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A New Miniature Loudspeaker For Room Acoustical Scale Model Experiment

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ABSTRACT

A new miniature dodecahedral loudspeaker appropriate for a 1/10 -1/20 scale room acoustical model experiment was developed. This sound source consists of a PVDF bimorph film as a transducer, whose vibrating surface shape was mechanically modified so as to improve the acoustical characteristics. The reproducible frequency range is from 15 to 160 kHz with relatively flat responses, and the sound pressure is large enough to allow accurate measurements. Major acoustical characteristics of this source, some new results of the scale model experiment and the proposed signal processing algorithm are reported.

INTRODUCTION

Scale model experiments are widely conducted as a principal tool, along with computer simulation, in today's acoustic design of concert halls. One of major technical tasks in those experiments may be due to the accuracy of sound sources for the acoustic measurement. Many researchers have tried to come up with varying sound sources unique to themselves, and some of them have been actually used in those acoustic model experiments [1-3]. We devised a new type of sound source that uses piezoelectric vibrators on an experimental basis, and its characteristics and applications are described in this report.

MINIATURE SOUND SOURCE

Our prototype sound source was produced to apply to acoustic experiments using models in scales from 1/10 to 1/20, and to simulate the regular dodecahedral loudspeaker to ensure compliance with ISO 3382[4] (Fig. 1). A piezoelectric vibrator (9.5 x 7 mm in external dimensions) was attached to each face of the dodecahedron (which is an equilateral pentagon of 22 mm per side) as a driving unit. This vibrator is made of PVDF (polyvinylidene fluoride) bimorph film molded into corrugated shape, and because of its low stiffness, it has a resonant frequency lower than that of an ordinary PVDF film. Conventional types of PVDF films need auxiliary treatments, such as adhesion of additional mass on the vibrating surface, to adjust its frequency characteristics [3], but our vibrator element has relatively flat frequency characteristics over a wide frequency range. The basic specifications of the prototype sound source are given in Table 1.

Acoustic Characteristics

Frequency characteristics of the sound pressure level of the prototype sound source for 1/3 oct. band noise signal is shown in Fig. 2, where the microphone was placed at 150 mm away from the sound source. As shown in the figure, almost flat frequency characteristics appear from 16 kHz to 100 kHz. According to separate measurement result of a single PVDF element, it was found that this flat sound pressure response is maintained up to about 160 kHz. Accordingly, this sound source alone provides almost flat frequency characteristics without filtering correction in order to compensate the frequency response. For lower frequency below 20 kHz, the measurement will be made using another miniature dodecahedral loudspeaker previously developed.

Fig.1 Miniature dodecahedral loudspeaker.

Table 1 Specification of sound source

Overall size	ϕ 61mm	
Weight	52g	
Impedance	30kΩ	1kHz
	3kΩ	10kHz
Capacitance	4.5nF	1kHz,10kHz
Normal input voltage	180V	r.m.s.
Max. input voltage	250V	p.-p.

Figure 3 shows the directional characteristics at a point 1 m away from the sound source for 1/1 octave band noise signal. The deviation of the directionality is ±2.8 dB at 20 kHz and ±3.6 dB at 40 kHz. These values are slightly poorer than the corresponding real-scale dodecahedral sound source. One of the causes is that the piezoelectric element is not attached in such a way that places the element level with the surface of the sound source. We are currently producing the improved version. According to the theoretical calculation by Tarnow [5], the cutoff frequency that allows omni-directionality is about 6 kHz for our sound source and about 1 kHz for a 1/1 scale sound source. It means the preferable cutoff frequency (10 kHz) won't be achieved even if simply changing the size of the sound source 1/10.

Figure 4 shows the radiated impulse response (IR) waveforms for the 1/1 oct. band pass filter. In addition to the primary response, the additional tail is observed in the transient response. This is mainly caused by the diffraction at the baffle edges. The duration of this waveform is about 3 ms when converted to the real scale, which allows measurement with proper time resolution for usual room acoustical criteria.

