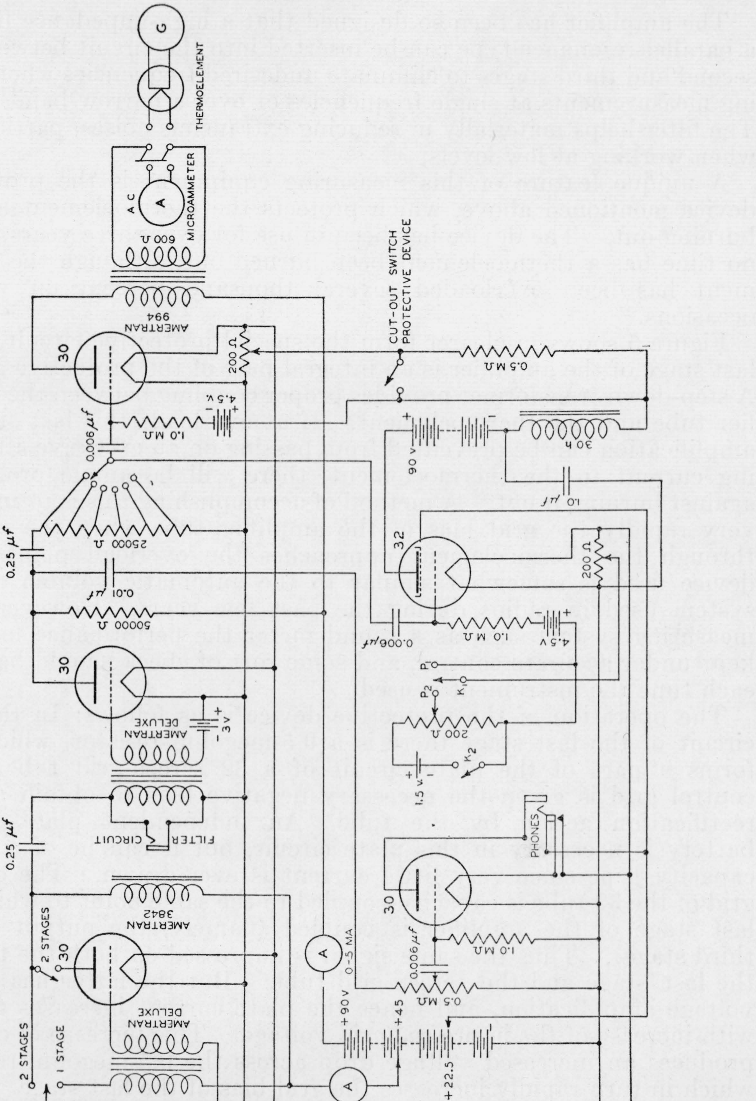

FIGURE 4.—*Circuit diagram of amplifier and protective device for thermoelement.*

The amplifier has been so designed that a high-impedance filter of a parallel-resonance type can be inserted into the circuit between the second and third stages to eliminate undesired frequencies when making measurements at single frequencies or over a narrow-band width. The filter helps materially in reducing extraneous noises, particularly when working at low levels.

A unique feature of this measuring equipment is the protective device mentioned above, which protects the thermoelement against burning out. The device has been in use for over three years and at no time has a thermoelement been burned out, although the equipment has been overloaded several thousand percent on various occasions.

Figure 5 shows in clearer form the special protective circuit. The last stage of the amplifier is an integral part of the protective device. A step-down transformer provides proper coupling between the amplifier tube and the thermoelement. If at overloads this last stage of amplification can be prevented from passing on an excessive alternating current to the thermoelement, there will be ample protection against burning it out. A method of accomplishing this is to increase very rapidly the grid bias of the amplifier tube when the current through the thermoelement approaches the overload point. The device used is somewhat similar to the automatic volume control system used in radios during the past few years. However, in a measuring system such as a sound meter the performance must be kept under accurate control, and some sort of check should be made each time the instrument is used.

