Underwater Acoustic Channel Characterization at 6kHz and 12kHz in a Shallow Water near Jeju Island

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***Abstract*—An underwater acoustic communication experiment (JACE13) has been performed in a shallow water near Jeju Island. One of its main purposes is to measure underwater acoustic channels at 6 and 12 kHz. During the experiment we used an array of four hydrophones and altered the horizontal distance and depth of the transmitting source. Both narrowband and broadband signals are used for channel probing. In this paper the experimental data are analyzed using statistical approach. Coherence time, probability density functions (PDFs), level crossing rate, and channel responses are obtained. The results show that the channel behaves as a Rayleigh or Rician fading channel. We also found that the number of multi-paths and delay spread decrease as the horizontal range increases.**

Keywords—underwater acoustic channel; time-varying channel; statistical characterization; shallow water; coherence time; probability density function; level crossing rate; channel impulse response;

I. Introduction

Recently, Korea Institute of Ocean Science and Technology (KIOST, former KORDI) launched a new research project on underwater acoustic communications in August 2012. Its final goal is to develop an underwater acoustic network system which covers a wide area. The project has three phases and the first phase is related to the development of a long range (a few tens of kilometers) acoustic modem.

In order to design communication algorithms for the acoustic modem the propagation channels should be studied first. Due to the time-varying behavior of underwater channels in the oceans many researchers have used statistical approach for channel characterization [1-4]. The relation between fluctuating channel and ocean environmental data is also investigated [5].

Up to the year 2011, KIOST has also measured channel impulse responses in Jinhae Bay, which is surrounded by the southern coast of Korea and several small islands [6-7]. At that time primary aim was to measure high frequency propagation channel (around 25 kHz). In 2013 KIOST tried another field experiment (JACE13; Jeju Acoustic Communication Experiment 2013) for channel measurement. At this time considering long range communication we measured channel data at open sea near Jeju Island - but still shallow water - using lower frequencies (6 kHz and 12 kHz). As we did before both narrowband and broadband signals are used for channel probing. Various statistical parameters are investigated based on the experimental data. Ocean environmental data are also gathered for finding any relation to time-varying characteristics.

II. Description of the Experiment

A field experiment has been performed on April 29 through May 2 in 2003. One of the main purposes is to measure the underwater acoustic channel responses at 6 kHz and 12 kHz. The experimental site is located to the east of Jeju Island as marked in Fig. 1. The water depth is around 100 meters and the measured bottom geography using a multibeam echo sounder shows that it is very flat area.

Fig. 2 illustrates the measurement configuration. One omni-directional projector and four standard hydrophones were used as acoustic transducers. We placed the projector at the depth of either 20 m or 60 m. The receiver array was installed vertically for each hydrophone to have the depth of 60 m (ch #1), 40 m (ch #2), 20 m (ch #3), and 10 m (ch #4) respectively. We varied the distance between the transmitter and receiver from 1 km to 8 km.

In order to statistically characterize the channel pure tone signals were used. Broadband signals (M-sequence with BPSK modulation) were also transmitted to get the information on channel impulse responses. More detail parameters are shown in Table I.

Each data sample was gathered for 300 seconds with the sampling rate of 100 kHz. During the experiment environmental data were also collected such as sound velocity profiles, the height and direction of surface waves, and ambient noise.

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TABLE I. PARAMETERS OF THE BROADBAND SIGNALS

Parameter	Value
Carrier Frequency	6, 12 kHz
Symbol Rate	2.5 kHz for fc=6 kHz 5 kHz for fc=12 kHz
Pulse Shaping Filter	Root-raised Cosine
Roll-off Factor	1
Symbol Length	255 for fc=6 kHz 511 for fc=12 kHz

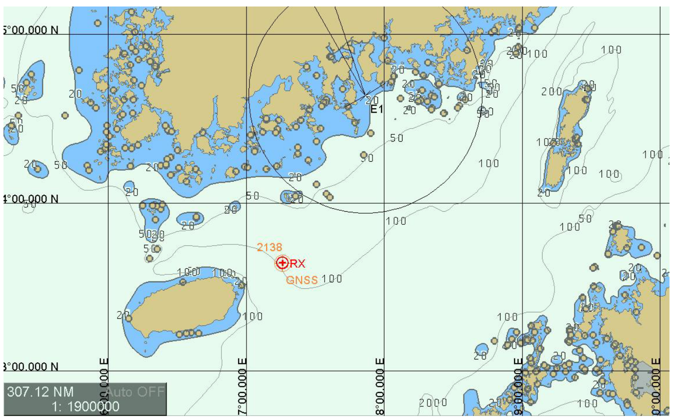

Fig. 1. Location of the experiment site ('+' mark with RX in red): 30km aprat to the east of Jeju Island

