Evaluation on flexible beamformers with curved-type parametric loudspeaker for spatial audible area design

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ABSTRACT

In the fields such as evacuation guidance and entertainment, it is important for each listener to provide different sound information by using some loudspeakers in a same room. However, listeners have difficulty obtaining target sound information because various sound signals are mixed by using a general loudspeaker which has a wide directivity. To solve this problem, a parametric loudspeaker which has a high directivity by utilizing an ultrasound wave is ideal candidate. The parametric loudspeaker can provide each listener the target sound information because it can form the spatial audible area to the narrow space. However, the conventional parametric loudspeaker system requires a large system using too many parametric loudspeakers corresponding to each listener. In this paper, we therefore propose flexible beamformers with curved-type parametric loudspeaker for spatial audible area design using a small system. The proposed method utilizes the curved surface arrangement of ultrasound transducers and can design various spatial audible areas by changing its curvature. Finally, we evaluated the relationship between its curvature and spatial audible area in the proposed method. As a result of the evaluation experiment, we confirmed the effectiveness of the proposed method.

Keywords: Parametric loudspeaker, Directivity, Spatial audible area, Flexible beamformer, Curvature

I-INCE Classification of Subjects Number(s): 01.4

1. INTRODUCTION

Acoustic waves are usually emitted by a general loudspeaker. The general loudspeaker can transmit acoustic waves to many listeners because it has a wider directivity. However, acoustic waves become noise when they are transmitted to non-listener. In using several general loudspeakers in a public space such as a platform, it is difficult for listeners to obtain the target sound information because various acoustic waves are mixed. To solve this problem, a parametric loudspeaker has recently been focused on to achieve the acoustic transmission for individual listeners. It has a higher directivity by utilizing an ultrasound wave (1). Therefore, it can also form a spatial narrow audible area which a particular listener can obtain the target sound (2). In addition, it is also important to transmit the same target sound to several listeners in particular area because public space can be utilized by dividing acoustic space to multiple groups. To achieve it by the narrow audible area with the parametric loudspeaker, huge system with many parametric loudspeakers is required. Therefore, it is necessary to design the spatial audible area which can cover multiple listeners with a single parametric loudspeaker.

In this study, we propose the flexible beamformers with curved-type parametric loudspeaker for spatial audible area design. The curved-type parametric loudspeaker consists of ultrasonic transducers arranged on curved surface. It can flexibly steer the directivity by changing its curvature. Therefore, the proposed method can form various spatial audible areas by utilizing a single parametric loudspeaker.

In this paper, we confirm the effectiveness of the proposed method through evaluation experiment for various curved-type parametric loudspeakers.

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2. PARAMETRIC LOUDSPEAKER

A parametric loudspeaker has a higher directivity by utilizing an ultrasound wave as a carrier wave (1). The parametric loudspeaker intensely emits the amplitude modulated (AM) wave which designed by modulating the amplitude of the carrier wave with an audible sound wave (3). The AM wave $W_{AM}(t)$ is derived from,

