3P4-9

Directivity control using Array of Film-structured Parametric Loudspeakers

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1. Introduction

Various signals such as light, radio waves, and sound waves are used in sensing technology, and sensing technology employing sound waves, in particular, has found practical applications in living organisms and in water. However, in contrast, despite various studies focusing on acoustic sensing technology in air, several challenges still remain to be solved. For example, sound waves in air are highly susceptible to the surrounding environment, and ultrasonic waves in air with high frequency and short wavelength have difficulties propagating over long distances due to attenuation[1)~4)].

In this study, we focused on a film-type parametric speaker that can obtain a relatively broadband sound source. It uses a difference sound and has a much narrower beamwidth than predicted by linear theory at low frequencies.

Subsequently, the phased array technology used for antennas and general loudspeakers is applied to film-type parametric loudspeakers. Specifically, our focus was on controlling directivity using an array of film-type parametric speakers. By combining this technology with occlusion area sensing, our goal is to develop a system capable of detecting targets situated beyond the visible area from the air.

2. Experiment Overview

The purpose of this experiment was to verify the angular amplitudes of equally spaced, phase-shifted sound sources simultaneously output from multiple film-type parametric loudspeakers. This is an implementation of phased-array technology, predominantly utilized in the field of antennas.

2.1 Method

Six parametric loudspeakers were placed on a rotating plate and rotated while emitting sound. Sound recordings were taken at 2-degree intervals using a microphone. The results are used to verify the angle of the parametric loudspeaker that produces the highest sound pressure.

The experiment setup is shown in **Fig. 1**. The Python-sounddevice library of Python 3.11 was utilized to produce sound from the PC. For the measurement, a 44.1 kHz carrier wave was employed. The measurements were performed under two conditions: for the case where the phase of the carrier wave was changed, and for the case where the phase of the carrier wave was changed and an information signal was mixed. Phase differences of 0°, 10°, and 20° were considered. The information signal was a 1 kHz amplitude-modulated sine burst sampled at 192 kHz.

2.2 Confirmation of Phase difference

An oscilloscope was connected to the back of the loudspeaker to check the phase difference. Data was taken for 10 times, and the phase difference between each channel and 1 channel was shown in a box-and-whisker diagram as shown in **Fig.2**.

2.3 Result

The experimental results are shown in **Fig.3**. Fig.3(a), (b), and (c) show the results when the phase of the carrier wave is changed, and (d), (e), and (f) show the results when the phase of the carrier wave is changed and the information signal is mixed.

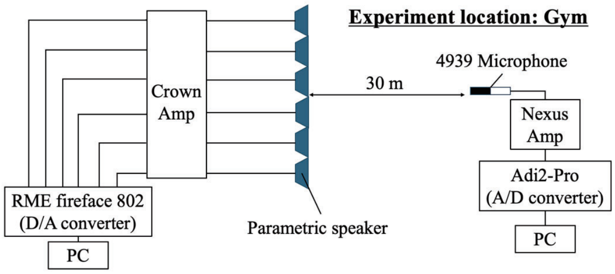

Fig. 1 The system of the experiments

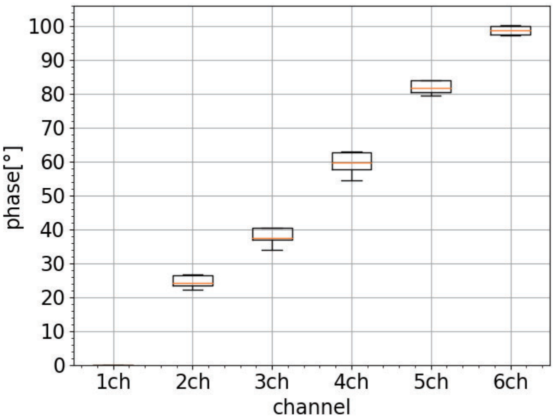

Fig. 2 Phase at each channel when output with a phase difference of 20°

Fig.3(a), (b), and (c) show that the swings were 0° for a phase difference of 0°, 2° for a phase difference of 10°, and 4° for a phase difference of 20°. In Fig.3(d), (e), and (f), the swings were 0° for a phase difference of 0°, 2° for a phase difference of 10° and 6° for a phase difference of 20°.