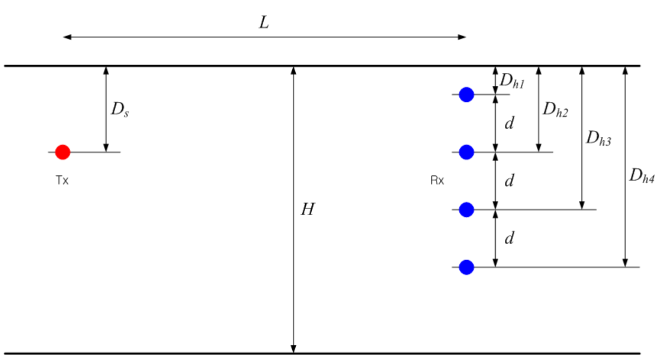

Fig. 2. Experimental configuration

III. EXPERIMETNAL RESULTS

A. Environmental Data

1) Sound Velocity Profiles

The measured sound velocity profiles are in the typical form [8] as shown in Fig. 3. Near surface mixed layers (-30 m) are observed and below the mixed layers are thermocline (30-70 m). Isothermal layers also exist deeper than 70 m. Figs. 3(a) and 3(b) are the data measured at the transmitter and receiver points respectively.

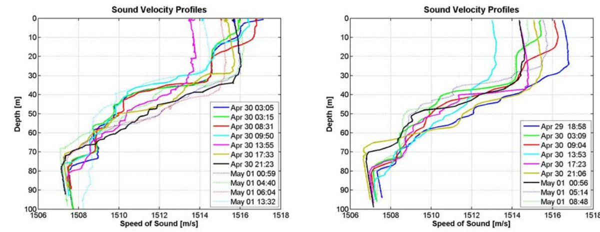

Fig. 3. Sound velocity profiles (a) at the transmitter (b) at the receiver

2) Surface Waves

Fig. 4 illustrates the significant wave height and wave direction at the peak frequency. They can be divided into three phases. During the first phase (until April 30 10hr) the wave direction is to the south and the significant wave height is around 0.6 m. During the second phase (until May 1 1hr) the significant wave height increases rapidly up to 1.4 m while the direction maintains to the west. After that the wave direction is reversed with the large wave height.

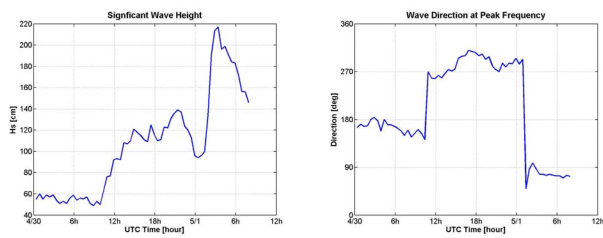

Fig. 4. Characteristics of surface waves (a) significant wave height (b) wave direction at the peak frequency

3) Background Noise

Both measured and theoretical background noise [9] spectra are shown in Fig. 5. Sea state 5 is assumed for the theoretical model. Measured spectra are little bit higher than theoretical one especially in the lower frequency range. The sound pressure level (SPL) is greater at shallower depth.

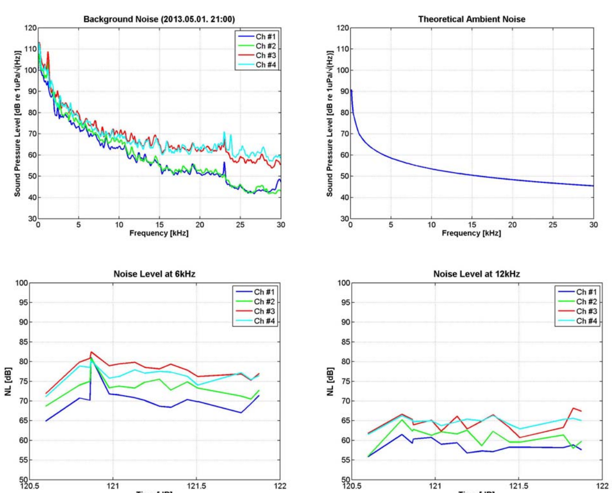

Fig. 5. Background noise (a) Measured noise spectrum (b) Theoretical ambient noise (c) Sound pressure level at 6 kHz (d) Sound pressure level at 12 kHz

B. Coherence Time

Temporal correlations were calculated with the measured pure tone data and coherence time was obtained by finding -6dB point from its maximal value. Table II shows samples of estimated coherence time. The coherence time decreases as the range increases and the depth decreases, which means the higher rate of channel estimation is required for longer range and at shallower depth. The main causes of small coherence time may be come from the decreasing signal-to-noise ratio (SNR) and time-varying characteristics. The small values (less than 10 ms) at 8 km are due to low SNR.

