System Adaptation*

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A communication system for the pick-up and reproduction in auditory perspective of symphonic music must be designed properly with respect to the acoustics of the pick-up auditorium and the concert hall involved. The reverberation times and sound distribution in the two auditoriums, the location of the microphones and loud speakers, and the response-frequency calibration of the system and its equalization are considered. These and other important factors entering into the problem are treated in this paper.

WHEN the effect of music or the intelligibility of speech is spoiled by bad acoustics in an auditorium, the audience is well aware that acoustics do play a most important part in the appreciation of the program. One may not be conscious of this fact when the acoustical conditions are good, but a simple illustration will show that the effect still is present. Thus, of the sound energy reaching a member of the audience as much as 90 per cent may have been reflected one or more times from the various surfaces of the room, and only 10 per cent received directly from the source of the sound.

In listening to reproduced sound in an auditorium or concert hall, the effect of the room acoustics is perhaps even more important, for in this case the audience does not see any one on the stage and must rely entirely upon the auditory effect to create the illusion of the presence there of an individual or a group. Imperfections in the reproduced sound that are caused by defects in the acoustics of the auditorium may destroy the illusion and be ascribed improperly to the reproducing system itself.

In some types of reproduced sound, radio broadcast for example, where the reproduction normally takes place in a small room, the attempt is made to create the illusion that the listener is present at the source.[1, 2] In the case considered here, however, where symphonic music is reproduced in a large auditorium, the ideal is to create the illusion that the orchestra is present in the auditorium with the audience. Since the orchestra is playing in one large room and the music is heard in another, the acoustical conditions prevailing in both must be considered.

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Pick-Up Conditions

The source room is the auditorium of the American Academy of Music in Philadelphia. This room has a volume of approximately 700,000 cubic feet, and a seating capacity of 3000. Measured reverberation time curves for this auditorium, and preferred values [3, 4] for a room of this volume, are given in Fig. 1. It may be seen that with a

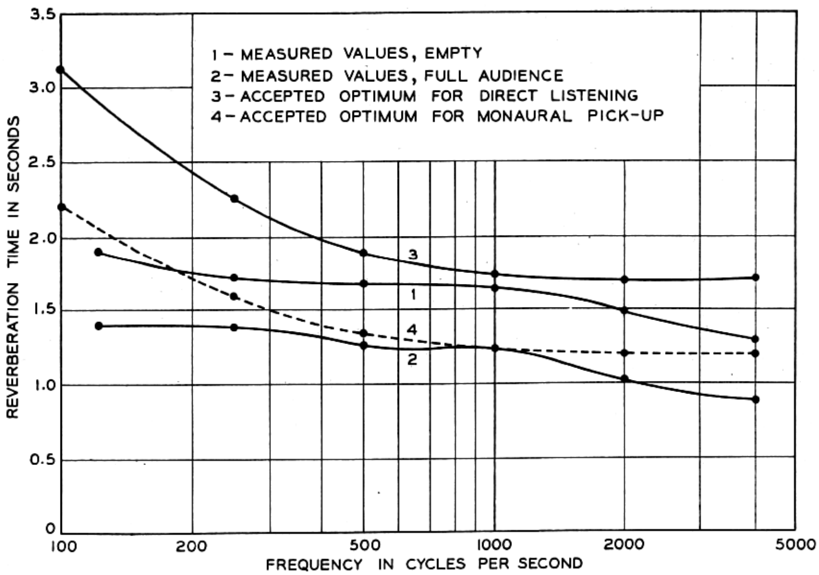

Fig. 1—Reverberation characteristics of Academy of Music, Philadelphia, Pa.

full audience this room might be considered somewhat dead, but would be considered generally satisfactory for pick-up either with or without an audience. A floor plan of the Academy auditorium and stage, showing the location of the three microphones used, is given in Fig. 2. The microphone positions were selected after judgment tests using several locations and are much nearer the orchestra than they would be for single channel pick-up.[2] The use of the microphones near the orchestra results in picking up a high ratio of direct to reverberant sound and thus reduces the effect of reverberation in the source room upon the reproduced music. A high ratio of direct sound is desirable in the present case also because of the use of three channels. The perspective effect obtained with three channels depends to a considerable extent upon the relative loudness at the three microphones, and since the change in loudness with increasing distance from the source is marked for the direct sound only, and not for the reverberant, there would be a definite loss in perspective effect if the microphones were placed at a greater distance from the orchestra. This effect is discussed more fully in another paper of this symposium.