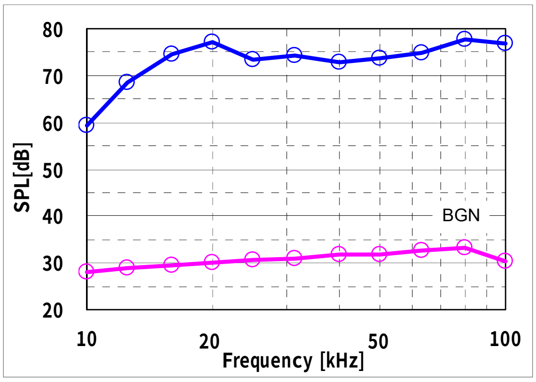

Fig.2 SPL at 15cm distance from the new dodecahedral loudspeaker.

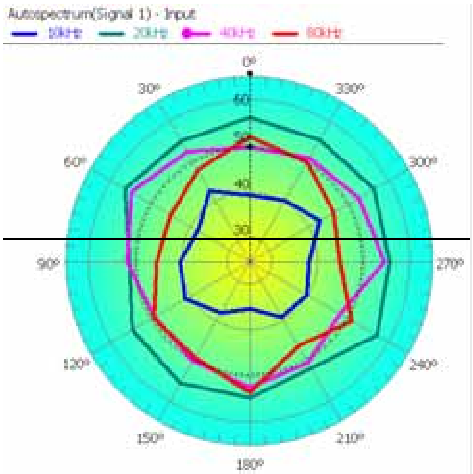

Fig.3 Directional distribution for 1/1 oct. band noise.

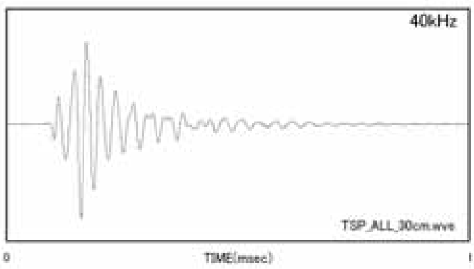

Fig.4 Radiated waveform for 1/1 Oct. band impulse signal.

APPLICATION

Measurement in a scale model

The 1/10 scale model used in this report is shown in Fig. 5. This is a shoebox hall mainly intended for music performance with an audience seating of about 1,230 (room volume: 11,100 m^3; total surface area: 4,330 m^2; width of main floor: 20.2 m). Lattice-like diffusion modules that gradually increase in size (from the fine to large scale) from down to up are attached onto the sidewalls in the hall. A large curved reflector is set up around the stage.

The model experiments were executed in reference to the specification in ISO 3382, when the above-mentioned two miniature sound sources were used. The frequencies covered by each were divided by 15 kHz, and the stretched pulse was generated as a source signal, applying 100 synchronous summations.

Fig.5 1/10 Scale model for experiment.

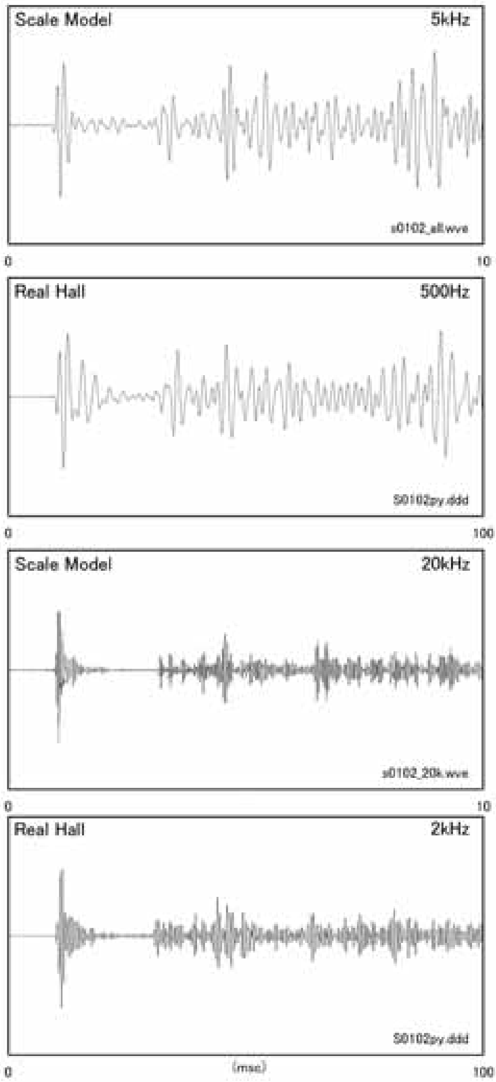

Fig.6 Comparison of reflectogram in a scale model measured with 1/8 inch microphone and in the real hall: 1/1 oct. band response at center main-floor seat.