The operation of the protective device is as follows: In the grid circuit of the last stage there is a 0.5-megohm resistor, which also forms a part of the plate circuit of a 32 screen-grid tube. The control grid is given the necessary negative bias to obtain a good rectification action by the tube. An independent plate supply battery is necessary in this plate circuit, but it can be of a small-capacity type since very little current is ever drawn. The control grid of the 32 tube is capacity-coupled to the same point to which the last stage of the amplifier is coupled (namely, the output of the third stage). Thus the same signal is impressed on both the tube in the last stage and the screen-grid tube. But the latter has a high voltage amplification, and hence the plate current increases rapidly with increase of the impressed grid voltage. This increase of current produces an increased voltage drop across the 0.5-megohm resistor, which in turn rapidly increases the grid bias of the last stage. With a large increase in grid bias the plate current in the last stage decreases to a very small magnitude and prevents a large alternating current from flowing to the thermoelement. The normal operating range of the thermoelement and galvanometer is such that this decrease in plate current does not take place to any appreciable extent until the galvanometer reading is beyond the maximum reading of the scale. Beyond this point there is a great decrease in the plate current in the last stage, and consequently the alternating current through the thermoelement decreases very rapidly.

To maintain the calibration of the system, it is necessary to introduce a simple method of testing and adjustment. This has been accomplished by making it possible to apply a definite grid bias to the screen-grid tube by means of a voltage-divider across a dry cell.