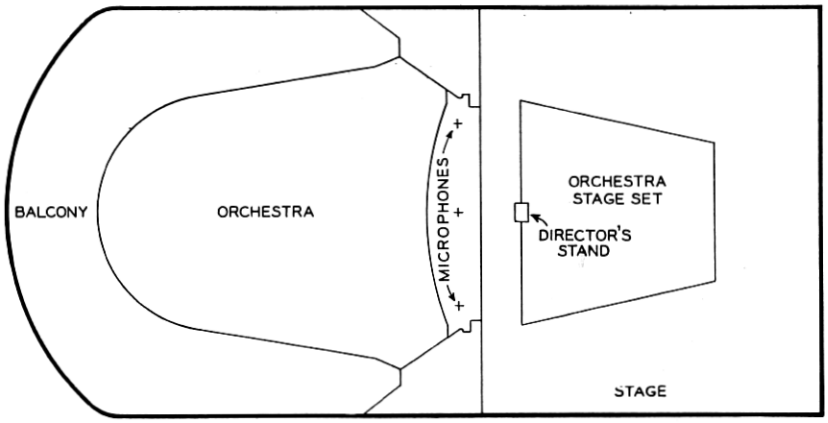

Fig. 2—Floor plan of Academy of Music, showing location of microphones.

With the microphones located close to the orchestra their response-frequency characteristics will be essentially those given by the normal field calibration, since relatively little energy is received from the sides and back. For a distant microphone position it would be necessary to use the random incidence response characteristic, which differs from the normal because of the variation in directional selectivity of the microphones as the frequency varies. This difference in response characteristic depends upon the size of the microphone and may amount to as much as 10 db at 10,000 c.p.s. It may be pointed out here that this difference in response is one factor frequently overlooked in the placement of microphones.

In addition to the three microphones regularly used, a fourth was provided to pick up the voice when a soloist accompanied the orchestra. In this case only the two side channels were used for the orchestra, the voice being transmitted and reproduced over the center channel. The solo microphone was so shielded by a directional baffle that it responded mainly to energy received from a rather small, solid angle. This arrangement permitted independent volume and quality control for the vocal and orchestral music.

The Concert Hall

The music was reproduced before the audience in Constitution Hall in Washington, D. C. This hall has a volume of nearly 1,000,000 cubic feet, and a seating capacity of about 4000. A floor plan of the auditorium showing the location of the loud speakers and of the control equipment is given in Fig. 3. The loud speakers are placed so that each of the three sets radiates into a solid angle including as nearly

