3P6-3

Numerical Simulation of Underwater Digital Acoustic Communication Using Parabolic Reflector
音響反射鏡を用いた水中ディジタル音響通信の
数値シミュレーション

Ryotaro Chinone[1†], Takuya Aoki[1], Tadashi Ebihara[1], Yuji Sato[1], Koichi Mizutani[1] and Naoto Wakatsuki[1] ([1]Univ. Tsukuba)
茅根涼太郎 [1†]，青木拓也 [1]，海老原格 [1,2]，佐藤裕治 [1]，水谷孝一 [1,2]，若槻尚斗 [1,2]
（[1] 筑波大院・シス情工, [2] 筑波大・シス情系）

1. Introduction

Underwater acoustic (UWA) communication is one of the technologies to establish a wireless link in the ocean, and omnidirectional transducers are typically used to cover large areas where the exact location of the transmitter and receiver is unknown[1)]. However, the use of omnidirectional transducers requires massive transmission power, and complicated signal processing to cancel the delay spread of the channel[2)]. On the other hand, the use of directional transducers is attracting considerable attention recently, since it has the potential to achieve low-power and simple communication if the exact locations of the transmitter and the receiver are known [3,4)].

In this paper, we evaluate the possibility of UWA communication using the parabolic reflector as a directional transducer, as shown in **Fig. 1**. Different from existing directional transducers (e.g., single transducer with a large aperture and array of multiple transducers), parabollic reflector with a small number of transducers has a potential to achieve directional signal transmission and reception without large transducers or complicated signal processing. Although the performance of the parabolic reflector has been evaluated in terms of underwater imaging [5)], its potential for UWA communication has not clarified yet. Hence, in this paper, we perform numerical simulation to evaluate the performance of UWA communication using such directional transducer.

2. Design of Directional Transducer Using Parabolic Reflector

We designed a directional transducer using a

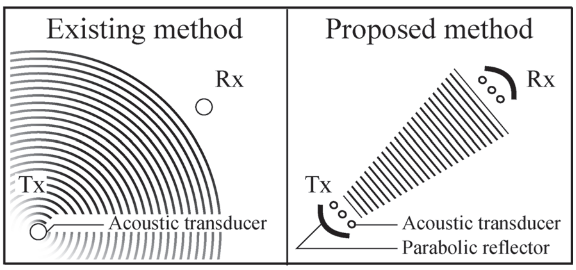

Figure 1: Underwater acoustic communication using parabolic reflector.

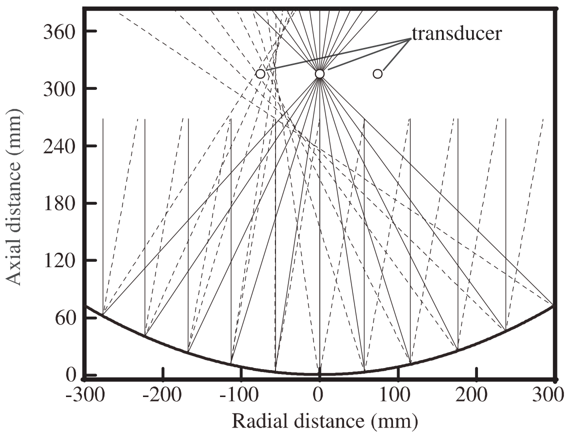

Figure 2: Path diagrams of designed parabolic reflector (solid line; $\theta = 0°$ and dotted line; $\theta = 10°$)

parabolic reflector based on the assumption that the radiation of sound from the reflector can be approximated to that from the circular piston. To achieve a wide angle of view while enhancing the gain of the signal, we designed a reflector having three omnidirectional elements (**Fig. 2**), where θ represents the incident angle. This reflector was designed to have a half-power beam width of 10° for each transducer (ka = 12, where k and a are the wavenumber and the radius of the reflector, respectively), and the total angle of view becomes ±10°.

3. Simulations

We performed an FDTD simulation of UWA communication when we employ the designed directional transducer in the receiver. **Figure 3** shows the simulation environment. First, the impulse responses of the transducers were calculated by changing the incident angle. Specifically, a chirp signal (center frequency: 60 kHz and bandwidth: 10 kHz) was emitted from a line source (distance between the reflector and line source: 3.0 m). The line source was rotated to change the incidence angle θ. The center of rotation corresponds with the center transducer. The signal was received by three transducers, and the impulse responses on the receiver were obtained by calculating a cross-correlation function between the transmitted and received signals. The channel impulse responses when we do not employ the reflector (three omnidirectional

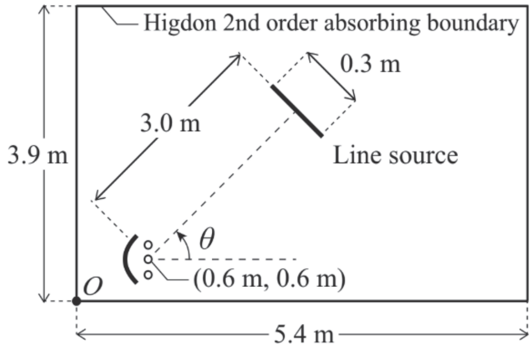

Figure 3: Simulation environment.

transducers) were also calculated as reference.