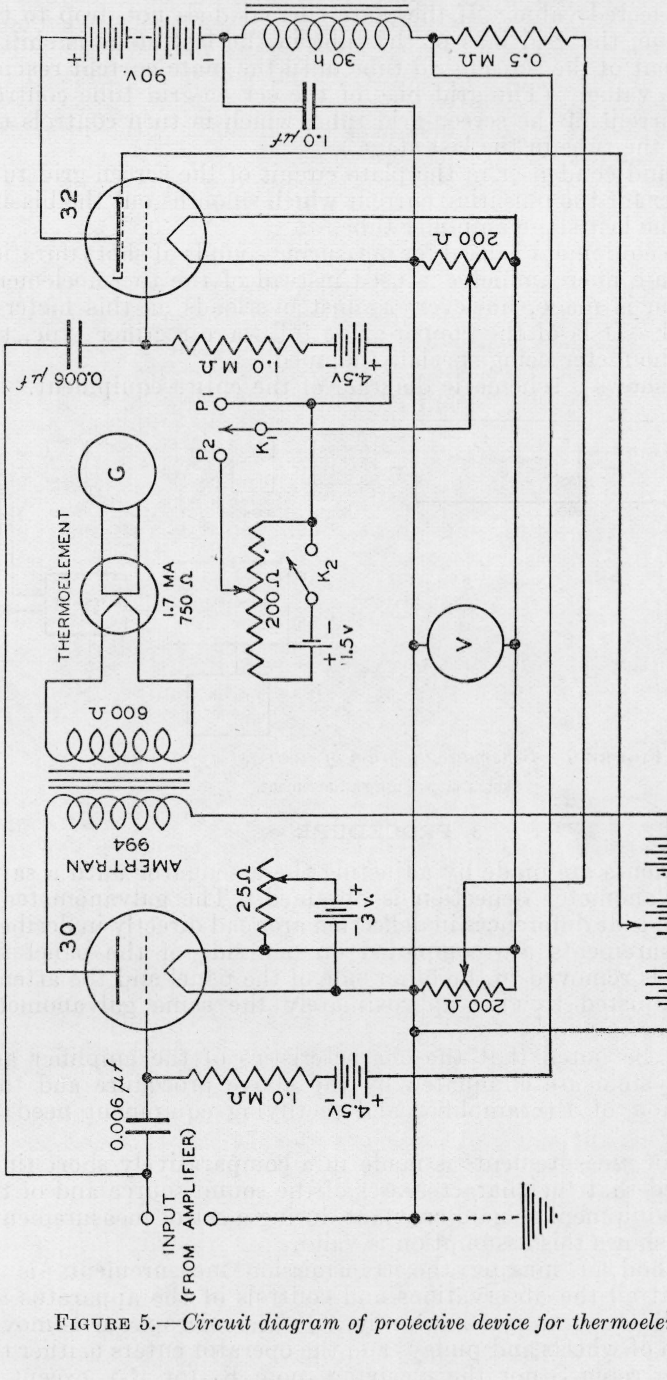

FIGURE 5.—*Circuit diagram of protective device for thermoelement.*

The constants of the circuit are so adjusted that when this definite change in grid bias is made, the plate current in the last stage should drop to a selected value. If the plate current does not drop to the selected value, the grid bias of the tube in the last stage is shifted by adjustment of the screen-grid tube until the plate current reaches the selected value. (The grid bias of the screen-grid tube controls the plate current of the screen-grid tube, which in turn controls the grid bias of the tube in the last stage.)

A choke and condenser in the plate circuit of the screen-grid tube act as a filter for the pulsating current which smooths out the biasing voltage of the last-stage amplifier tube.

When the equipment is used for measuring sounds of short duration a sensitive a-c microammeter is used instead of the thermoelement. No provision is made, however, against overloads as this meter is very rugged. It is of the copper-oxide full-wave rectifier type, the pointer of the meter being specially damped.

Figure 6 shows a schematic diagram of the entire equipment.

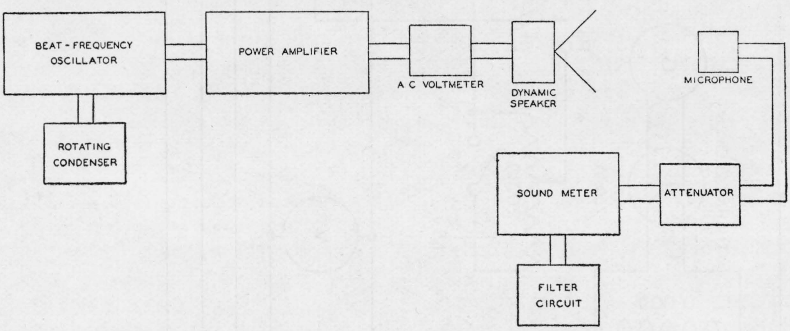

FIGURE 6.—*Schematic diagram of electrical apparatus.*

Sketch shows entire arrangement.

3. PROCEDURE

Measurements are made by adjusting the attenuator until a satisfactory galvanometer deflection is obtained. The galvanometer is calibrated so that differences in deflection are read directly in decibels. When measurements are completed on one side of the panel the microphone is removed to the other side of the panel and the attenuator is readjusted to give approximately the same galvanometer deflection.

It should be noted that the characteristics of the amplifier and rectifying system are eliminated by the above procedure and that no calibration of the amplifier and rectifying equipment need be maintained.

As a set of measurements is made in a comparatively short time, it is assumed that the characteristics of the sound source and of the measuring equipment remain constant during a set of measurements. Experience shows this assumption is valid.

The method of making the transmission measurements is so planned that all the observations and controls of the apparatus are effected in the laboratory L. (See fig. 1.) The microphone is moved by a system of wheels and pulleys and the operator enters neither the transmitting room S nor the receiving room R_1 (or R_2), except to move the microphone from one to the other or to remove or replace the panel under test. A series of measurements consists of eight sound-pressure determinations made at different points along a line perpendicular to the middle point of the panel in room S, and an equal number in room R_1 (or R_2). Two independent series of such measurements are made at each frequency.

When this work on transmission measurements was first started, panels were tested at four frequency bands well distributed over the audiofrequency range. As this work progressed, it seemed desirable to increase the number of bands at which measurements were made, with the result that measurements are now made at nine frequency bands.

V. RECENT EXPERIMENTAL RESULTS

Table 1, page 754, contains some of our more recent results on sound-transmission measurements.