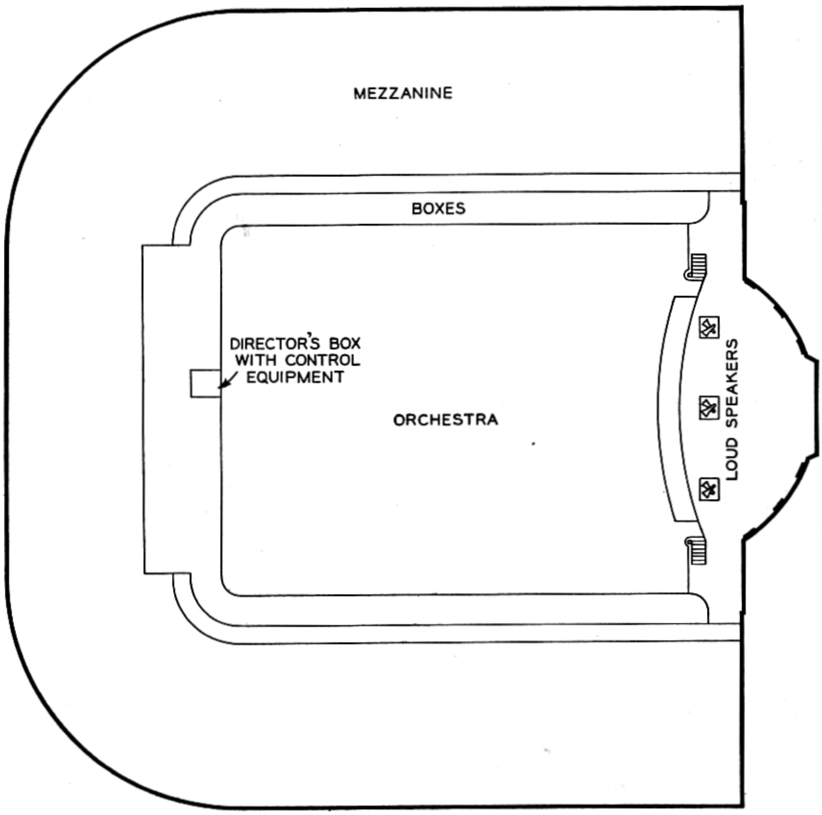

Fig. 3—Floor plan of Constitution Hall, Washington, D. C., showing locations of loud speakers.

as possible all the seats of the auditorium. Figure 4 shows the reverberation-frequency characteristics of Constitution Hall. The values given by the curve for the empty hall were measured through the use of the three regular loud speakers and several microphone positions in the room. The values for the hall with an audience present were calculated from known absorption data for an audience, and the optimum values are taken from accepted data for an auditorium of the volume of this one.[3] The reverberation times were considered satisfactory and no attempt was made to change them for this demonstration. The reverberation time measurements for both Constitution Hall and the Academy of Music were made with the high speed level recorder.[5] This instrument measures and plots on a moving paper chart a curve

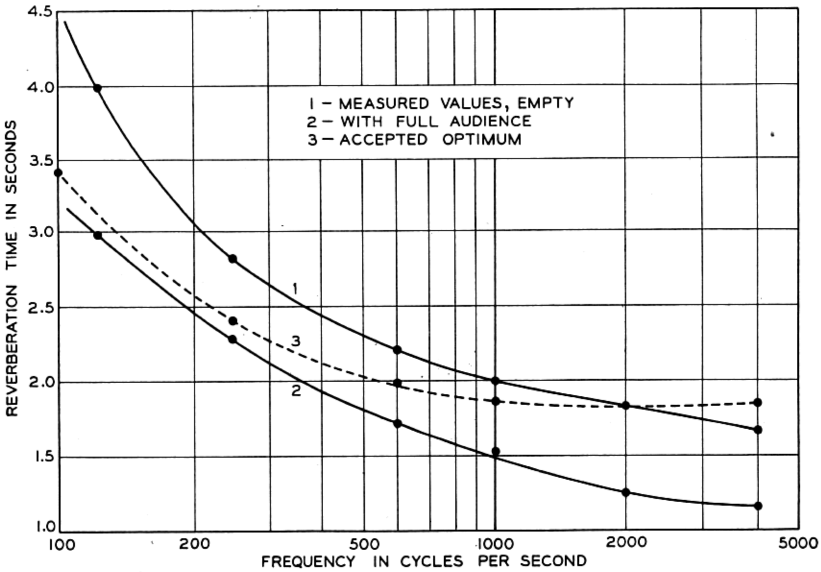

Fig. 4—Reverberation characteristics of Constitution Hall.

the ordinate of which is proportional to the logarithm of the electrical input furnished to it. When used in connection with a microphone for reverberation time measurements, curves are obtained showing the intensity of sound at the microphone during the period of sound decay. The rates of decay, and hence the reverberation times, are obtainable immediately from the slopes of these recorded curves and the speed of the paper chart.