TABLE II. ESTIMATED 6 DB COHERENCT TIME (UNIT: SEC) AT 6 KHZ WHEN THE TRANSMITTER DEPTH IS 60M

Range	Hydrophone No.			
	#1	#2	#3	#4
1 km	0.5765	0.2953	0.3081	0.2213
2 km	0.5503	0.2977	0.2845	0.2636
4 km	0.3460	0.1499	0.0863	0.0672
8 km	0.1443	0.0070	0.0066	0.0067

C. Probability Density Functions

The probability density functions (PDFs) of magnitudes are obtained. A bandpass filter with the bandwidth of 100 Hz is applied for the processing. Figs. 6 and 7 show the results for pure tone sound. Most PDFs are similar to the Rayleigh distribution and the estimated K-factors based on curve fitting are less than 1. The exceptional case is observed when the transmitter depth of 60m at 2km, where the estimated K-factor is about 2.4. PDFs of phases match a uniform distribution as we had observed in [7].

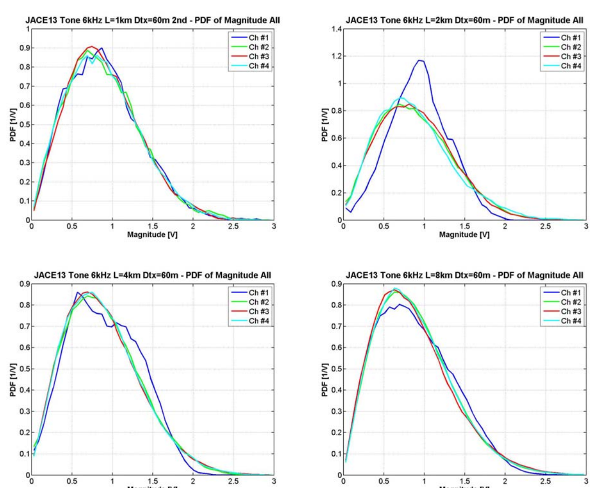

Fig. 6. Probabiltiy density functions of magnitude of 6 kHz pure tone sound (transmitter depth: 60 m) (a) 1 km (b) 2 km (c) 4 km (d) 8 km

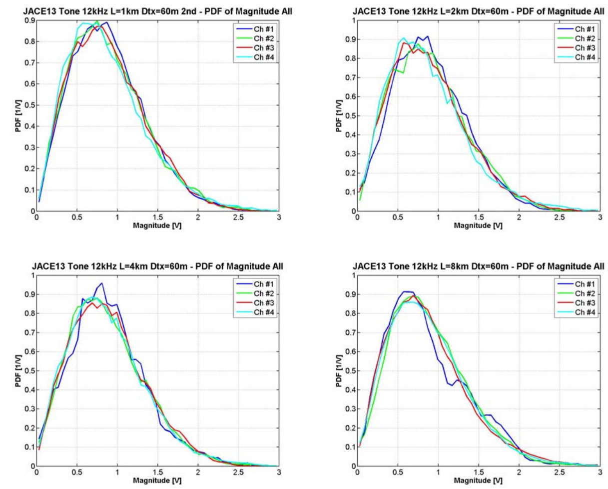

Fig. 7. Probabiltiy density functions of magnitude of 12 kHz pure tone sound (transmitter depth: 60m) (a) 1km (b) 2km (c) 4km (d) 8km

D. Level Crossing Rate

The level crossing rate [10] is another important statistical parameter in fading channels. It indicates how fast the time-varying channels fluctuate. As shown in Fig. 8 depth effect of the hydrophones is greater in 6kHz.