$$W_{AM}(t) = (1 + mW_S(t))W_C(t), \tag{1}$$

$$W_C(t) = A\cos(2\pi Ft), \tag{2}$$

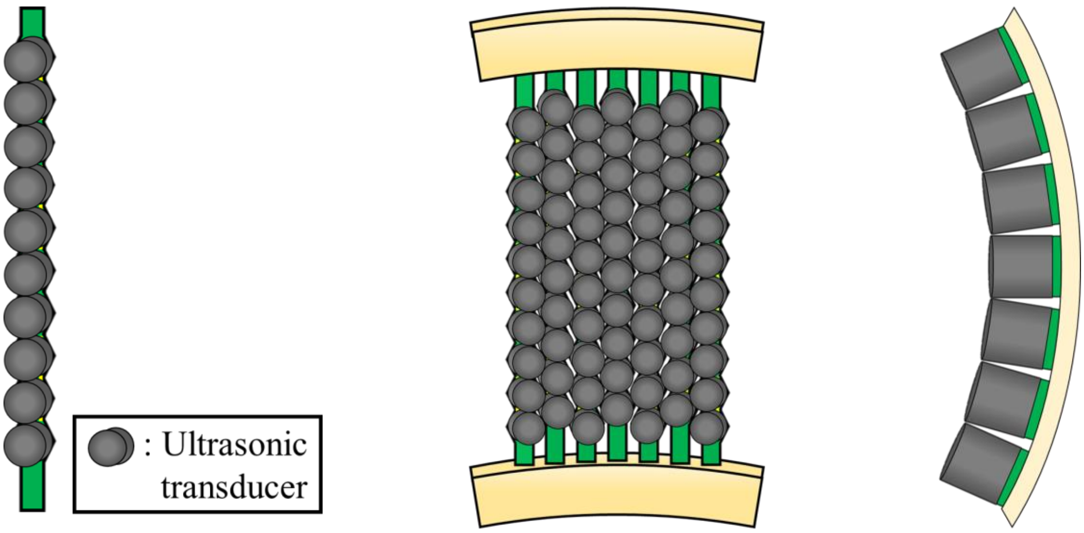
$$W_S(t) = \cos(2\pi ft), \tag{3}$$

where t [s] presents a time index, $W_C(t)$ and $W_S(t)$ present the carrier wave and the audible sound wave, respectively, F [Hz] and f [Hz] represent the frequency of the carrier wave and the audible sound wave, respectively, A represents the maximum amplitude of the carrier wave, and m represents an amplitude modulation index. The intense emitted AM wave by the parametric loudspeaker is demodulated into the original audible sound by nonlinear interaction in the air (4). The demodulated audible sound also has a higher directivity as with the ultrasound wave. Therefore, the parametric loudspeaker can transmit the target sound to a particular listener (2).

However, it is difficult for a single parametric loudspeaker to transmit the same target sound to several listeners in particular area. To solve this problem, it is necessary to steer the directivity of the parametric loudspeaker.

3. PROPOSED METHOD

In this paper, we propose the flexible beamformers with the curved-type parametric loudspeaker. The curved-type parametric loudspeaker consists of the several boards as shown in Fig. 1 (a). Each board has several ultrasonic transducers arranged in a straight line. These boards are arranged on arc as shown in Figs. 1 (b) and 1 (c). The overview of the curved-type parametric loudspeaker is shown in Fig. 2. In the proposed method, we employ the concave-type parametric loudspeaker which can focus the emitted sound on a particular point as shown in Fig. 2. This is because the AM wave is demodulated by nonlinear interaction efficiently when it has powerful sound pressure level. In this paper, the curvature is determined by the radius r_1 of the arc as shown in Fig. 2. In Fig.2, d_1 represents the chord length of the arc, d_2 represents the beam-wide, and r_2 represents the distance between the focus point A and point D. The beam-wide d_2 is calculated by Eq. (4).



(a) Board of the parametric loudspeaker (b) Side view (c) Top view

Figure 1 – Overview of the curved-type parametric loudspeaker

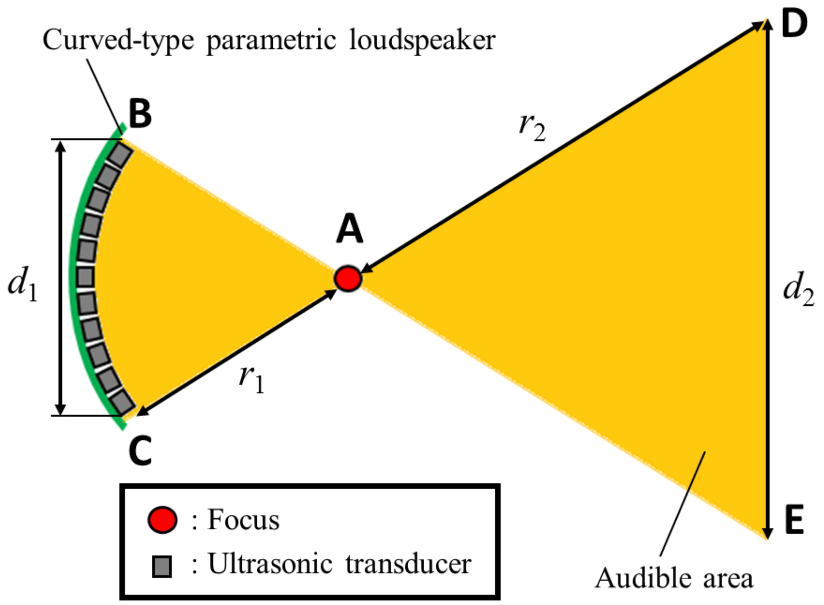


Figure 2 – Geometry of the curved-type parametric loudspeaker, the focal point and the spatial audible area

$$d_2 = d_1 \frac{r_2}{r_1} \tag{4}$$

From Eq. (4), the beam-wide d_2 depends on the radius r_1 of the arc. Therefore, the curved-type parametric loudspeaker can steer the directivity by changing its curvature.