Calibration of the System

In calibrating the system, a heterodyne oscillator connected to the loud speakers through the amplifiers was used. The oscillator was equipped with a motor drive to change the frequency, and as the frequency was varied through the range from 35 to 15,000 c.p.s. the sound was picked up with a microphone connected to the level recorder. Continuous curves of microphone response as a function of frequency thus were obtained for several positions in the auditorium, and for each channel independently. These response curves provided a check on a uniform coverage of the audience by each loud speaker, and also provided data for the design of the equalizing networks required to give an over-all flat response-frequency characteristic. If the system, including the air path from the loud speakers to one position in the auditorium, is made flat, it will not, in general, be flat for other positions or for other paths in the room. This variation in characteristic is due partly to the variation in the ratio of direct to reverberant sound, and partly to the fact that the sounds of higher frequency are absorbed more rapidly by the air during transmission.[6, 7] This latter effect is of considerable importance; it depends upon the humidity and temperature of the air, and may cause a loss of more than 10 db in the high frequencies at the more distant positions in a large auditorium. Some compromise in the amount of equalization employed therefore is necessary. Probably the most straightforward procedure would be to design the networks according to the response curves obtained with the microphones near the loud speakers. This would insure that for both the response measurements and the pick-up the microphone characteristics would be the same, and any deviation from a uniform response in the microphones would be corrected for in this way, along with variations in the loud speaker output. This procedure was modified somewhat for the case under discussion, however, because by far the greater portion of the audience was at a distance from the stage such that they received a relatively large ratio of reverberant sound, and it was believed that a better effect would be achieved by equalizing the system characteristic in accordance with response measurements taken at some distance from the loud speakers.

Control Equipment

In addition to the equalizing circuits used to obtain a uniform response characteristic, two sets of quality control networks which could be switched in or out of the three channels simultaneously were employed. One set modified the low frequencies as shown at *A*, *B*, and *C* of Fig. 5, while the other gave high frequency characteristics as shown at *D*, *E*, *F*, and *G*. These latter networks permitted the director to take advantage of the fact that the electrical transmission and reproduction of music permits the introduction of control of volume and quality which can be superimposed on the orchestral variations. Quality of sound can be divorced from loudness to a greater degree than is possible in the actual playing of instruments, and the quality can be varied while the loudness range is increased or decreased. Electrical transmission therefore not only enlarges the audience of the orchestra, but also enlarges the *capacity* of the orchestra for creating musical effects.

The quality control networks and their associated switches were mounted in a cabinet (Fig. 6) at the right side of the director's position. Continuously variable volume controls for the three channels were mounted on a common shaft and housed in the center cabinet of Fig. 6.

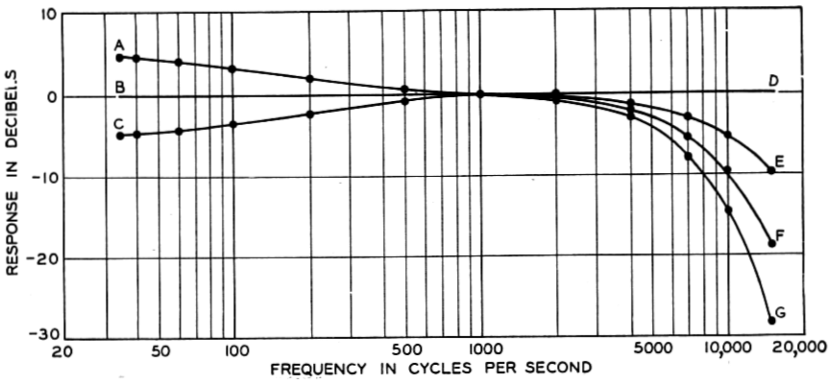

Fig. 5—Transmission characteristics of quality control networks used in the Philadelphia-Washington experiment.