In a few cases the sound which was transmitted at 4,096 cycles per second was so weak that it was not possible to make an accurate measurement. In these cases the transmission loss in decibels has been marked as being greater than 80.0, but in averaging, the value 80.0 has been used at 4,096 cycles per second. In two other cases the sound could not be heard at 4,096 cycles per second, hence no attempt was made to determine the transmission loss, but the value 80 was used in computing the average.

Whenever practical the test panels were weighed, but in many cases the panels were built in position and it was necessary to destroy them in removal, hence the weight was not determined.

The results of these experiments give additional support to the statements published in previous papers [7] that when a wall or floor is more or less homogeneous it must be excessively heavy to be a good sound insulator. If, however, the wall or floor is built in layers which are as loosely connected together as possible, the sound-insulating properties will be greatly improved. This is illustrated by comparing panel 130 with panels 132a, 132b, or 132c. The essential difference between panel 130 and the others was that in 132a, 132b, and 132c, the finish floor was separated from the rest of the structure by a material which would yield a small amount and thus prevent an efficient transfer of energy from one part of the structure to the other. It should be noticed that this holds for both air-borne and tapping sounds. Similar results are shown by panels 129a, 129b, and 129c.

Panel 136a shows a decided improvement over panel 135 due to a hung ceiling and a 2-inch concrete floor slab. Panel 136b shows a still further improvement, especially for tapping noise, by separating the concrete slab from the steel section.

Most measurements in the past have indicated that filling material in walls or floors is of little or no value, but when the surface material was light as in the construction of airplane cabins, it was found that a light filling material was of value. Hence, it seemed reasonable that a filling material possessing the proper characteristics might be of value in a wall having plaster surfaces. Panels 143a and 143b show that rock wool is of some value for this purpose.

[7] BS J. Research 2, 541 (1929) RP48. Cir. BS 403 (June 23, 1933).

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A comparison of the results obtained from panels 147a and 147b is of some interest. These two panels are identical in construction, except that paper was inserted between the 1- and 3-inch sheets of Thermax to prevent the plaster from pushing through the joints of the 1-inch Thermax and bonding it to the 3-inch Thermax. By eliminating this rigid bond between the two layers of Thermax the average sound-insulating value of the panel was increased about 5.7 decibels.

VI. DISCUSSION

The results marked "tapping" in table 1 represent only one phase in the reduction of impact noises, such as walking. The figures given represent the difference between the noise levels in the rooms above and below the floor panel. By changing the floor covering, the absolute noise level in these two rooms may be greatly reduced, although the difference in noise level may not be changed enough to be of any practical importance.

For noises which originate from impacts on the floor, the floor covering acts somewhat in the nature of a shock absorber. Hence, the softer and more yielding the floor covering the less is the amount of energy transferred to the floor that can be radiated as noise. For instance, the noise produced by walking on a floor covered with rubber or cork tiles is somewhat less than that produced when walking on bare concrete; while that produced by walking on a heavy carpet is considerably less than that produced on a concrete floor.

The amount of noise generated also depends upon the type of object which strikes the floor. As two extremes, suppose we consider the leather heel of a shoe with an iron clip on the bottom, and a rubber heel. When walking on a concrete floor, there will be a difference of several decibels in the noise levels produced by these two kinds of heels. If the floor covering consists of rubber or cork tiles, the difference in noise levels produced by these two types of heels is smaller. If we use a still softer material, such as a heavy carpet, the difference in noise levels produced by the two types of heels becomes negligible for all practical purposes.

In most of these cases, except for a bare concrete slab, the transmission loss through the panel will remain approximately the same.

Vibrations from machinery which are carried into a building structure and cause noise throughout the building may be largely eliminated in a somewhat similar manner. In this case a resilient mounting, having considerable internal damping, is placed between the machine and the building structure. It is not the intention of this paper to go into the details of proper mountings for various types of machines.

When comparing panels, it should be remembered that, owing to the form in which the results are expressed, the improvement of one panel over another should be expressed as a difference of their transmission losses in decibels and not as a ratio.