4. OBJECTIVE EVALUATION EXPERIMENT

We carry out an objective evaluation experiment to confirm the relationship between the curvature and the directivity in the proposed method.

4.1 Experimental conditions

In this paper, we calculate the directivities of the five curved-type parametric loudspeakers (r_1 = 10 cm, 15 cm, 20 cm, 25 cm and 30 cm) and compare these directivities. Table 1 shows experimental conditions. Table 2 shows experimental equipment. Figure 3 shows the experimental arrangement of the curved-type parametric loudspeaker and the microphones. In this paper, we use the curved-type parametric loudspeaker which consists of 15 boards as shown in Fig. 4. Each board consists of 10 ultrasonic transducers. The directivities are calculated by measuring the power of audible sound (0-20kHz) at the 25 microphone positions as shown in Fig. 3. The power of audible sound is calculated by extracting the direct sound from impulse response obtained by the time stretched pulse (TSP) method (5).

Table 1 – Experimental conditions

Environment	Soundproof room
Background noise level	18.5 dB
Sound source	TSP(2^{19} points)
Sampling frequency	192 kHz
Quantization bit rate	16 bits

Table 2 – Experimental equipment

Microphone	SONY, ECM-88B
Microphone amplifier	HEG, MICA-800A
A/D, D/A Converter	RME, FIREFACE UFX
Power amplifier	YAMAHA, IPA 8200

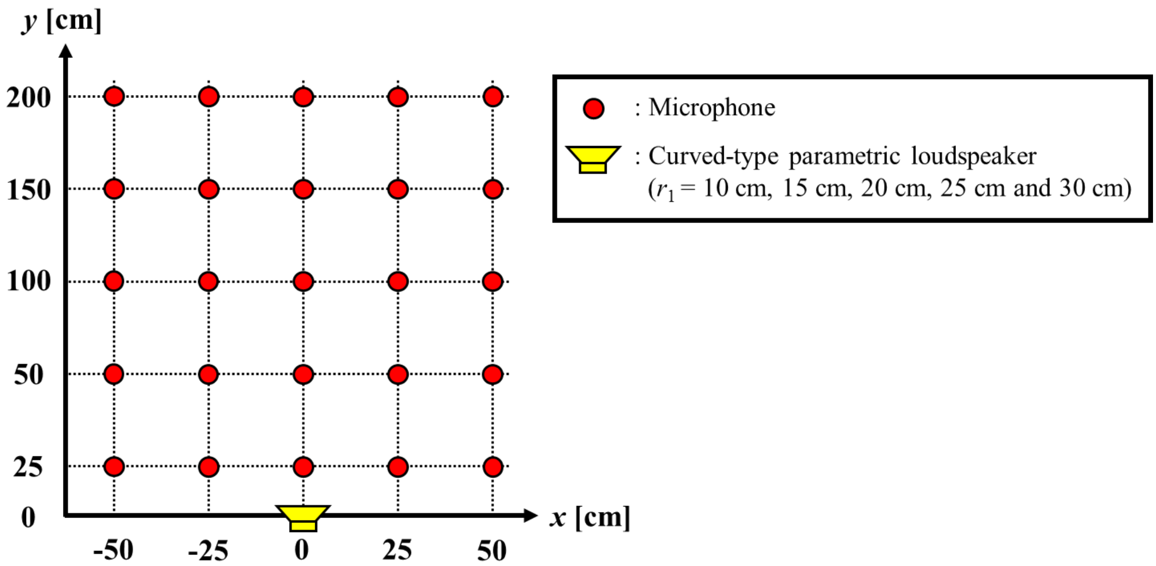


Figure 3 – Experimental arrangement of the curved-type parametric loudspeaker and microphones

