[Control of sound pressure in audible spot using parametric speakers]

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Abstract

To give the information to only the target person by sound, we have been researching about forming audible spot with two parametric speakers. By transmitting modulated ultrasounds from each speakers respectively, audible spot is formed only at the cross point of them. However, because of frequency characteristics of parametric speakers, the area of audible spot is changed when the frequency of played sound is changed. To deal this issue, we propose control method of sound pressure for forming stable audible spot in this paper. In proposed method, sound pressure of transmitted sound is controlled as same level at every frequency. By keeping constant sound level at every frequency, it is also expected to keep constant area of audible spot at every frequency. Proposed method was evaluated by indoor environment. As the result, area change was suppressed from 70 % to 10 % by introducing control method, and the availability of proposed control method was confirmed.

Keywords: Parametric speaker, Audible spot, Single side band modulation

1 INTRODUCTION

1.1 Background

Audio assist is often used to give the information at museums, stations, and so on. In case a normal loudspeaker is used for audio assist, because the sound diffuses spherically from the loudspeaker, giving the sound to only the target person is difficult. To solve this problem, a parametric speaker is sometimes used. A parametric speaker consists arrayed ultrasonic speakers, and it has high directivity[1, 2, 3]. Transmitted ultrasound with modulation is demodulated to audible sound by acoustic non-linearity of the air. By high directivity of a parametric speaker, the information can be given to the particular direction. Some systems using a parametric speaker are already used for practical[4]. However, there is the problem caused by high directivity. Because a parametric speaker emits the sound in one direction with high power, the sound propagates straightly with low attenuation. In this case, reflected sounds from a wall, floor, ceiling reach to no-target person. Then, the technique to form audible spot instead of audible direction is required.

1.2 Related research

There are some studies to form audible spot. For example, Fukasawa et al. developed the system to form audible spot using 128 speakers placed around the area of 5m square[5]. They could form four audible spots in the area with such a large scale system. To develop more smaller scale system, Matsui et al. proposed audible spot forming system using two parametric speakers[6]. They achieved forming audio spot by transmitting modulated signals by a kind of amplitude modulation from each speaker. However, there is the problem that the area of audible spot is changed when the frequency of played sound is changed. To form stable audible spot, additional method is needed.

1.3 Approach

To deal above issue, we propose control method of sound pressure for forming stable audible spot with two parametric speakers in this paper. In proposed method, sound pressure of transmitted sound is controlled as same level at every frequency. By keeping constant sound level at every frequency, it is also expected to keep constant area of audible spot at every frequency. Audible spot is formed in indoor environment using proposed method, and sound field is measured for evaluation and discussion.

2 METHOD

For playing audible sound with a parametric speaker, the modulation considering acoustic non-linearity of the air is used. A career signal transmitted from a parametric speaker $v_c(t)$ and required audible sound $v_s(t)$ are defined as follows:

$$v_c(t) = A_c \sin 2\pi f_c t, \quad (1)$$
$$v_s(t) = A_s \sin 2\pi f_s t. \quad (2)$$

A_c and A_s are amplitudes of a career signal and audible sound, f_c and f_s are frequencies of them, t is the time. As the modulation method, double side band (DSB) modulation which is a kind of amplitude modulation is often used[7]. Modulated signal by DSB based on Eq. 2 for playing Eq. 1 is given as follows:

$$v_{dsb}(t) = A_c \sin 2\pi f_c t + \frac{A_s}{2} \sin 2\pi(f_c + f_s) + \frac{A_s}{2} \sin 2\pi(f_c - f_s)t. \quad (3)$$

The first term is a career signal, the second one is upper side band (USB) signal and the third one is lower side band (LSB) signal. By transmitting $v_{dsb}(t)$ from one parametric speaker, $v_{dsb}(t)$ is demodulated due to acoustic non-linearity of the air, and difference tone between a career signal and USB signal or LSB signal at the frequency of f_s. Single side band (SSB) modulation which is simplified DBS is also used[8]. Modulated signal by SSB is given as follows:

$$v_{ssb}(t) = A_c \sin 2\pi f_c t + \frac{A_s}{2} \sin 2\pi(f_c - f_s)t. \quad (4)$$

In SSB, USB is omitted from DSB. Compared to DSB, audible sound $v_s(t)$ played by SSB modulated signal has half the amplitude but harmonic distortion is suppressed.

