Multiple Audio Spots Design Based on Separating Emission of Carrier and Sideband Waves

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ABSTRACT

The parametric loudspeaker has sharper directivity and it can an achieve audio spot which can represent the audible sound to a narrow spatial area. However, the parametric loudspeaker has problems caused by reflections and intercepts because they become noise to other listeners except a target listener. Here, we focus on that principle of the parametric loudspeaker. It can be formulated as non-linear interaction of carrier and sideband waves in emitted ultrasonic sounds on the air. This suggests that we can design audio spot by individually emitting the carrier and sideband waves. Thus, we have proposed the design method of audio spot with separating emission of the carrier and sideband waves. The former proposed method has designed a single audio spot using multiple parametric loudspeakers. In the present paper, we propose the design method of multiple audio spots based on separating emission of the carrier and sideband waves using multiple parametric loudspeakers. More specifically, the audible sound is demodulated at multiple audible areas where the single carrier and sideband waves individually emitted from each parametric loudspeaker are overlapped. As a result of evaluation experiments with the sound energy distribution, we confirmed the effectiveness of the proposed method.

Keywords: Audio spot, Parametric loudspeaker, Separating emission, Carrier wave, Sideband wave
I-INCE Classification of Subjects Number(s): 01.4

1. INTRODUCTION

A parametric loudspeaker with sharper directivity can reproduce an audible sound in the particular area called “audio spot” (1, 2, 3, 4). The parametric loudspeaker emits an amplitude modulated (AM) wave which is generated by modulating amplitude of the ultrasound (carrier) with the audible sound. The emitted AM wave is demodulated into the original audible sound by non-linear interaction in the air (4, 5). The AM wave consists of the carrier and sideband waves. The demodulated audible sound is represented by the difference tone between the carrier and sideband waves.

In the parametric loudspeaker, reflections and interceptions of emitted sounds cause severe problem, because they become noise to non-listeners. Thus, we have proposed the design method of audio spot for reducing reflections and interceptions (6). Specifically, we have attempted to design audio spot by using the separating emission of the carrier and sideband waves with multiple parametric loudspeakers. Then, audio spot is formed in the overlapped area of carrier and sideband waves. The former proposed method forms single audio spot. However, the multiple target listeners require simultaneous listening the audible sound. In this paper, we propose the design method of multiple audio spots using multiple parametric loudspeakers for sideband wave.

2. THE PRINCIPLE OF THE CONVENTIONAL PARAMETRIC LOUDSPEAKER

The parametric loudspeaker emits the AM wave designed by amplitude modulating the carrier wave with an original audible sound. AM wave consists of the carrier and sideband waves. The audible sound is reproduced as the difference tone between the carrier and sideband waves. The carrier wave $v_c(t)$ and the original

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audible sound $v_s(t)$ are indicated as follows:

$$\begin{aligned} v_c(t) &= V_{cm}\sin 2\pi f_c t, & (1)\\ v_s(t) &= V_{sm}\cos 2\pi f_s t, & (2)\end{aligned}$$

where t is time index, V_{cm} and V_{sm} are maximum amplitudes of the carrier wave and audible sound, respectively. f_c and f_s are frequencies of the carrier wave and audible sound, respectively. From Eqs. (1) and (2), the AM wave v_{dsb} is indicated as follows:

$$\begin{aligned} v_{dsb}(t) &= (v_s(t)+V_{cm})\sin 2\pi f_c t \\ &= (V_{sm}\cos 2\pi f_c t+V_{cm})\sin 2\pi f_c t \\ &= V_{cm}\sin 2\pi f_c t+\frac{V_{sm}}{2}\sin 2\pi(f_c+f_s)t+\frac{V_{sm}}{2}\sin 2\pi(f_c-f_s)t, \qquad (3)\end{aligned}$$

where, $V_{cm}\sin 2\pi f_c t$ is a component of the carrier wave, $\frac{V_{sm}}{2}\sin 2\pi(f_c+f_s)t$ is a component of the upper sideband (USB), $\frac{V_{sm}}{2}\sin 2\pi(f_c-f_s)t$ is also a component of the lower sideband (LSB). The AM method using LSB and USB is called double sideband (DSB) modulation method, as shown in Eq. (3). The parametric loudspeaker can reproduce the louder audible sound by the DSB modulation method. However, the harmonic distortions occur by the difference tone between the LSB and the USB (7). The single sideband (SSB) modulation method has been proposed to reduce the harmonic distortions. SSB modulation method designs the AM wave which has the carrier wave and single sideband wave (LSB or USB). SSB modulation method obtains the single sideband by eliminating LSB or USB from v_{dsb}. In this paper, we remove the USB from v_{dsb} using the low pass filter and generate the AM wave which is designed by the SSB modulation method v_{ssb}. It is indicated as follows:

$$v_{ssb}(t) = V_{cm}\sin 2\pi f_c t+\frac{V_{sm}}{2}\sin 2\pi(f_c-f_s). \qquad (4)$$

