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# Design of Wide Angle Compound Eye Underwater Acoustic Lens

広角複眼水中音響レンズの設計

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## 1. Introduction

Recently, the network of multiple underwater vehicles gets much attention to obtain a glimpse of the underwater world efficiently [1]. Underwater acoustic (UWA) communication is one of the techniques to establish the network. However, the use of UWA communication among multiple vehicles is still challenging since the collision of packets from multiple transmitters leads to performance degradation. Thus, multiple access techniques (e.g., time-, frequency-, code- or space-division multiplexing) or packet scheduling algorithms have been proposed.

As an alternative, we propose an UWA communication with space-division multiplexing using an acoustic lens. The use of an acoustic lens has the potential to achieve simple UWA network since it allows transmission and reception of multiple beams simultaneously without a complicated circuit. However, current acoustic lens used for imaging has a limited angle of view. To achieve multi-user communication, an acoustic lens with a wide angle of view is necessary. In this paper, we design a compound eye lens system to achieve a wide angle of view and evaluate its communication performance with simulation.

## 2. Design of Lens System

A compound eye lens consists of multiple aplanatic lenses. Hence, we employ an aplanatic lens designed in [2], with a refractive index of $n$ = 0.56, thickness of $d$ = 5 mm and back focus of $f_b$ = 395 mm (material: acrylic resin). **Figure 1(a)** shows the lens and the raytrace diagrams of incidence angle $\theta$ = 0° and 15°. As shown in the figure, the aplanatic lens can remove spherical and coma aberrations. However, there exists a field curvature, and the focal point of $\theta$ = 15° is shifted to the lens side. The resolution of the lens is 8.6° in angle and 15 mm in length at 200 kHz.

We next design a compound eys lens by constituting five aplanatic lenses [**Fig. 1(b)**]. The lens axis of each lens cross at 30°, and the angle of view is expected as 150°. As shown in the figure, the focused sound is received by a concave receiver with a red line whose radius of curvature is 150 mm to adapt the focal point of $\theta$ = 15°. The center of

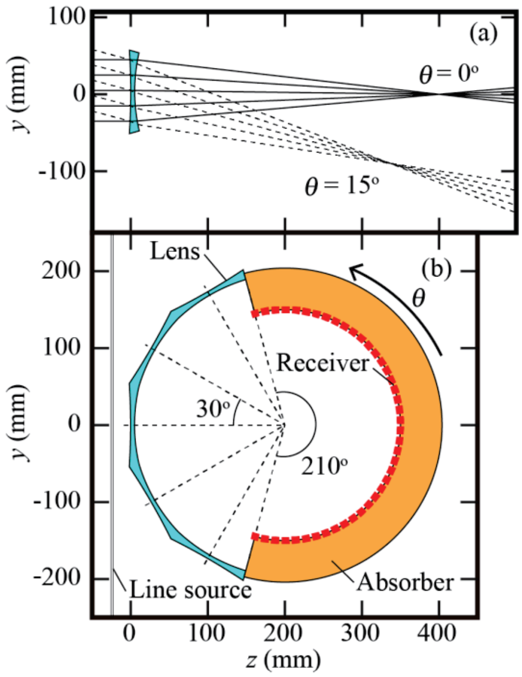


Fig. 1 Schematic views of compound eye lens; (a) single lens and (b) compound eye lens system.

receiver corresponds with the cross point of lens axes. The receiver consists of 42 elements whose length is about 13 mm. An absorber is set behind the receiver to reduce reflection between the lens and receiver.

## 3. Simulation

### 3.1 Simulation Environment

An impulse response of the compound eye lens system is calculated with the 2D FDTD method. In the simulation, the discretization steps were set as $\Delta t$ = 0.125 μs in time and $\Delta s$ = 0.5 mm in space. The size of the simulation field and calculation time was set as 500×500 (mm²) and 8.75 ms, respectively. The parameters of mediums are shown in **Table I**. A chirp signal (center frequency and bandwidth: 200 kHz) is emitted from

Table I: Parameters used in simulation.

| | Water | Lens | Absorber |
|---|---|---|---|
| Sound speed (m/s) | 1500 | 2700 | 1000 |
| Density (kg/m³) | 1000 | 1140 | 1190 |
| Attenuation rate (Np/m) | 0 | 7.2 | 70 |

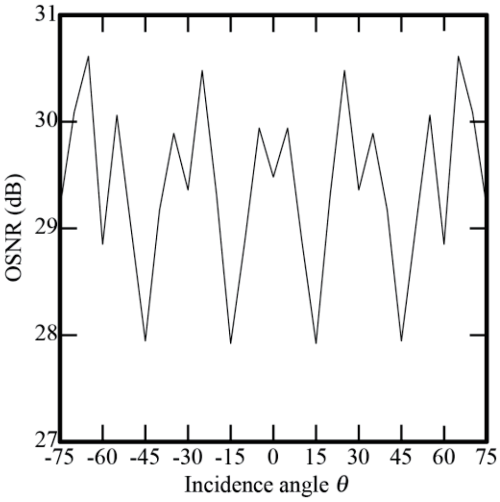


Fig. 2 Relationship between incident angle $\theta$ and OSNR in single-user communication.

line source at $z$ = 50 mm. The lens system is rotated virtually to change the incidence angle $\theta$. The center of rotation corresponds with the cross point of axes of lenses.