A career signal and a side band signal are transmitted from one parametric speaker. Then, audible area spreads in the direction of transmission. In this research, for forming audible spot, a career signal and a side band signal are transmitted from two parametric speakers, respectively. By separating them, audible area is formed only at the cross point of them. For high audio quality, SSB modulation is used in this system. A signal transmitted from the first speaker $v_{ssb1}(t)$ and that from the second speaker $v_{ssb2}(t)$ are given from Eq. 4 as follows:

$$v_{ssb1}(t) = A_c \sin 2\pi f_c t, \quad (5)$$
$$v_{ssb2}(t) = \frac{A_s}{2} \sin 2\pi(f_c - f_s)t. \quad (6)$$

However, because of frequency characteristics of parametric speakers, amplitudes of a career signal and a side band signal, A_c and $A_s/2$, change with the frequencies of them. In case that, the area of audible spot also changes. To keep constant area, A_c and $A_s/2$ are controlled at every frequency as follows:

$$A_c = \frac{A_s}{2}. \quad (7)$$

By introducing this control method, it is expected to form stable audible spot at every frequency.

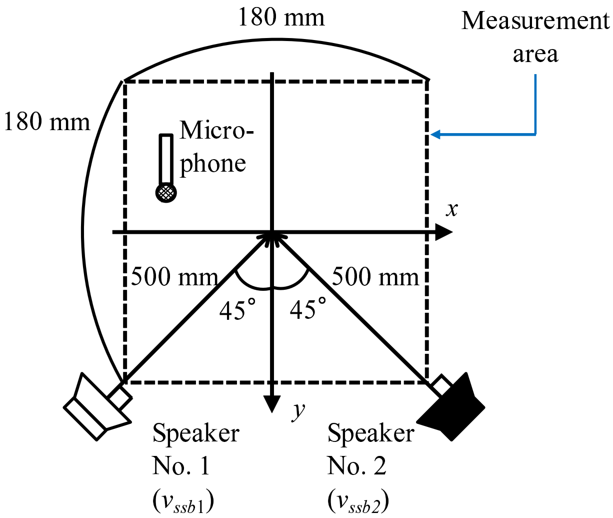

Figure 1. Experimental configuration.

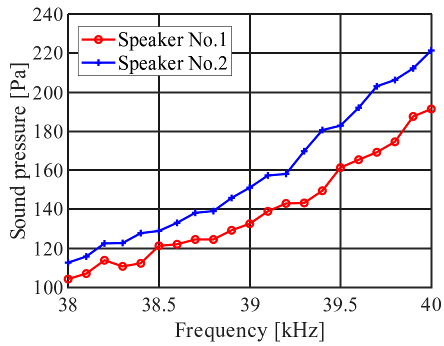

Figure 2. Frequency - sound pressure characteristics of speakers when input voltage is 2 V_{pp}.

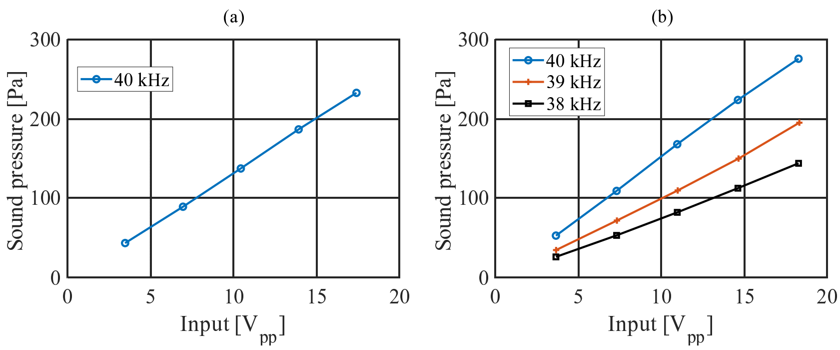

Figure 3. Input - sound pressure characteristics of (a) speaker No. 1, (b) speaker No. 2.

