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Correlation Analysis of Fading Variation and Communication Performance according to Depth in Underwater Frequency Selective Channel

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1. Introduction

An underwater acoustic communication channel is time-varying fast fading channel[1)]. The factors in fluctuation of the underwater acoustic channel should consider the impulse response, delay spread, scattering function, Doppler spread, correlation bandwidth, frequency selective fading, correlation time and time-varying amplitude fading, etc. In particular, fluctuations in sea surface and sea bottom reduce communication performance by increasing delay spread of reflected waves, inter-symbol interference, and frequency selectivity[2-4)].

In this paper, we analyzed the correlation between the fading variation and communication performance according to the depth in the underwater frequency selection channel through the sea experiment.

2. Underwater frequency selective channel

Figure 1 show underwater multipath channel. **Fig.** 1(a) shows the received signal reflected on the interface through the multipath, and **Fig. 1**(b) shows the frequency characteristics of the received signal with the response of the multipath channel.

Multipath waves in the underwater acoustic channel are observed as sea surface boundary reflections and scattering waves due to rough surfaces. When the sea surface boundary is time varying, the scattered wave is observed time varying and is affected by the depth of the transmitter and receiver.

When the transmitter and the receiver are fixed, the normalized three path signals of the direct wave(S_d), the sea surface reflection wave(S_s) and the sea bottom reflection wave(S_b) are shown in Eq.(1) ~ (3)[4,5)].

$$S_d=1 \quad (1)$$

$$S_s=\alpha_s e^{-j2\pi f\tau_s}+\int r_s e^{-j2\pi f\tau_s} d_\tau \quad (2)$$

$$S_b=\alpha_b e^{-j2\pi f\tau_s}+\int r_b e^{-j2\pi f\tau_s} d_\tau \quad (3)$$

where, $\alpha=-exp[-2(kh\theta)^2]$ is the magnitude of the

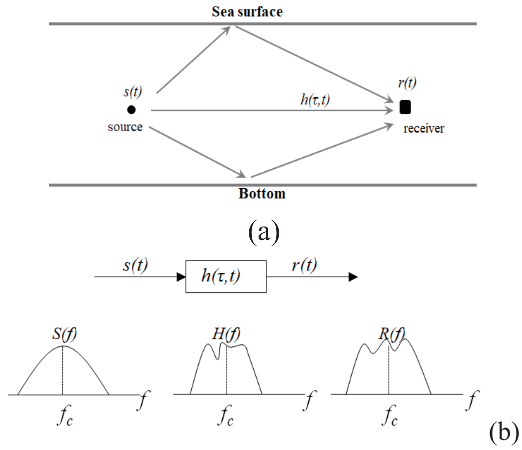

Fig. 1 (a) Underwater multipath, (b) Frequency characteristic in multipath.

sea surface and bottom reflection wave. k is sea surface roughness, h is wave height, and θ is the angle of incidence of the signal. $r=(f,h,\theta,\tau)$ is the magnitude of the scattering wave with the center of the sea surface and the sea bottom interface and the delay time. f is frequency, h is wave height, θ is the angle of incidence of the signal and τ is delay time.

3. Experimental Results

The experiment was conducted in about ~57 m deep ocean near Haeundae Beach in Korea on September, 2016. The effective surface wave height h is less than 0.5 m. The bottom sediment in the experimental site is sand and muddy.

The experimental parameters and configuration are shown in **Table I** and **Fig. 2**, respectively. The source and the receiver are located at depth of 20 m and 10 m, 20 m, respectively. source and the receiver are distance 100 m.

Table I. The experimental parameters.

Modulation	MFSK
Carrier frequency	Mark frequency 14 kHz
Bit rate	100 bps
Transmission bit	20000 bit
Distance	100 m
Transmitter / receiver depth	20 m/ 10 m, 20 m

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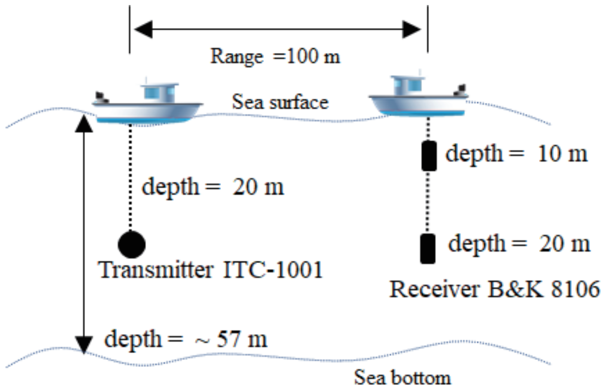
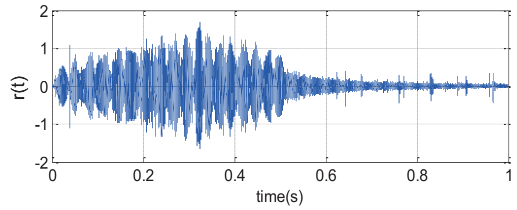
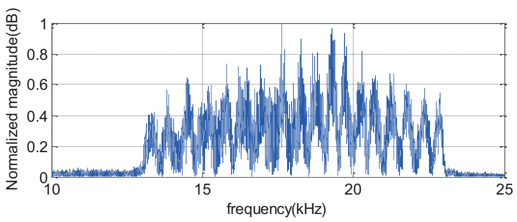


Fig. 2 The experimental configuration.

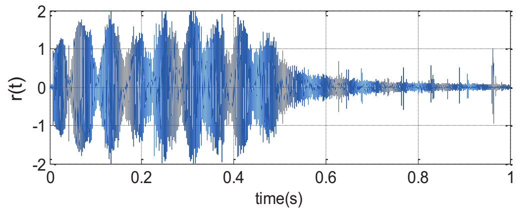


(a)

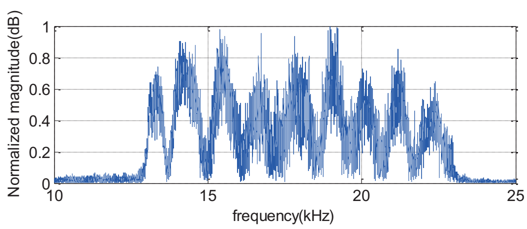


(b)

Fig. 3 (a) received signal, (b) frequency response (receiver depth 10 m).



(a)



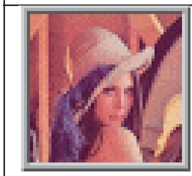
(b)

Fig. 4 (a) received signal, (b) frequency response (receiver depth 20 m).

Figure 3 shows the received time signal using liner frequency modulation (LFM) and receiver depth 10 m, 20 m. LFM frequency range is 13 kHz ~ 23 kHz. **Fig. 4** shows the frequency response of received signal using LFM.

Table 2 shows the result of reconstructing the received signals at depths of 10m and 20m. The depth of 10 m is relatively high in frequency selectivity due to sea level variation. However, a depth of 20 m has a relatively low impact on sea level fluctuations. The results of the experiment also have a relatively low error.

Table II. The performance of underwater communication

MFSK (Mark freq. 14 kHz)		
Source	Depth 10 m	Depth 20 m
		
BER	0.07	0.053

4. Conclusions

In this study, we assessed the underwater communication performance of according to the depth in the underwater frequency selection channel through the sea experiment. As a result of the experiment, it was found that the sea surface fluctuations differed according to the water depth. In addition, the effect of sea surface on communications in a multipath environment should be considered.

Acknowledgment
This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (Ministry of Education) NO. NRF-2019R1I1A1A01063575).

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