3. Simulation

The array factor is a means of simulating a phased array. The array factor is the directivity estimated by the arrangement of the elements, and the directivity of an array transmitter is the multiplication of the element directivity and the array factor. The equation is as in

$$AF(\theta) = \sum_{k=0}^{n} a_n \exp\left(j2\pi \frac{kd}{\lambda} sin\theta\right) \qquad (1)$$

$$E(\theta) = g(\theta)AF(\theta) \qquad (2)$$

where $g(\theta)$ is the element directivity, a_n is the excitation amplitude, and d is the distance between the elements[5].

The simulation results are shown in **Fig.4**(a), (b), and (c). Here, cardioid was used for the element directivity. Fig.4 shows that the output in the simulation swings at the same angle as the phase difference of the sound source.

4. Conclusions and Further Works

The present results confirm that he outputs sound radiates at a smaller angle than the simulation results. On the other hand, in all cases, the output swings by more than 2°. When the loudspeaker and the target are 100 m apart, then $100 \times \tan 2° \approx 3.5$ m, which means that the expected swing is at least 3.5 m to the side of the target. This demonstrates that the directivity can be controlled by using an array of Film-structured loudspeakers.

In upcoming experiments, we plan to utilize M-sequence signals, which offer the advantage of improved signal-to-noise ratio (SNR) and spatial resolution to verify whether further directionality control is possible.

References

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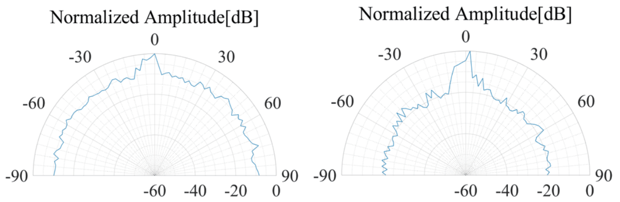
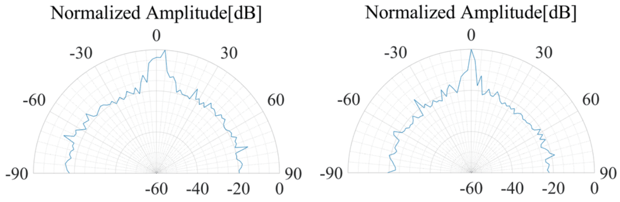


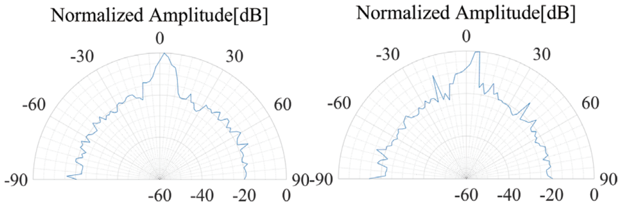
(a) Career wave (Phase difference 0°)

(b) Career wave (Phase difference 10°)



(c) Career wave (Phase difference 20°)

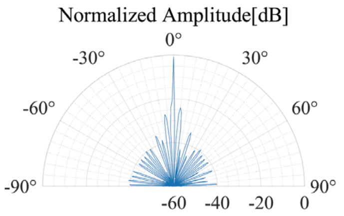
(d) Information signal (Phase difference 0°)



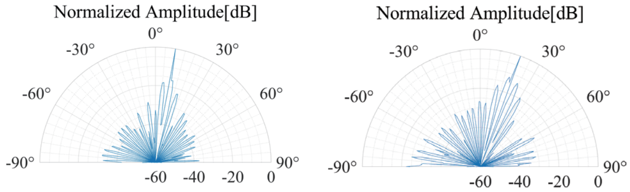
(e) Information signal (Phase difference 10°)

(f) Information signal (Phase difference 20°)

Fig. 3 Experimental results



(a)Phase difference 0°



(b)Phase difference 10°

(c)Phase difference 20°

Fig. 4 Simulation results

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