교회의 전기음향 시스템 설계 및 성능평가

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Design and Evaluation of Electro-Acoustic System in Church

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1. Introduction

The good intelligibility for speech, in general, requires a short reverberation time from 0.9s to 1.4s, whereas for music it requires rather longer reverberation time from 1.2s to 5.0s. The reverberation time interval has been considered as main ploblem in designing procedure of multipurpose hall including church.

Under the test church, the reverberation time is too long for speech, but optimum for religious music. Speech intelligibility is poor without the use of a reinforcement system. Therefore, a sound reinforcement system for understanding speech was installed, providing many sound sources. This is made possible to understand speech, but speech intelligibility was poor because of highly distributed sound reinforcement system, the source localization was also lost. Every person judged the acoustics of the church very bad, complaining about echo and speech intelligibility.

In designing sound systems to be installed in rooms, we should properly take into consideration not only the function of sound amplification but also improvement of acoustical properties of room. The purpose of this study is to improve the speech intelligibility without any acoustic treatments, i.e., adding the absorbing material to the room. In this paper, we will describe the results of acoustic evaluation after PA system renovation.

2. Room acoustic parameters

Internal space in church has the volume of 5,200m. The room parameters are shown in Table1. In order to know the room acoustic environment to be installed electroacoustic system, room acoustic parameters were analyzed in empty room. Important parameters derived from the measurements are the reverberation time, Deutlichkeit, RASTI, and echo.

Table 1. Room characteristics

Volume	16,613 m^3
Surface	5,809 m^2
V/N	8.3
Number of seats	2,000 seats
RT at 500Hz	2.5s
Room constant	1730
Critical distance	18m

1)Reverberation time

Reverberation time measurements were made with pistol shot at 24 receiver positions in seat areas. The reverberation decays were measured according to the Schroeder's integrated impulse method[1]. The octave reverberation times for the 24 receiver positions are plotted in Fig.1. It is shown that the measured reverberation times do not depend on the position. The mean RT at 500Hz is 2.3s and frequency characteristic shows significant rise at middle frequencies. This reverberation time is definitely long side for speech, but optimum for music.

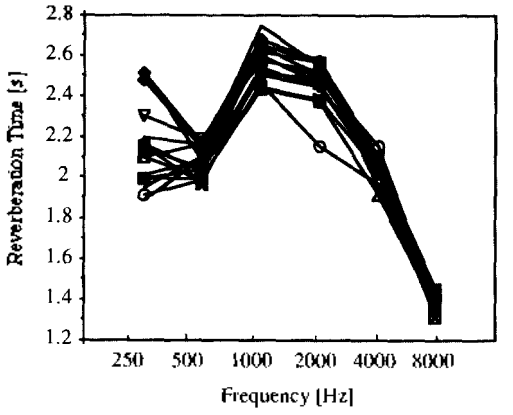


Fig. 1 The octave reverberation time at 24 receiver points.

2)Deutlichkeit

The importance of early reflected sound has been appreciated as contributing to the intelligibility of speech sound. As a measure of speech intelligibility, Deutlichkeit is defined as the ratio of early sound energy in the first 50ms after the arrival of the direct sound to the total sound energy[2]. Deutlichkeit was calculated numerically from impulse response. Table 2 shows the value of Deutlchikeit in each seat. Those are definitely low values for speech intelligibility. For a speech, D value should be larger than 0.6[2].

3) RASTI

To evaluate the physical characteristics of speech transmission, we use the rapid speech transmission index(RASTI) which evaluates speech intelligibility between any speaker-listener combination in the room. The RASTI method is very quick; it is possible to measure the intelligibility at one listening position within about 30 seconds[3].

In this study, the speech transmission meter(B&K type 3361) was used. At each receiver position at least one measurement of 32 second duration was performed. The sound source was placed at a position of the pulpit where the head of the preacher would normally be located, positioning toward the nave. The measured results show the range of 0.35 to 0.44, which is based on an average of results in the 500 Hz and 2000Hz octave bands. In general, RASTI above 0.75 indicates that speech intelligibility is excellent; from 0.6 to 0.74 it is good; from 0.45 to 0.58 fair; 0.3 to 0.44 poor; and below 0.3 bad[4].

3. Electroacoustic treatment

A distributed arrangement of loudspeakers causes time difference among outputs from different loudspeakers, it is possible to produce echoes. Therefore, we decided to change the central cluster speaker system which is preferred in most auditorium situations because of its economical aspect and naturalness.

If a directivity of loudspeaker system is synthesized as shown in Fig.2, a large percentage of radiated sound power is absorbed in seats which have large absorption coefficients. Therefore, sound coming from a loudspeaker system up to a microphone of stage is reduced and howling threshold rises, so that sound pressure in the room is possible to be increased. Increase of direct sound from the loudspeaker system and decrease of scattered sound are able to improve Deutlichikeit and also speech intelligibility. It can produce highly satisfactory listening conditions.