We next evaluated a relationship between incident angle and communication performance. **Figure 4** shows the block diagram of the UWA communication. The transmitter calculated a transmission signal by performing single-carrier modulation (training sequence: 100 symbols, message: 200 symbols, modulation: QPSK, carrier frequency: 60 kHz and signal bandwidth: 5 kHz). Then, the received signals (from line source to each transducer) were obtained by calculating convolutions of the transmitted signal and each channel impulse response. The noises at specific variance were added to the received signals. Finally, the receiver performed demodulation and equalization by using the multichannel RLS-DFE equalizer (FF: 303 taps, FB: 100 taps and forgetting factor: 0.98).

Figure 5 shows the simulation results. We first focus on the relationship between incident angle θ and input signal-to-noise ratio (ISNR) [Fig. 5(a)]. As shown in the figure, the ISNR of the directional transducer (blue line) has a larger value to that of omnidirectional transducer (red line) when θ does not exceed 20°. We next focus on the relationship between θ and output signal-to-noise ratio (OSNR) [Fig. 5(b)]. From this figure, we found that the UWA communication using the directional transducer outperformed that using the omnidirectional transducer when θ does not exceed 20°. Note that the gain of OSNR sometimes exceeded that of ISNR when we used the directional transducer. This is because the receiver can utilize the channel diversity in equalization process, because the impulse responses of each channel become different due to the signal reflection at the reflector.

Consequently, we found that UWA communication using parabolic reflector can become a viable alternative to achieve low-power and simple communication.

4. Conclusions

A parabolic reflector was designed, and communication using this was evaluated by simulation. As a result, we found that UWA communication using parabolic reflector can become a viable alternative to achieve low-power and simple communication.

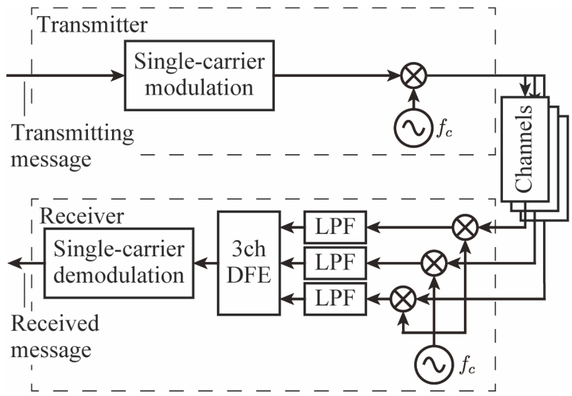

Figure 4: Block diagram of UWA communication

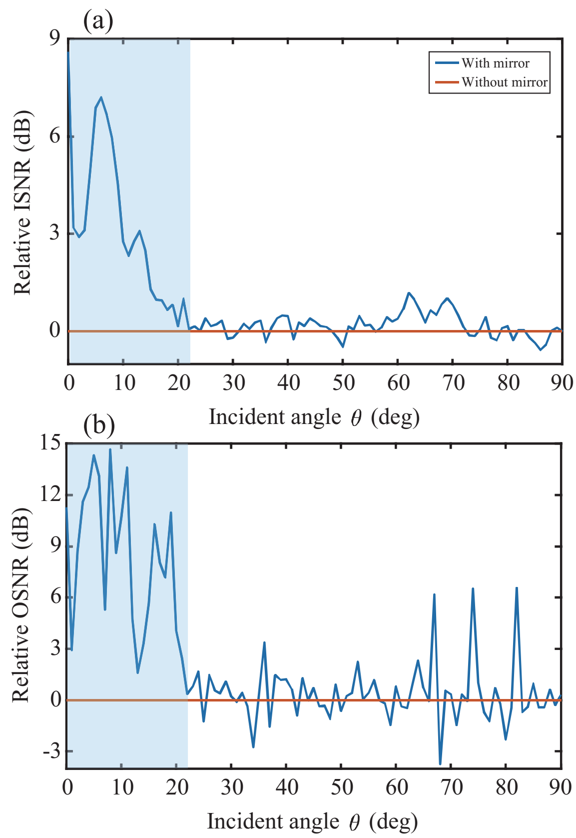

Figure 5: Simulation results; relationship between incident angle θ and (a) ISNR and (b) OSNR.

Acknowledgment
This work was supported by JSPS KAKENHI Grant Number 19H02351.

References

1. M. R. Dhanak, N. I. Xiros: *Springer Handbook of Ocean Engineering* (Springer, Cham, 2016) 359-386.
2. R. S. H. Istepanian and M. Stojanovic: *Underwater acoustic digital signal processing and communication systems* (Kluwer Academic Publishers, Boston, MA, 2002) Chap. 1.
3. L. E. Emokpae, S. E. Freeman, G. F. Edelmann and D. M. Fromm: IEEE J. Oceanic Eng. **44**.1 (2018) 229-239.
4. J. M. Jornet, M. Stojanovic, and M. Zorzi: *Proc. third ACM Int. workshop on Underwater Networks.* (2008) 75-82.
5. M. J. Buckingham: U.S. Patent 5,333,129 (1994).