When it is desirable to express the percentage transmission loss as heard by the ear, one must know the initial loudness level of the sound. Anyone interested in expressing results in this manner should refer to some of the more recent work (see footnote 4) on loudness measurements.

The most important fact to know about a panel is not how much better it is than another, but whether it will reduce a given sound to a point where it ceases to be annoying or possibly to a point where it is completely inaudible. To determine this, two other factors should be known in addition to the transmission loss through the panel and the total absorption in the room—the loudness level of the sound which it is desired to reduce to inaudibility and the masking effect of the sounds in the room where the listener is located. For instance, any sound having a loudness level of 20 decibels might easily be masked by other noises in the room. Under these conditions, if the noise which we wish to reduce to inaudibility has a loudness level of 70 decibels, a wall having a transmission loss of 50 decibels will be satisfactory for the purpose. If, however, the room where the listener was located be absolutely quiet this wall will not be satisfactory. Hence, whether a partition is satisfactory or not depends upon the loudness level of the other noises present.

VII. DESCRIPTION OF PANELS

129a. Combination floor panel constructed of 4- by 12- by 12-inch, 3-cell partition tile. The ceiling of this panel was finished with ½-inch of brown-coat gypsum plaster and a smooth white finish coat. The floor surface consisted of 13/16-inch oak flooring, nailed to 2- by 2-inch nailing strips 16 inches on centers, which were grouted into the concrete.

129b. Same as 129a, except that United States Gypsum resilient steel clips were inserted between the concrete and nailing strips.

129c. Same as 129b, except that the oak flooring was removed, and ½-inch gypsum plaster board was attached to the nailing strips and 1½-inch Hydrocal was applied on top of the plaster board.

129d. Same as 129c, except that 13/16-inch oak flooring was applied to the Hydrocal with a mastic cement.

130. Floor panel, 2- by 8-inch wood joist. Plaster on metal lath applied to lower side, subflooring and 13/16-inch oak flooring to upper side.

131. Floor panel, 2- by 4-inch wood joist. Plaster on metal lath applied to lower side, subflooring and 13/16-inch oak flooring to upper side.

132a. Floor panel, 2- by 8-inch wood joist. Plaster on metal lath applied to lower side, subflooring to upper side. 1-inch Balsam Wool was laid over the subfloor and on this were placed small squares (2½ by 2½ inches) of hard-pressed Nuwood spaced 16 inches on centers in each direction. Nailing strips 1¾ by 1¾ inches were placed on top of these Nuwood squares and held in place by a metal strap. The finish floor (13/16-inch oak) was nailed on top of these nailing strips.

132b. This was a floor in an apartment house and supposed to be constructed the same as 132a.

132c. Floor panel. This panel was the same as 132a, except that ½-inch Balsam Wool was used instead of 1 inch.

133a. Floor panel, 2- by 8-inch wood joist. Plaster on metal lath applied to lower side, subflooring to upper side. ½-inch Balsam Wool was laid over subfloor and ½-inch Nuwood was placed on top of the Balsam Wool. 1¾- by 1¾-inch nailing strips were spaced 16 inches on centers on top of the Nuwood and held in position by driving one nail at each end through the strip and into the subfloor. A finish floor of 13/16-inch oak was applied on top of the nailing strips.

133b. Floor panel. This panel was the same as 133a, except that strips of Nuwood 2½ inches wide were placed under the nailing strips, instead of entirely covering the ½-inch Balsam Wool with sheets of Nuwood.

134. Steel floor section with "Keystone section."

135. Steel floor section with flat top.

136a. Floor panel constructed by using steel section 135. The top of this section was covered with 2 inches of concrete and a suspended metal lath and plaster ceiling attached to the bottom, leaving approximately 4 inches between the metal section and plaster.