Smaller harmonic distortions occur by the emitted AM wave which is designed by SSB modulation method than that by DSB modulation method. In this paper, we define the emitting AM wave which is designed by the SSB modulation method as the conventional method. In the conventional method, the original audible sound is demodulated in the area of including emitted AM wave. The parametric loudspeaker emits the AM wave with sharper directivity. Consequently, audio spot is designed a linear shape. However, the initial reflections of the reproduced audible sound have higher sound pressure. Therefore, the initial reflections become a noise to non-listener who hears reflections.

3. SUGGESTION OF SEPARATING EMISSION OF THE CARRIER AND MULTIPLE SIDEBAND WAVES FOR FORMING MULTIPLE AUDIO SPOTS

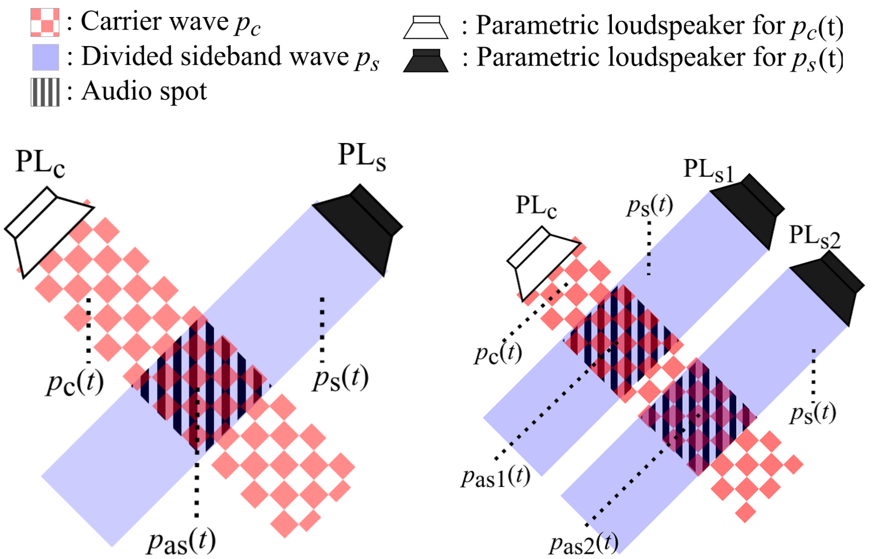
The demodulated audible sound is represented by the difference tone between the carrier and sideband waves. Therefore, we proposed the design method of the audio spot with separating emission of the carrier and sideband waves. Figure 1 (a) shows the overview of the former proposed method using single parametric loudspeaker for sideband wave. In Fig. 1, PL_c is the parametric loudspeaker for the carrier wave $p_c(t)$. PL_s is the parametric loudspeaker for the sideband waves $p_s(t)$. $p_c(t)$ and $p_s(t)$ are indicated as follows:

$$\begin{aligned} p_c(t) &= V_{cm}\sin 2\pi f_c t, & (5)\\ p_s(t) &= \frac{V_{sm}}{2}\sin 2\pi(f_c+f_s)t. & (6)\end{aligned}$$

In Fig. 1 (a), in the overlapped area of carrier and sideband waves, the observed sound is indicated as follows:

$$\begin{aligned} p_{as}(t) &= p_c(t-\tau_c)+p_s(t-\tau_s) \\ &\approx v_{ssb}(t), & (7)\\ & & (8)\end{aligned}$$

where, τ_c and τ_s are the time delays of the carrier and sideband waves, respectively. In the overlapped area of carrier and sideband waves, the frequency components of the observed sound p_{as} is similar to the frequency



(a) The former proposed method using single sideband.

(b) The proposed method using multiple sidebands.