Table 2 Deutlichkeit at each seat

Seat	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Room response	0.35	0.21	0.26	0.21	0.26	0.24	0.24	0.23	0.33	0.27	0.29	0.25	0.31	0.29
PA response	0.72	0.71	0.65	0.66	0.55	0.62	0.54	0.60	0.70	0.55	0.68	0.64	0.61	0.65

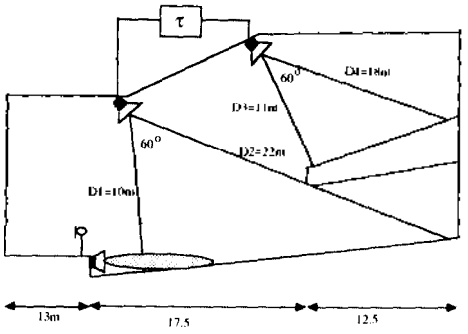


Fig.2 Loudspeaker system with good-design directivity

Sound pressure is nearly determined by direct sounds from loudspeakers within the critical distance. Even if the reverberation time is quite long, if the ratio of direct to reverberant sound is sufficiently high, we can easily understand the speech. Critical distance(Dc) is important because it allows to determine the approximate direct to reverberant sound ratio at the listener. Dc is defined as the distance from sound source where the direct sound and reverberant sound are of equal magnitude[5].

Dc can be calculated as follow:

$$Dc = 0.14\sqrt{QR}$$,

where, Q: Directivity of loudspeaker,

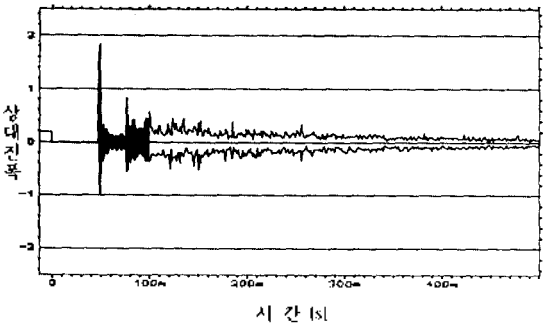
R: Room Constant, $S\,\bar{\alpha}\,/1-\bar{\alpha}$,

$\bar{\alpha}$: Absoption coefficient.

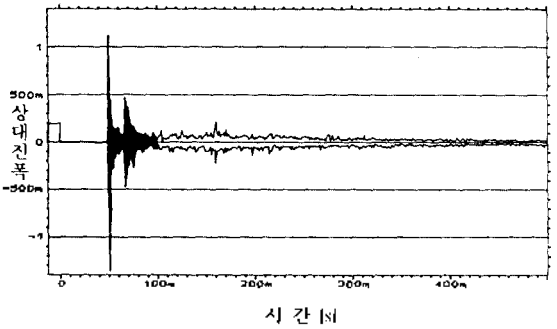
At critical distance, the ratio of direct to reverberant sound is unity. Longer reverberation times, lower ratio is necessary to ensure good intelligibility.

From the eqation, we could obtain the Dc value of 18m in the church. Three synthesized loudspeakers were installed in the ceiling as shown in Fig.2. The measured impulse responses through the loudspeaker system are shown in Fig.3. Deutlichkeits in each seat calculated numerically from impulse responses are shown in Table 2. It is shown that Deutlichkeits are remarkably increased.

At the same time front loudspeakers were installed for the audience seated in the front rows, which contribute to move the sound image toward the stage. Frequency response characteristic of the room is almost flat in the range of 100Hz to 10kHz.



(a) Impulse response of room (Deutlichkeit: 0.21)



(b) Impulse response using electroacoustic system (Deutlichkeit: 0.71)

Fig 3. Comparison between the impulse response without PA system and with PA system.

4. Speech Intelligibility Test

After renovation, most people judged good acoustics about the speech intelligibility.

Three nonsense monosyllabic list sets were used as test signals[6]. Each list consists of 50 word. The words were uttered by a male speaker in the sound-treated room. The tests were played from a tape recorder. The output of the tape recorder was connected to the amplifier of the PA system. The sounds at 5 seat were picked up using dummy head (Sennheiser MKE 2002) which has microphones placed in the ear canal positions, and recorded on the two

tracks of a DAT tape for stereophonic reproduction.

The amplification of the PA system was set to produce a speech level of 70dB(A) in ear canal of the dummy head. The speech levels were measured with sound level meter. 18 subjects with normal hearing were participated in the tests. Tests were performed in a sound treated room using headphones(Sennheiser HD 540). In all cases, articulation score of 70% or better was obtained.

5. Conclusion

We had observed that even in highly reverberant room, good intelligibility could be obtained if it is provide high ratio of direct to reverberant sound energy at the listener. In the case of speech intelligibility, this report offered evidence that the direct to reverberant sound ratio is a predictor of intelligibility.

Reference

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