136b. Floor panel. This was the same as 136a, except that the 2-inch concrete slab was removed and ½ inch of emulsified asphalt applied directly to the top of the steel section. A 2-inch concrete slab was cast on top of this asphalt.
137. Floor panel constructed of 8-inch Mac Mar Joist, with 3-inch Thermax clipped on top and 1-inch Thermax clipped on bottom of joist. ½ inch of concrete was poured on top of the 3-inch Thermax. The floor was finished by cementing ¼-inch battleship linoleum on top of the concrete. The ceiling was finished by applying a brown coat of gypsum plaster and a smooth white finish coat.
138. Gypsum-tile wall panel constructed of 3- by 12- by 30-inch tile with circular cores lengthwise, United States Gypsum resilient clips, metal lath, and gypsum plaster on one side, gypsum plaster applied directly to tile on the other side.
139. Cinder-block panel constructed of 4- by 8- by 18-inch standard Straub hollow cinder blocks. Plastered on both sides with ⅝ inch of brown-coat gypsum plaster, smooth white finish coat.
140. Hollow clay-tile panel constructed of standard 4- by 12- by 12-inch New Jersey porous clay tile. Plastered on both sides with ⅝-inch of brown-coat gypsum plaster, smooth white finish coat.
141. Hollow clay-tile panel constructed of 4- by 12- by 12-inch New Jersey hollow clay tile with 1-inch shells. Plastered on both sides with ⅝ inch of brown-coat gypsum plaster, smooth white finish coat.
142. Hollow clay-tile panel constructed of 4- by 12- by 12-inch New Jersey standard clay partition tile. Plastered on both sides with ⅝ inch of brown-coat gypsum plaster, smooth white finish coat.
143a. Wall panel constructed of 1½-inch Steeltex Channels for studs, Steeltex lath on each side, scratch- and brown-coat gypsum plaster, smooth white finish coat.
143b. Same as 143a, except that space between metal studs was filled with rock wool.
144. Cinder-block wall panel constructed of 4- by 8- by 16-inch cinder blocks. Plastered on both sides with ⅝ inch of brown-coat gypsum plaster, smooth white finish coat.
145. Cinder-block wall panel constructed of 3- by 8- by 16-inch cinder blocks. Plastered on both sides with ⅝ inch of brown-coat gypsum plaster, smooth white finish coat.
146. Wall panel constructed of Thermax sheets 3 inches thick laid in mortar composed of gypsum plaster. Plastered both sides with a brown coat of gypsum plaster, smooth white finish coat.
147a. Wall panel constructed of Thermax sheets 3 inches thick laid in mortar composed of gypsum plaster. When the gypsum had set, 1-inch Thermax sheets were nailed on one face. Plastered both sides with a brown coat of gypsum plaster, smooth white finish coat.
147b. Wall panel. This panel was constructed the same as 147a, except that Sisal-Kraft paper was placed between the 1-inch and 3-inch Thermax, thus preventing any mortar penetrating through the joints of the 1-inch Thermax, and bonding it to the 3-inch Thermax.

VIII. GENERAL SPECIFICATIONS FOR CONSTRUCTION OF TEST PANELS

1. *Erection of Clay Tile.*—Unless otherwise specified, the tiles were laid in a mortar composed of 1 part of portland cement, 1 part of mason's hydrated lime, and 4 parts of sand by volume. The surfaces to be plastered were reasonably true and free from dirt or other loose material. The joints were flush with the surface.

2. *Erection of Cinder Block.*—Unless otherwise specified, the cinder blocks were laid in a mortar composed of 1 part of portland cement, 1 part of mason's hydrated lime, and 4 parts of sand by volume. The surfaces to be plastered were reasonably true and free from dirt or other loose material. The joints were flush with the surface.

3. *Erection of Gypsum Tile.*—Tile 3 by 12 by 30 inches, with circular core lengthwise, were used. They were laid in a mortar composed of 1 part of retarded neat-gypsum plaster to 2 parts of sand, by volume,

to form a 3-inch wall. The surfaces to be plastered were reasonably true and free from dirt or loose material. The joints were flush with the surface.