Figure 1 – Overview of the proposed method.

components of the AM wave. Thus, the audible sound is demodulated at p_as. On the other hand, it is impossible that the original audible sound is demodulated in the area without overlapping carrier and sideband waves. Therefore, audio spot is formed in the overlapped area of carrier and sideband waves. However, the audible area is formed in single spatial area with the former proposed method. Thus in this paper, we propose the design method of multiple audio spots using multiple parametric loudspeaker for sideband wave. The proposed method implements the simultaneous listening of the audible sound to the multiple targets. Figure 1 (b) shows the overview of the proposed method using multiple parametric loudspeakers for sideband wave. In Fig. 1 (b), in the multiple overlapped area of carrier and sideband waves, the observed sounds are indicated as follows:

$$\begin{aligned} p_\mathrm{as1}(t) &= p_\mathrm{c}(t-\tau_\mathrm{c1}) + p_\mathrm{s}(t-\tau_\mathrm{s1}) \\ &\approx v_\mathrm{ssb}(t), \end{aligned} \tag{9}$$

$$\begin{aligned} p_\mathrm{as2}(t) &= p_\mathrm{c}(t-\tau_\mathrm{c2}) + p_\mathrm{s}(t-\tau_\mathrm{s2}) \\ &\approx v_\mathrm{ssb}(t), \end{aligned} \tag{10}$$

where, $\tau_\mathrm{c1}, \tau_\mathrm{c2}, \tau_\mathrm{s1}$ and τ_s2 are the time delays of the carrier and sideband waves, respectively. In the area p_as1 and p_as2, the frequency components of the observed sound are similar to the frequency components of p_as in Fig. 1(a). Therefore, audio spots are formed in the multiple audible area.

4. EVALUATION EXPERIMENT

4.1 EVALUATION CONDITION

We carried out the objective evaluation experiment to confirm the effectiveness of the proposed method. We measured the sound pressure level (SPL) of the audible sound with the presently and former proposed methods and conventional method. In audio spot, the SPL of the audible sound is higher. Thus, we expect that SPL is higher in the overlapped area of carrier and sideband waves with the proposed method. Table 1 shows the experimental equipments and Tbl. 2 shows the experimental conditions. Figure 2 shows the experimental environment. In Fig. 2, $\mathrm{PL_c}$ is the parametric loudspeaker for the carrier wave, $\mathrm{PL_{s1}}$ and $\mathrm{PL_{s2}}$ are the parametric loudspeakers for the sideband wave. We measured the SPL distribution for confirming our expectation.

4.2 EVALUATION RESULT

Figure 3 shows the SPL distribution with the conventional method. From Fig. 3, we confirmed that the audible sound was reproduced in the linear area with the conventional method. Figures 4 (a) and 4 (b) show the distribution of SPL under the condition that using $\mathrm{PL_{s1}}$ or $\mathrm{PL_{s2}}$, for emitting sideband wave with the former proposed method, respectively. From Figs. 4 (a) and 4 (b), we confirmed that SPL with the former

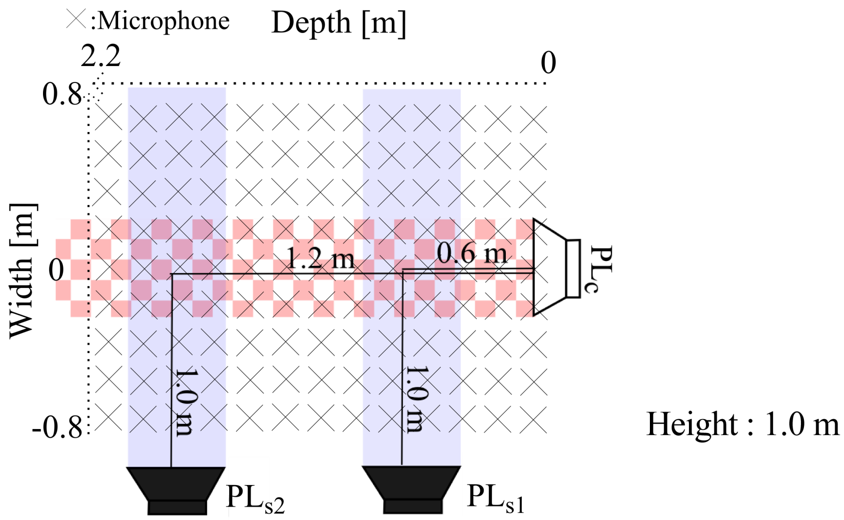


Figure 2 – Experimental environment.