The impulse response on the receiver was calculated by calculating a cross-correlation function between the transmitted and received signals, from $\theta = -75^{\circ}$ to $\theta = 75^{\circ}$ at intervals of 5°. Then the received communication signal on each hydrophone is calculated by convoluting a communication data block and the impulse response. The communication signal is calculated by modulating data block consisted of training sequence of 400 bit and message sequence of 1,000 bit by BPSK, and up-converting to the frequency of 200 kHz (signal bandwidth: 200 kHz). The received signals are equalized by RLS-DFE (FF: 201 taps, FB: 200 taps, and forgetting factor: 0.999). Finally, the communication performance is evaluated by the output signal-to-noise ratio (OSNR) and bit error rate (BER) of each $\theta$.

In the simulation, we consider two scenarios; single-/multi-user communication. Two received signals arriving from the angle of $\theta_1$ and $\theta_2$ are added in multi-user communication scenario.

### 3.2 Simulation Results

**Figure 2** shows the OSNR calculated in single-user communication. We found that the angle of view reaches 150° because OSNR shows high communication performance in all incidence angles. We also found that the OSNR decreases periodically at $\theta = -45^{\circ}$, -15°, 15°, and 45°, which is caused by aberration.

**Figures 3 and 4** show the BER in multi-user communication (number of users: 2). From Fig. 3, we found that BER achieves 0 at 784 points in 961 combinations of $\theta_1$ and $\theta_2$. Furthermore, from Fig. 4, we found that BER increases when $\theta_1 - \theta_2 < 35^{\circ}$, which is larger than the resolution of the lens. It is

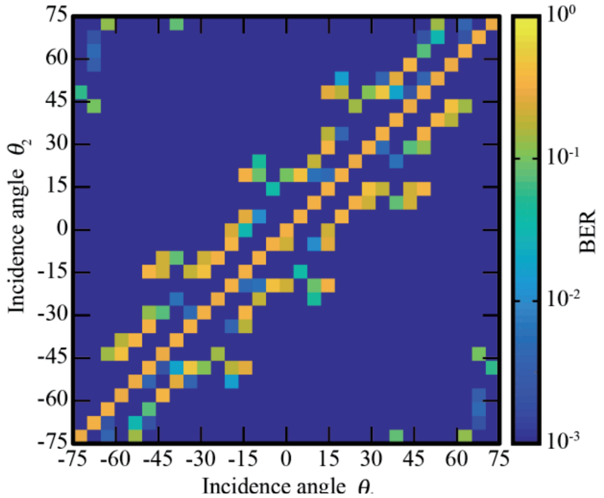


Fig. 3 Relationship between BER, $\theta_1$, and $\theta_2$ in multi-user communication (number of users: 2).

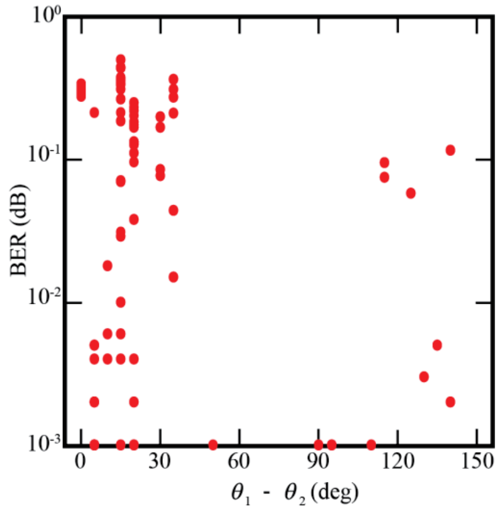


Fig. 4 Relationship between BER and $\theta_1 - \theta_2$ in multi-user communication (number of users: 2).

considered the focal points of adjacent lenses are overlapped on particular combinations.

The obtained results suggest that the designed lens system can achieve space-division multiplexing successfully, when there exist arriving angle of difference between two signals.

## 4. Conclusions

We designed the compound eye lens system having a wide angle of view and evaluated its communication performance with simulation. We found the lens system has an angle of view of 150° and has a potential to achieve UWA communication using space-division multiplexing.

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**References**

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