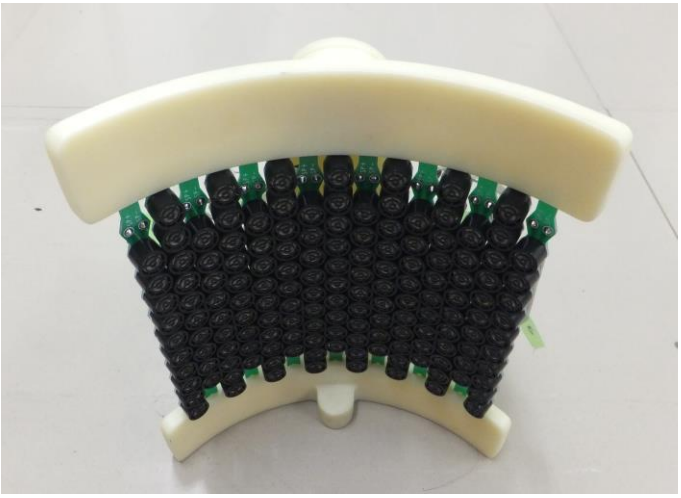


Figure 4 – Prototype of the curved-type parametric loudspeaker

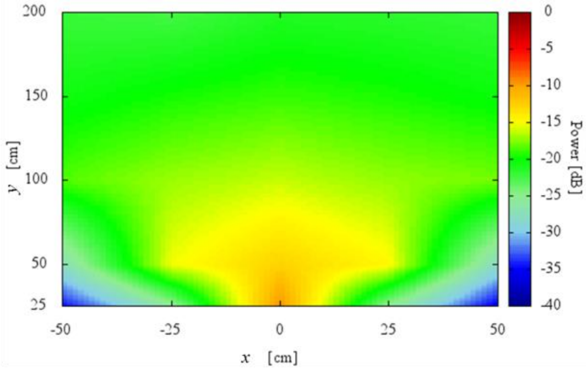
4.2 Experimental results

Experimental results are shown in Figs. 5 and 6. Figures 5 (a) to 5 (e) show the directivities of the five curved-type parametric loudspeaker (r_1 = 10 cm, 15 cm, 20 cm, 25 cm and 30 cm). Figure 6 shows the sound pressure distributions of the five curved-type parametric loudspeakers on y = 200 cm in Fig. 5.

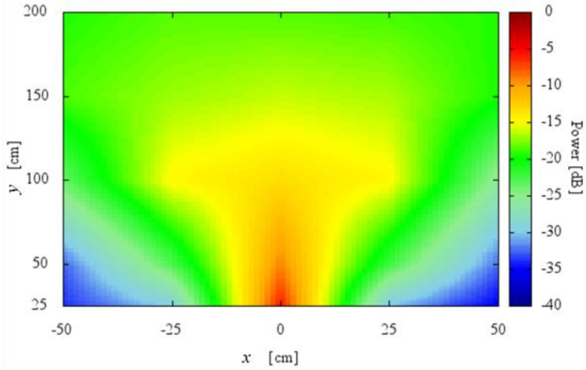
Figure 5 (a) shows that the curved-type parametric loudspeaker (r_1 = 10 cm) has a wider directivity. In Fig. 6, the maximum sound pressure level of the curved-type parametric loudspeaker

(r_1 = 10 cm) is lower than the others. From these results, we confirmed that the curved-type parametric loudspeaker (r_1 = 10 cm) can expand the spatial audible area with lower sound pressure level. This is because the curved-type parametric loudspeaker (r_1 = 10 cm) forms a focus point at the position which is close to itself. From Fig. 5 (d), we confirmed that the microphone position in (x, y) = (0, 25) has high sound pressure level. This is because the curved-type parametric loudspeaker (r_1 = 25 cm) forms a focus point at (x, y) = (0, 25). Figure 5 (e) shows that the curved-type parametric loudspeaker (r_1 = 30 cm) has a sharper directivity. In Fig. 6, the maximum sound pressure level of the curved-type parametric loudspeaker (r_1 = 30 cm) is higher than the others. From these results, we confirmed that the curved-type parametric loudspeaker (r_1 = 30 cm) can form a narrow audible area with higher sound pressure level. This is because the curved-type parametric loudspeaker (r_1 = 30 cm) forms a focus point at the position which is distant from itself.

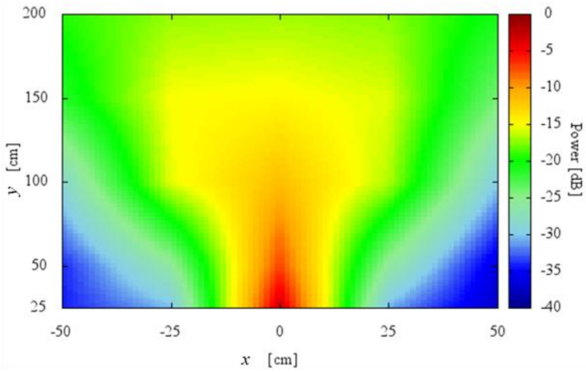
Therefore, we confirmed that the curved-type parametric loudspeaker can form various directivities by changing its curvature.