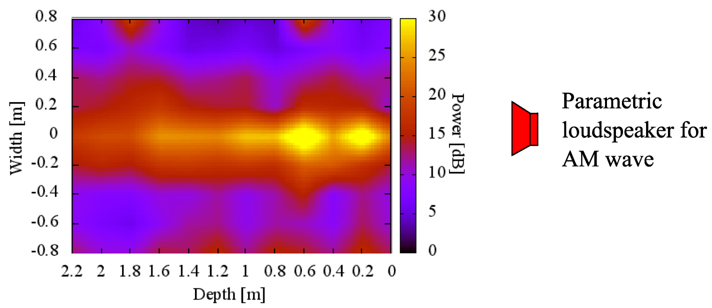
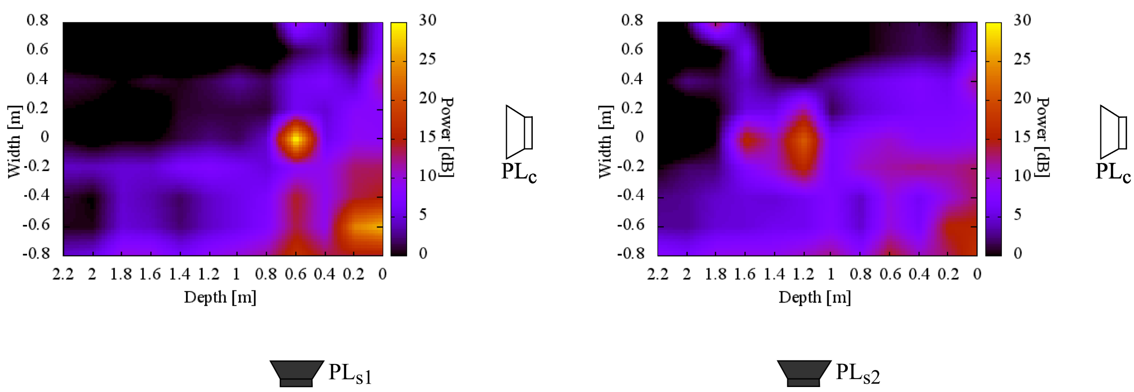


Figure 3 – Experimental result for the conventional method.

proposed method is nearly to SPL with the conventional method in the audio spot. In addition, SPL out of the overlapped area of carrier and sideband waves with the former proposed method is lower. Figure 5 shows the distribution of SPL under the condition that using PL_{s1} and PL_{s2}, for emitting multiple sideband wave with the proposed method. From Fig. 5, we confirmed that SPL with the proposed method using multiple sideband waves is similar to SPL with the the former proposed method using single sideband wave in the each audio spots. Therefore, we confirmed the effectiveness of the proposed method for forming multiple audio spots.



(a) Emitting sideband using PL_{s1} (b) Emitting sideband using PL_{s2}

Figure 4 – Experimental results for the former proposed method.

Table 1 – Experimental equipments.

Parametric loudspeaker	MITSUBISHI, MSP-50E
Power amplifier	VICTOR, PS-A2002
Microphone	SONY,ECM-88B
A/D, D/A converter	ROLAND, UA-1010

Table 2 – Experimental conditions.

Sampling frequency	96 kHz
Quantization	16 bits
Carrier frequency	40 kHz
Ambient noise level	L_A =34.3 dB
Sound source	One Japanese sentence
Evaluated frequency	0.5 $\sim$ 8 kHz

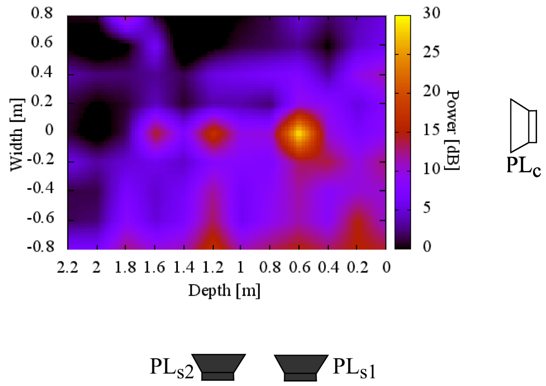


Figure 5 – Experimental result for the proposed method.

5. CONCLUSIONS

In this paper, we proposed the design method of multiple audio spots using multiple parametric loudspeakers for sideband waves. We carried out the objective evaluation experiment to measure the SPL of the demodulated audible sound. As a result, we confirmed the effectiveness of the proposed method for forming multiple audio spots. In future work, we intent to expand the audible area of audio spot.

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