The most influential factor on the total absorption in a hall is that by chairs. As is well known, it is difficult to simulate the sound-absorbing material in a scale model [6], and particularly difficult is simulating the absorption of (seated) chairs for all frequency bands with only one type of the model chair. We divided the frequency bands into a few bands and devised model chairs that simulate the absorption in each subdivided frequency band. Then acoustic measurements were made for each band separately with the corresponding chairs, and if necessary the IR for all frequency bands was digitally synthesized as explained later.

Reflectograms

Figure 6 compares the reflectogram of the scale model with that of actual hall after the completion. It might be said those two reflectograms correspond fairy well to each other. Since the surface structure of the model was simplified as a matter of course, the reflectograms for the scale model show simpler patterns.

Reverberation decay curve

Figure 7 shows decay curves in the 1/3 octave band, where the SN-ratio of about 40 dB is observed for both of them in the two bands, 40 Hz and 80 Hz. The new sound source is appropriate for measurement of the late reverberation process up to 1/20 scale. The following equation can be used when one simply needs to estimate (corrected) reverberation time, without the air absorption compensation.

$$\mathrm{RT_C} = \mathrm{RT_M}\left(1 - \frac{c(m_\mathrm{M} - m_0)}{6\ln 10}\mathrm{RT_M}\right)^{-1}$$

Where $\mathrm{RT_C}$ and $\mathrm{RT_M}$ are respectively the corrected reverberation time (RT) and RT obtained from the IR with no air correction, c sound velocity, and m_0 and m_M an air attenuation constant for standard condition (relative humidity 0% and temperature 20°C) and for actual condition at the experiment, respectively.

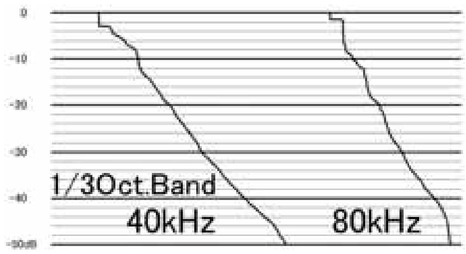

Fig.7 Decay curves for 1/3 oct band noise.

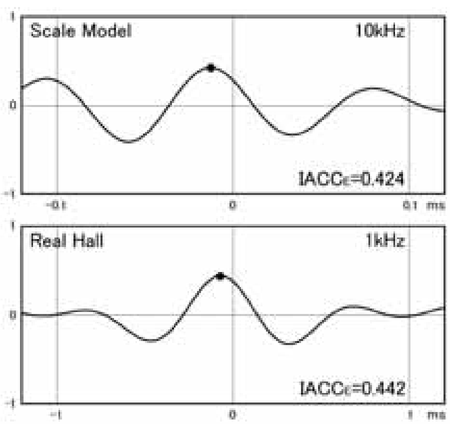

Fig.8 IACFs measured in 1/1 scale model and real hall.

Interaural cross-correlation (IACC)

Values of interaural cross-correlation function (IACF) and IACC measured in the scale model and the actual hall are compared in Figs. 8 and 9. These results indicate the good agreement between both measurements by raising the precision of the sound source.

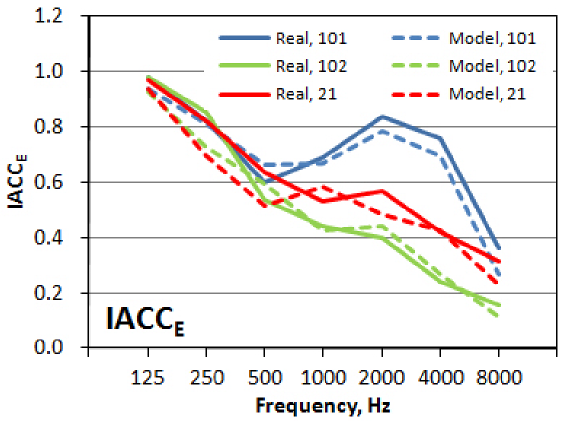

Fig.9 Comparison of IACC(Early) at three seating positions, two in main floor and one at balcony.