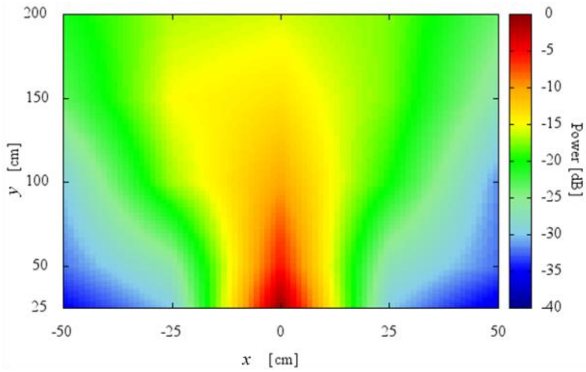
(a) r_1 = 10 cm



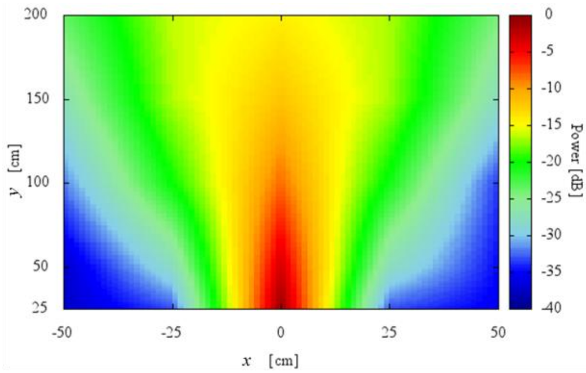
(b) r_1 = 15 cm



(c) r_1 = 20 cm



(d) r_1 = 25 cm



(e) r_1 = 30 cm

Figure 5 – Directivities of the curved-type parametric loudspeaker

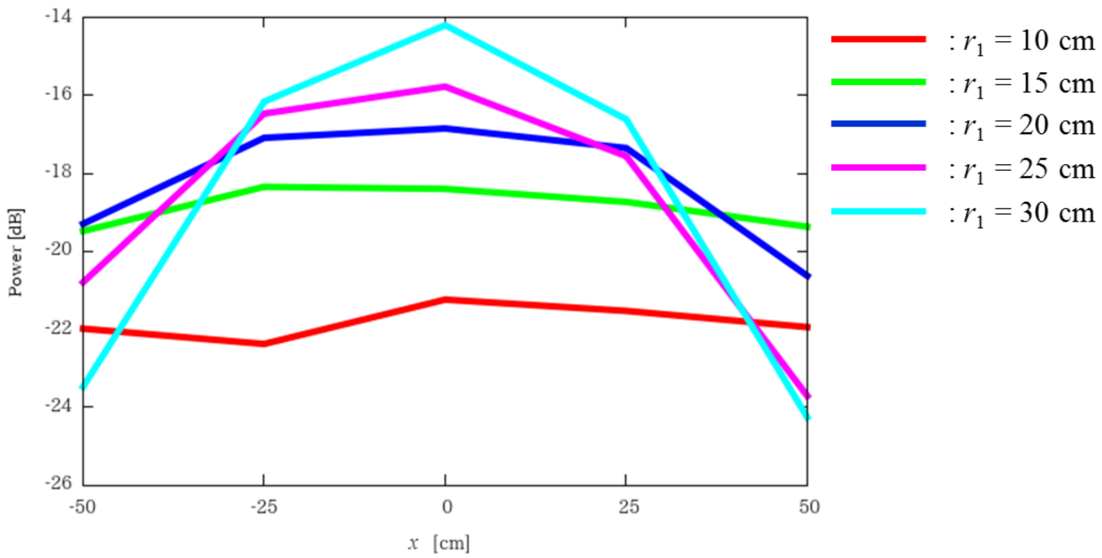


Figure 6 – Sound pressure distributions of the curved-type parametric loudspeaker on y = 200 cm

5. CONCLUSIONS

In this paper, we proposed flexible beamformers with the curved-type parametric loudspeaker in order to design various spatial audible areas by utilizing a single parametric loudspeaker. Then, we carried out the objective evaluation experiment to confirm the relationship between its curvature and the spatial audible area in the proposed method. As a result, we confirmed that the curved-type parametric loudspeaker with high curvature can form a wider directivity and it with low curvature can form a sharper directivity. Therefore we confirmed that the curved-type parametric loudspeaker can flexibly steer the directivities by changing its curvature.

In future, we will develop the curved-type parametric loudspeaker which can automatically steer the directivity.

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