3 EVALUATION EXPERIMENT

To evaluate the performance of proposed method, the experiment was performed.

3.1 Experimental configuration

Figure 1 shows experimental configuration. Two parametric speaker, No. 1 were No. 2, are located at the distance of 500 mm from audio spot forming point. Directions of transmission from each speaker were crossed at the angle of 90 degree. v_{ssb1} and v_{ssb2} were transmitted from the speaker No. 1 and No. 2, respectively. The cross point of transmitted directions defined as $\{x, y\} = \{0, 0\}$, and sound field was measured by obtaining acoustic signals using the microphone at some points. Measurement points were set as every 9 mm in the x range from -90 mm to 90 mm and the y range from -90 mm to 90 mm. This is the experiment for a basic study. Then, the side band signal which has single frequency was transmitted from the speaker No. 2, and audible sound which has single frequency was played. In this experiment, to play audible sound at the frequency f_s =0.1 to 2 kHz, the frequency of the career signal (f_c in Eq. 5) was set as 40 kHz, and that of the

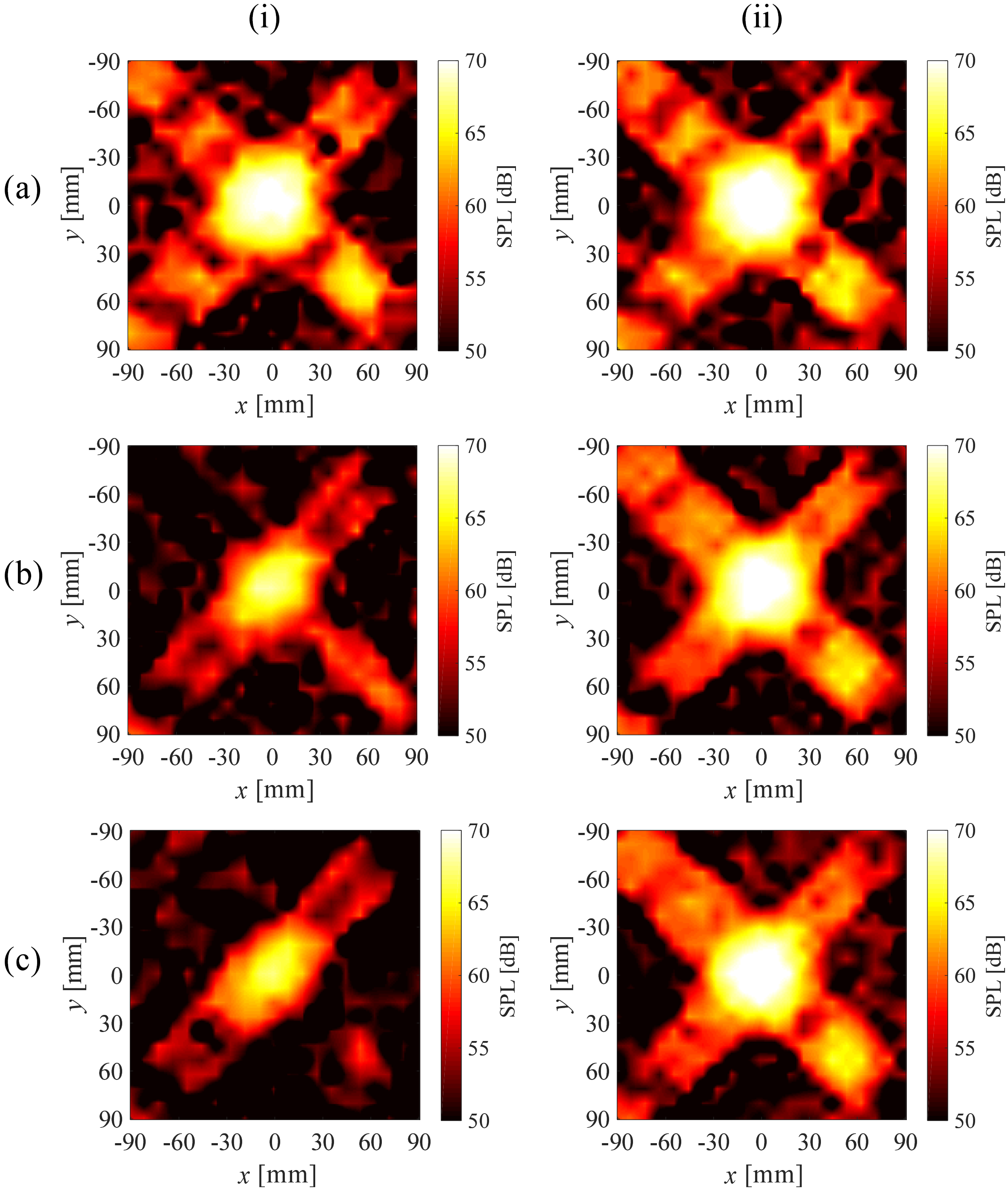

Figure 4. Measured sound fields when (a) $f_s = 0.1$ kHz, (b) $f_s = 1$ kHz, (c) $f_s = 2$ kHz. (i) Results without control, (ii) with control.

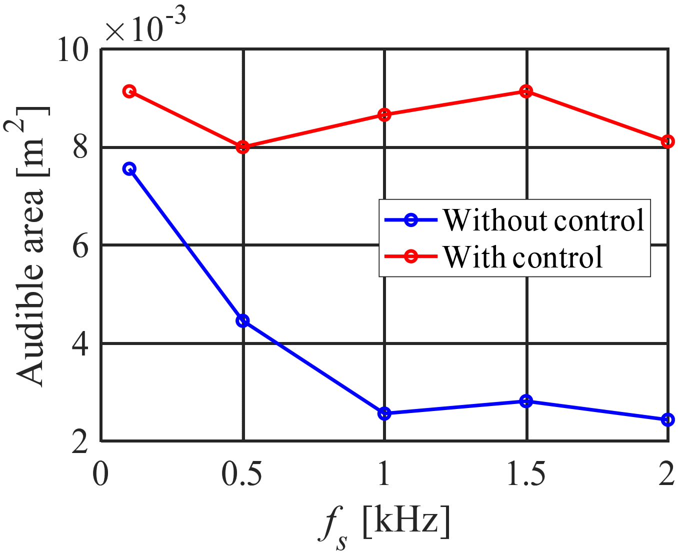

Figure 5. The area of audible spot.

side band signal ($f_c - f_s$ in Eq. 6) was set as 39.9 to 38 kHz.

Figure 2 and Figure 3 show frequency - sound pressure characteristics when input voltage is 2 V_{pp} and input - sound pressure characteristics of speakers. The horizontal axes represent the frequency and input voltage, respectively, and the vertical axis represents sound pressure. Sound pressures under each situation were measured at the distance of 500 mm. As shown in Figure 2 and Figure 3, these characteristics can be approximated as linear equation. Using this characteristics, sound pressures of the career signal and the side band signals were controlled as Eq. 7. In particular, $A_s/2$ was adjusted to A_c at each frequency.