4. *Erection of Combination Floor Slab (Panels 129a, b, c, d).*—This slab was constructed of 4- by 12- by 12-inch clay tile and concrete. The tiles were laid in rows spaced about 18 inches on centers. The spaces between the rows of tiles were filled with concrete and about 2 inches of concrete was poured on top, making a total thickness of 6 inches for the slab. The concrete mix consisted of 1 part of portland cement, 2 parts of concrete sand, and 4 parts of gravel by volume.

5. *Erection of Wood Joist.*—Except for panel 131, new straight 2 by 8's were used. They were spaced 16 inches on centers and securely nailed to a frame, which consisted of 2 by 8's. For panel 131, 2 by 4's were used in place of 2 by 8's.

6. *Erection of Steeltex Studs.*—1½-inch Steeltex channels were set in a wooden frame constructed of 3 by 4's. The channels were spaced about 16 inches on centers. The bottoms of the channels were perpendicular to the face of the panel.

7. *Erection of Thermax Wall Panels.*—Sheets of Thermax 3 inches thick, 20 inches wide, and 64 inches long were used. The Thermax was laid in mortar composed of 1 part of retarded gypsum plaster to 2 parts of sand, by volume, to form a 3-inch wall. The joints were flush with the surface.

8. *Erection of Mac Mar Joist.*—The 8-inch Mac Mar Joist were spaced approximately 20 inches on centers. Bridging, supplied by the manufacturer, was used between each joist.

9. *Erection of Metal Lath.*—This was expanded metal lath, painted, and of medium weight (3 lb/yd^2). The sheets were attached with their longer dimensions across the supports. The joints between the edges of the sheets were lapped one full mesh and tied with no. 18 iron wire midway between supports. Each sheet was securely fastened to every support it crossed, the fastenings being spaced about 6 inches apart, across the width of the sheet.

10. *Scratch-Coat Gypsum Plaster, on Metal Lath.*—This coat was composed of 1 bag of retarded neat fibered gypsum plaster to 1½ cubic feet of sand. The ingredients were thoroughly mixed, first dry and again wet, and applied to the lath with sufficient pressure to force the plaster through the lath to form a good key. The exposed surface was reasonably true and covered the lath about ⅛ inch. Before setting, the surface of the coat was scratched with an appropriate tool. This coat was allowed to set before applying the brown coat.

11. *Brown-Coat Gypsum Plaster.*—This coat was composed of 1 bag of retarded neat fibered gypsum plaster to 2½ cubic feet of sand. The ingredients were thoroughly mixed, first dry and again wet, and applied with sufficient force to form a good bond. When the plaster base was Thermax, this coat was built out to an average thickness of ½ inch, rodded and floated to a true, even surface. For masonry this thickness was ½ inch unless otherwise stated in the description of the panel. For metal lath the total thickness of the plaster from the face of the studs or joist to the face of the plaster was ⅞ inch.

12. *Smooth Finish Coat.*—This coat was composed of 1 bag of finishing hydrated lime to ½ bag of unretarded gypsum plaster. The

lime was made into a putty with water at least 24 hours prior to use. A small amount of this putty was circled out on a plasterer's board, some water put into the circle, and gaging plaster equal to one-half the volume of the putty dusted into the water. The whole was then mixed with a trowel, more water being added, if necessary. More material was not mixed at one time than could be used in 30 minutes. The mixture was not retempered, but each batch was started with clean board and tools. This plaster was applied as a thin, even layer over the brown coat. It was watched carefully for the appearance of incipient crystallization. When this occurred, it was immediately troweled down to a smooth, true finish, using considerable pressure on the trowel, and brushing the surface with water, if necessary. This coat was as thin as possible without permitting the brown coat to show through.

13. *Erection of Subflooring.*—New, straight 1 3/16- by 3 1/2-inch stock was used. It was applied diagonally across the floor joist and well nailed.

14. *Erection of Finish Flooring.*—New, straight 1 3/16- by 2 1/4-inch oak flooring was used. The oak flooring was applied perpendicular to the joist or nailing strips and securely nailed.