A separate control for the center channel was provided when that was used for the soloist. In addition to the high quality channels certain auxiliary circuits were supplied to aid the smoothness of performance. Supplementing the order wire connecting all technical operators, a monitor circuit was provided in the reverse direction. The microphone was located on the cabinet before the director, and loud speakers were connected in the control rooms and on the stage with the orchestra, enabling the control operator to hear what went on in the auditorium and allowing the director to speak to the orchestra. Two useful signal circuits were employed; one giving the orchestra a "play" or "listen" signal, and at the same time connecting either the auditorium or the orchestra's loud speakers, respectively; the other being a

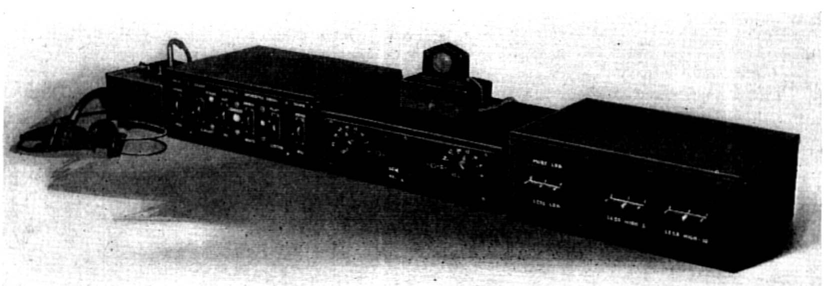

Fig. 6—Cabinets housing quality control networks and providing communication facilities for operation.

"tempo" signal to the assistant director leading the orchestra that could be operated during the rendition of the music. The switches for the auxiliary circuits and the order wire subset are shown at the control operator's position at the left in Fig. 6.

That a reproducing system may have quite different characteristics in different auditoriums is well illustrated in the case of the two halls considered here. From Fig. 3 it may be seen that in Constitution Hall the stage is built into the auditorium itself, and that there is no back stage space. The Academy of Music, however, has a large volume back stage. When the orchestra plays in the Academy the reflecting shell shown in Fig. 2 is used to concentrate the radiated sound energy toward the audience. When the reproducing system was set up in the Academy the shell could not be used because of the stage and lighting effects desired, and a large part of the energy radiated by the loud speakers at the low frequencies was lost back stage. The loss of low frequency energy is attributable partly to the fact that the loud speakers cannot well be made as directional for the very low frequencies as for the higher. The loss amounts to about 10 db at 35 c.p.s., and becomes inappreciable at 300 c.p.s. or more, as measured in comparable locations in the two auditoriums. This difference in characteristics emphasizes the fact that for perfect reproduction the acoustics of the auditorium must be considered as a part of the system, and that in general the equalizing networks must have different characteristics for different auditoriums.

References

1. "Acoustics of Broadcasting and Recording Studios," G. T. Stanton and F. C. Schmid. *Jour. Acous. Soc. Am.*, v. 4, No. 1, part 1, July 1932, p. 44.
2. "Acoustic Pick-Up for Philadelphia Orchestra Broadcasts," J. P. Maxfield. *Jour. Acous. Soc. Am.*, v. 4, No. 2, Oct. 1932, p. 122.
3. "Optimum Reverberation Time for Auditoriums," W. C. MacNair. *Jour. Acous. Soc. Am.*, v. 1, No. 2, part 1, Jan. 1930, p. 242.
4. "Acoustic Control of Recording for Talking Motion Pictures," J. P. Maxfield. *Jour. S. M. P. E.*, v. 14, No. 1, Jan. 1930, p. 85.
5. "A High Speed Level Recorder for Acoustic Measurements," E. C. Wente, E. H. Bedell, K. D. Swartzel, Jr. Unpublished paper presented before the Acous. Soc. Am., May 1, 1933.
6. "The Effect of Humidity Upon the Absorption of Sound in a Room, and a Determination of the Coefficients of Absorption of Sound in Air, V. O. Knudson. *Jour. Acous. Soc. Am.*, v. 3, No. 1, July 1931, p. 126.
7. "Absorption of Sound in Air, in Oxygen, and in Nitrogen—Effects of Humidity and Temperature," V. O. Knudson. *Jour. Acous. Soc. Am.*, v. 5, No. 2, Oct. 1933, p. 112.