3.2 Experimental results

Figure 4 shows measured sound fields. Figure 4(a), (b) and (c) show results when f_s ware 0.1, 1 and 2 kHz. Figure 4(i) and (ii) show results without control and with control. The color indicates sound pressure level (SPL) of each f_s. When f_s was 1 kHz, it can be seen that high SPL spots were formed around $\{x, y\} = \{0, 0\}$ in both case without control and with control. Middle SPL part observed around high SPL spots seems to be the effect of side lobes of each speaker. In results without control, decrement of the area of high SPL spot with increment of f_s can be seen. This is because that the amplitude of the side band signal declines with decrement of the frequency from 40 kHz as shown in Figure 2. On the other hand, comparing with with results without control, the area of formed high SPL spot with control seems not to change.

3.3 Discussion

To evaluate about changes of the area of audible spot quantitatively, the area was measured. Audible area was defined as the spot that SPL is higher than 60 dB. Figure 5 shows the change of the area of audible spot. The horizontal axis represent the frequency of audible sound f_s, and the vertical axis represents the area of audible spot. As shown in the result without control, the area decreased approximately 70 % with the increasing frequency. In the result with control, area change was suppressed to approximately 10 %. As results, the availability of proposed control method was confirmed. However, audible sound which has single frequency was played in this experiment. Therefore, we will study about forming audible spot which includes multiple frequency with proposed method in future work.

4 CONCLUSION

In this paper, we proposed sound pressure control method for forming stable audible spot with two parametric speakers. The area of formed audible spot without sound pressure control changes because of frequency characteristics of speakers. To keep constant area of audible spot, sound pressure of transmitted sound is controlled as same level at every frequency in proposed method. As the result of evaluation experiment, the availability of proposed control method was confirmed. In future work, we will study about forming audible spot which includes multiple frequency with proposed method.

REFERENCES

[1] Tomoo, K.; Masahide, Y.; Kazuo, I. Developments of Parametric Loudspeaker for Practical Use, Proceedings of 10th International Symposium on Nonlinear Acoustics, Kobe, Japan, July 24-28, 1984, pp 147-150.

[2] Bennett, B. M.; Blackstock, T, D. Parametric array in air, The Journal of the Acoustical Society of America, Vol 57 (3), 1974, pp 562-568.

[3] Yoneyama, M.; Fujimoto, J.; Kawamo, Y.; Sasabe, S. The audio spotlight: An application of nonlinear interaction of Sound waves to a new type of loudspeaker design, The Journal of the Acoustical Society of America, Vol 73 (5), 1983, pp 1532-1536.

[4] Kortbek, J. K.; Grønbæk, K. Interactive Spatial Multimedia for Communication of Art in the Physical Museum Space, Proceedings of the 16th ACM international conference on Multimedia, Vancouver, Canada, October 26-31, 2008, pp 609-618.

[5] Fukasawa, Y.; Shinagawa, K.; Horio, K.; Mitsuhashi, K.; Deguchi, A.; Kusunoki, F.; Inagaki, S.; Mizoguchi, H. Loudspeaker array system for exhibition support into museum Effectiveness verification of sound spot for science education, Proceedings of IEEE International Conference on Systems, Man and Cybernetics, Singapore, Singapore, October 12-15, 2008, pp 1175-1180.

[6] Matsui, T.; Ikefuji, D.; Nakayama, M.; Nishiura, T. A design of audio spot based on separating emission of the carrier and sideband waves, Proceedings of Meetings on Acoustics, Vol 19 (1), 2013, pp 1-9.

[7] Wang, Y.; Chen, M.; Li, H.; Zhou, Z. Defining the Parameters of Truncated Square-rooting DSB for Parametric Loudspeaker, Proceedings of IEEE International Conference on Mechatronics and Automation, Harbin, China, August 5-8, 2007, pp 1689-1693.

[8] Chen, M.; Qin, X.; Xu, L.; Du, Y.; Xu, L. The Distortion Analysis of the Single Side Band Method for Parametric Loudspeaker Based on Orthogonal Envelope Detection, Proceedings of the 2nd International Symposium on Systems and Control in Aerospace and Astronautics, Shenzhen, China, December 10-12, 2008, pp 1-5.