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Convergence Characteristics of Doublet with Acrylic Plano-Concave Lens and Silicon-Rubber Fresnel Lens
アクリル平凹レンズとシリコンフレネルレンズによるダブレットの集束特性

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1. Introduction

Aplanatic lenses, which have been developed for optical lens and can correct spherical and coma aberrations, are available for underwater acoustic lenses. We designed an acoustic aplanatic lens made of acrylic resin in the primitive process of our study [1]. However, it became thick and attenuated sound wave in simulations. Thus, an aplanatic Fresnel lens made of room temperature vulcanizing (RTV) silicone rubber, which was thinner shape than the non-Fresnel aplanatic lens, was designed [2]. The aplanatic Fresnel lens showed better convergence property than the aplanatic lens in simulations. However, it was too thin and soft to keep its shape. If the Fresnel lens is used in rapid flow, the lens would be deformed easily. Therefore, we consider to attach a hard cover on the first surface of lens [3].

In this report, we design a doublet with acrylic plano-concave lens as a cover and RTV silicon rubber Fresnel lens to correct aberrations with numerical calculation and clarify the convergence characteristics with experiment.

2. Simulation using FDTD method

The cover influences the convergence property of the Fresnel lens. So, we attempt to design a new cover to reduce the influence of the cover. It was considered that aberrations or impedance mismatch caused the negative influence.

Therefore, the lens and cover are designed in combination to correct aberrations. Yoshida's design method, which is developed in optics, is used for design. The first surface of cover must be flat to apply Yoshida's method for a doublet made of cover and lens [4].

Designed doublet with plano-concave cover and Fresnel lens and ray trace diagrams are shown in Fig. 1. Beam patterns are calculated with 2-D FDTD method. Calculated beam patterns of the Fresnel

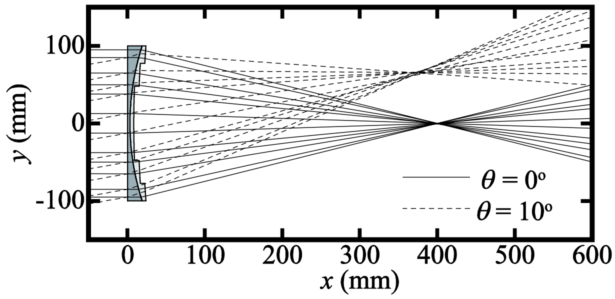

Fig. 1 Cross sectional shapes and ray trace diagrams of designed doublet.

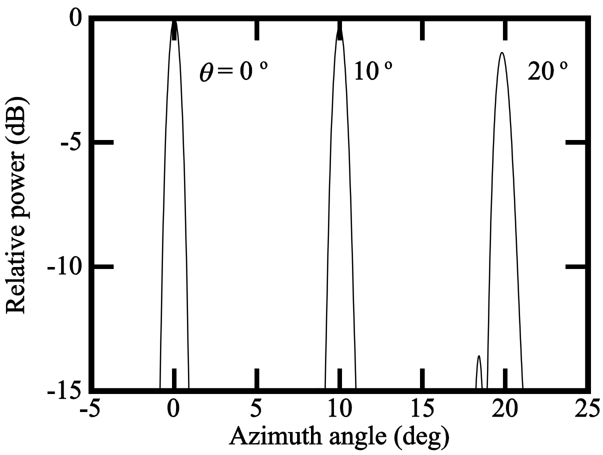

Fig. 2 Calculated beam patterns of the Fresnel lens with plano-concave cover.

Table 1 Parameters used for calculation.

	Water	Silicone rubber	Acrylic resin
Sound speed (m/s)	1500	1000	2670
Density (kg/m^3)	1000	1490	1200
Attenuation coeficient (Np/m)	0	57.6	9.2

lens with plano-concave cover are shown in Fig. 2. Parameters used for the calculation are shown in Table 1. The powers are normalized by the maximum power of the doublet in $\theta = 0^\circ$. The beam patterns of lenses with cover show smaller power than those of the lens without cover. Thus, it seems that decline of power is mainly caused by the impedance mismatch. However, the designed lens with plano-concave