Auralization

Our new sound source, that enables us to measure IR in a model hall with flat frequency response with improved SN-ratio, is expected to serve as a tool for auralization. Combining the IR's measured by two miniature sound sources mentioned above (low and high freq. type) at a proper frequency, i.e., near 15 kHz, the IR designed to the auralization with wider frequency range can be created. Figure 10 shows the IR's measured with the sound sources and the synthesized IR. Spectral representations of those IR's are shown in Fig. 11. Furthermore, when one needs to adjust the reverberation time and loudness of the IR for each band to any values, the desired IR is obtained by the synthesis flow shown in Fig. 12.

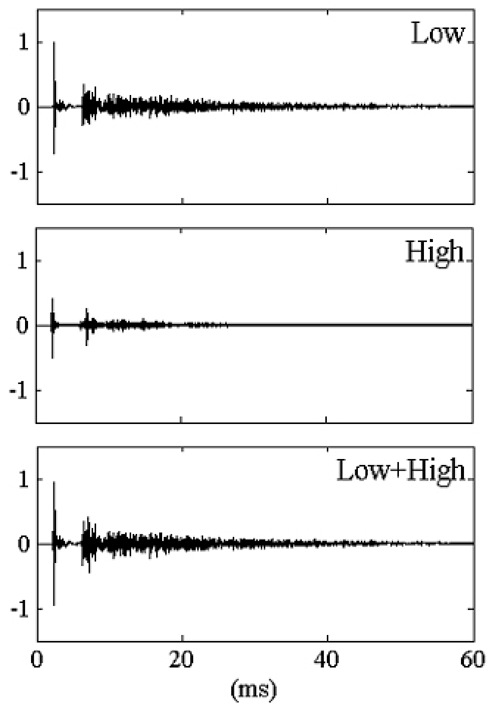

Fig.10 Room IR's measured by two miniature dodecahedral loudspeakers (Low and High), and synthesized one.

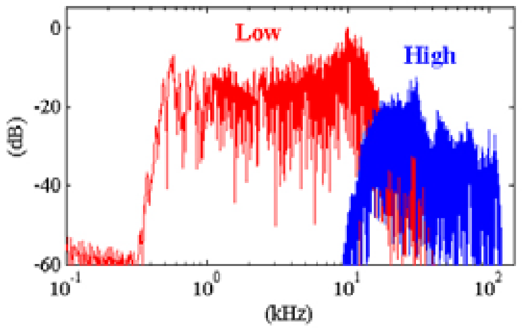

Fig.11 Frequency domain representation of the waveforms shown in Fig.10.

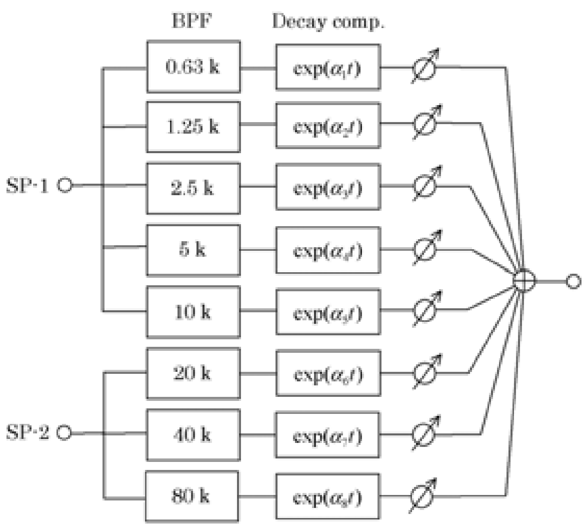

Fig.12 Block diagram of signal processing for auralization.

CONCLUSION

(1) A prototype dodecahedral sound source intended for 1/10 to 1/20 scale model experiments was developed applying PVDF element that features the improved characteristics. Compared with conventional sound sources of similar type, the sound source showed flat acoustic characteristics in wide frequency range.

(2) The new sound source enables us to observe reverberation decay curve up to 100 kHz with appropriate SN-ratios (above 40 dB) in the scale model experiment.

(3) The reflectogram and IACF produced from the model experiment were compared with those from real-scale measurements, and they agreed relatively well with each other. This indicates the new sound source is also a proper tool to evaluate early reflections.

The remained error in the model experiment especially at higher frequencies may be attributed to other factors, such as directionality of the microphone and the sound source and inadequate precision in model production in fine scales.

Acknowledgment

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