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4-FSK Performance in Very Shallow Ocean

Dandan Xue[‡], Chulwon Seo, Jihyun Park, Kyu-Chil Park, and Jong Rak Yoon
(Depart. of Inf. and Comm. Eng., Pukyong National Univ., Korea)

1. Introduction

The underwater acoustic communication channel is challenging since it is a time-varying due to the change of physical surroundings such as salinity and temperature, and also a delay spread due to multipath such as boundary reflections. Therefore it is characterized as a frequency selective fading channel. The received is strongly distorted and fluctuated and this causes inter-symbol interference (ISI) in underwater digital acoustic communication.

MFSK(multiple frequency shift keying) is a form of M-ary orthogonal modulation where each symbol is one of M orthogonal waveforms. It is non-coherent modulation but robust to time varying multipath channel with respect to phase tracking coherent modulation.

In this paper, the performance of 4-FSK system is examined in shallow ocean considering multipath coherence bandwidth and time varying coherence time.

2. Experiment

The experiment was conducted in about 20 m depth ocean near Geoje island in Korea on Aug. 6, 2014. The experimental configuration and parameters are shown in **Fig.1** and **Table I**, respectively.

The ranges between the transmitter and receiver are set to be about 100, 200, 400, and 800 m and the depth of receiver and transmitter are set to be 12 and 8 m, respectively.

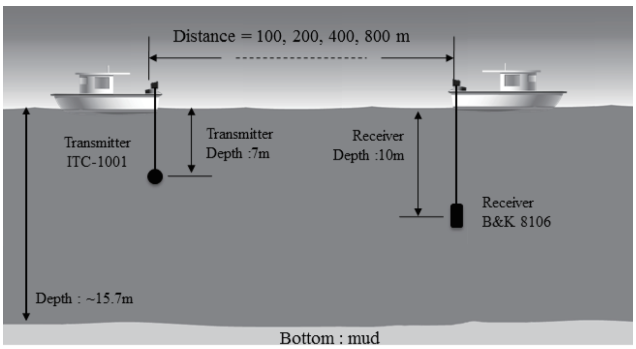


Fig. 1 Experimental configuration.

Email: jryoon@pknu.ac.kr

Table I. Experimental parameters

Modulation	4-FSK
Channel No.	4
Carrier frequency(kHz)	12-19
Symbol rates(sps)	50, 100, 200, 400 sps
Data transmission rates(bps)	400, 800, 1600, 3200
Channel guard band	symbol rate
Depth(m)	~15.7 m
Tx and Rx depth(m)	7, 10
Tx-Rx range(m)	100, 200, 400, 800
Information data(bit)	20,000
System	LabVIEW

4-FSK signals were transmitted by 4 channels to increase data transmission rate. Each of 4 orthogonal frequencies is spaced by symbol rate.

4 channels of 4 frequencies are transmitted simultaneously producing 8 x symbol rate(bits) in each symbol period but the actual payload is half of this since LFM(linear frequency modulation) and PN(pseudo noise) signals proceeding the data payload are allocated as shown **Fig. 2.**

Transmission time of one frame is limited to 1 s to cope with temporal coherence time variation. LFM and PN signals were used for the purpose of measuring the channel coherence bandwidth and symbol time alignment, respectively. For temporal coherence time analysis, LFM signal of 10 ms interval was transmitted for 20 s and PN of 20 s duration with 6 kHz bandwidth was also transmitted before data transmission.

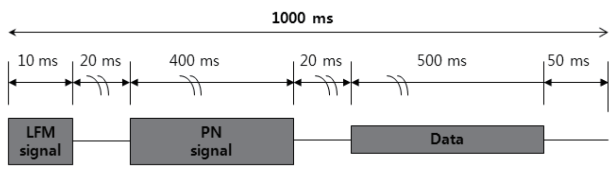


Fig.2 Frame structure.

3. Results

Figure 3 shows the sound velocity profiles for each transmitter to receiver range at receiver location. **Figure 4** shows the measured delay spreads for two different Tx-Rx ranges and corresponding coherence bandwidths

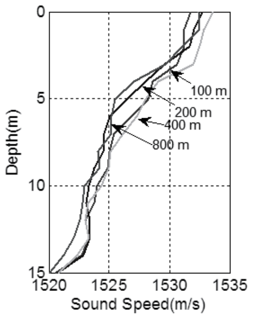
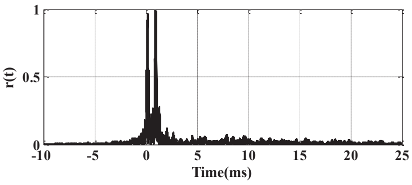
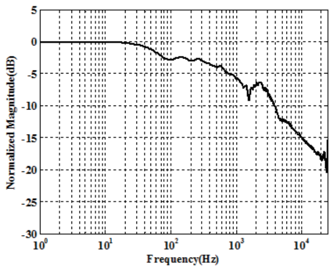


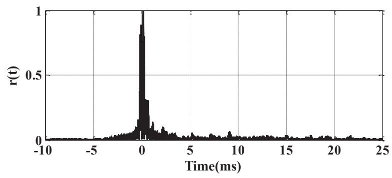
Fig.3 Sound velocity profiles for each Tx-Rx range.



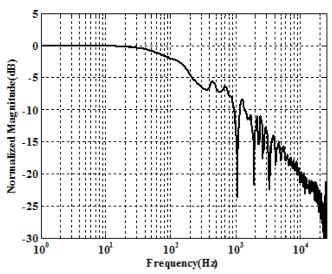
(a)



(b)



(c)

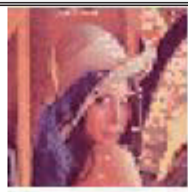


(d)

Fig.4 Measured delay spreads for two different Tx-Rx ranges and corresponding coherence bandwidths; (a) delay spread of range 100 m, (b) coherence bandwidth of range 100 m, (c) delay spread of range 800 m, and (d) coherence bandwidth of range 800 m.

Table 2 shows the received images and BERs of two different Tx-Rx ranges for 100 sps. Comparing coherence bandwidth and results in Table II, image quality and BER are closely related to delay spread or coherence bandwidth. Analysis for other symbol rates and Tx-Rx ranges are ongoing. Effects of time varying coherence time due to sea surface fluctuation are also being analyzed and will be given in conference.

Table II. Received images and BER for two different Tx-Rx ranges.

	100m	800m
Images		
Error bits/20000	670	281
BER	0.0335	0.0141

4. Conclusion

The performance of 4 channels 4-FSK system was examined in very shallow water. LFM and PN signals were used to measure the channel coherence bandwidth and symbol time alignment, respectively. LFM signal of 10 ms interval and PN signal of 20 s duration with 6 kHz bandwidth were also transmitted for temporal coherence time analysis.

Received standard Lena image quality and BER for 100 sps are closely related to delay spread or coherence bandwidth for a given Tx-Rx range. Analysis for other symbol rates and Tx-Rx ranges are ongoing. Effects of time varying coherence time due to sea surface fluctuation are also being analyzed and will be given in conference presentation.

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