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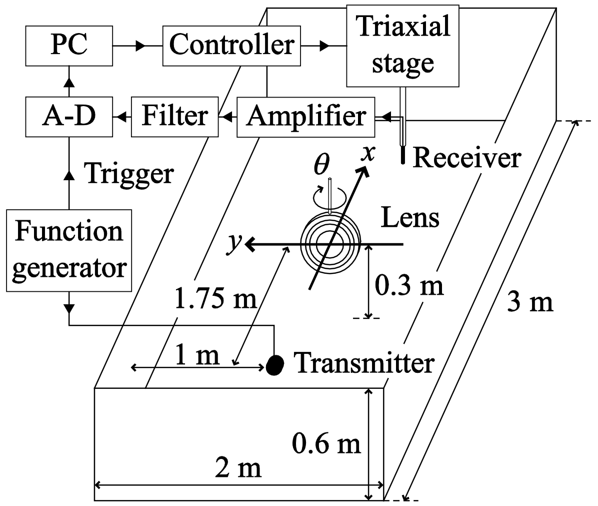

Fig. 3 Schematic view of experimental setup.

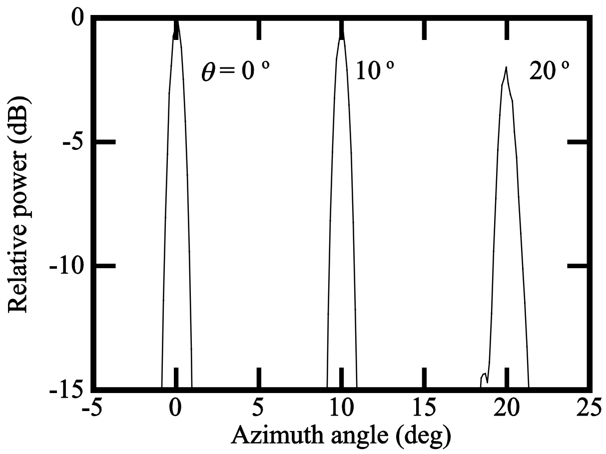

Fig. 4 Experimental beam patterns of the Fresnel lens with plano-concave cover.

cover shows larger power and narrower beam width than the previous lens with the uniform thickness cover in θ = 20˚. Hence, it seems that lens with cover correcting aberrations is effective in large incident angle.

3. Experiment in water tank

Schematic view of experimental setup is shown in Fig. 3. Dimensions of the water tank are 2 m × 3 m × 0.6 m. The lens, transmitter (RESON TC3029), and receiver (RESON TC4035) are sunk in the tank. Distance between the lens to transmitter is about 1.75 m. Sinusoidal signal, which is the same signal as the calculation, is applied to the transmitter by a function generator (Agilent 33120A). The receiver is scanned in the tank at intervals of 5 mm in *x*-direction, and 1 mm in *y*-direction. Received signal is amplified (NF 5307) and filtered (NF3628), whose pass-band is from 100 kHz to 750 kHz. Processed signal is sampled (ELMEC EC6904) at 10 MHz. Incident angle, θ, is varied by rotating the lens.

Figure 4 shows beam patterns of the doublet, which indicate the power distributions normalized by the doublet in θ = 0˚. These beam patterns are plotted at the distance to include maximum power point of each incident angle and very similar to the simulated result in Fig. 2. When the cover is not attached, the gains are about 20 dB and beam widths are almost the same in all incident angles. Thus, it seems that the residual coma aberration does not influence on the acoustical image. On the other hand, when the cover is attached, the beam becomes wide at small incident angle and side lobe becomes large at large incident angle. Additionally, the peak gains reduce about 5 dB in each incident angle. Therefore, the cover influences the convergence property of lens.

4. Conclusion

We designed a doublet which consists of acrylic plano-concave cover and RTV silicone-rubber Fresnel lens to keep the shape of lens, when we attempted to design the lens and cover in combination. The designed doublet with a plano-concave cover corrected coma and spherical aberrations and showed larger power and narrower beam width than the lens with cover of uniform thickness in large incident angle.

The beam patterns of the doublet were evaluated with water tank experiment. As a result, the experimental results agreed well with the calculated results, and it was verified that the plano-concave cover gave positive influence the convergence property of lens.

Acknowledgment

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