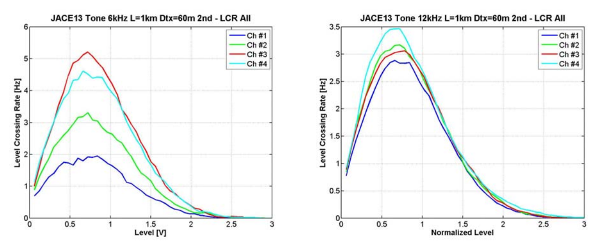

Fig. 8. Level crossing rate (transmitter depth: 60 m) at 1 km range (a) 6 kHz (b) 12 kHz

E. Channel Impulse Responses

Figs. 9 through 11 depict channel impulse responses acquired using the broad band signals for three cases. Figures only show multi-paths, the normalized magnitudes of which are greater than -20dB. The relative delay spreads out up to 30ms, which corresponds to 75 symbol length for R=2.5ksps. For all cases from JACE13 experiment maximal delay is less than 35ms, which occurs at 1 km range. As range increases number of multi-paths and delay spread decreases.

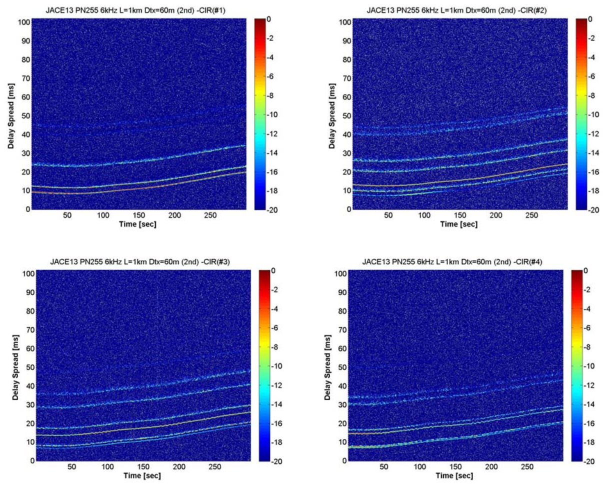

Fig. 9. Channel impulse responses (carrier frequency: 6 kHz, range: 1 km, transmitter depth: 60 m) (a) 60 m (b) 40 m (c) 20 m (d) 10m

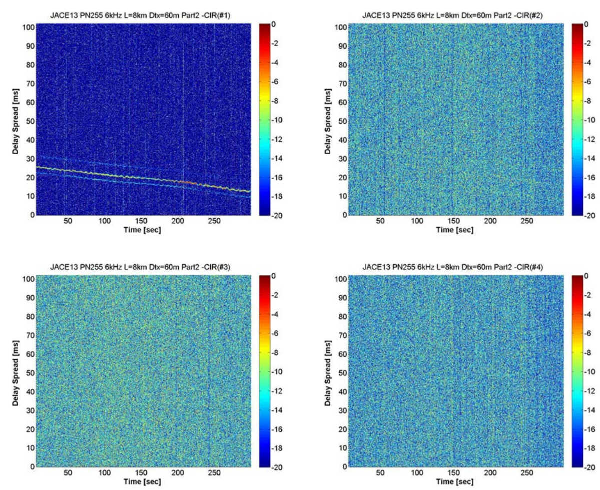

Fig. 10. Channel impulse responses (carrier frequency: 6 kHz, range: 8 km, transmitter depth: 60 m) (a) 60 m (b) 40 m (c) 20 m (d) 10m

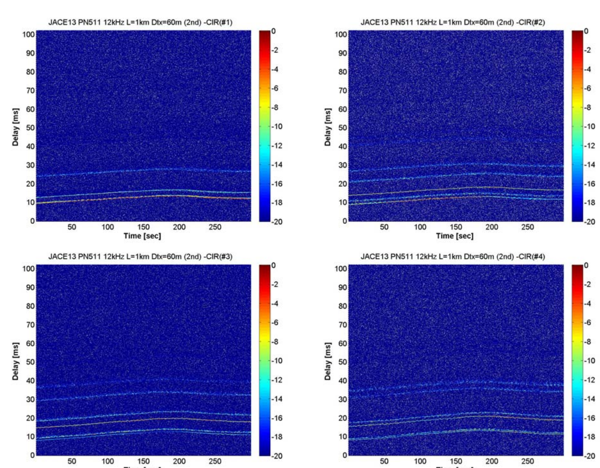

Fig. 11. Channel impulse responses (carrier frequency: 12 kHz, range: 1 km, transmitter depth: 60 m) (a) 60 m (b) 40 m (c) 20 m (d) 10m

IV. CONCLUSION

A field experiment (JACE13) for underwater acoustic channel measurement at a shallow water has been performed near Jeju Island in 2013. Both pure tone sound and broadband signals at 6 kHz and 12 kHz are used. The results show that coherence time is in the order of a few hundreds of milliseconds. As expected the shorter coherence time is observed for the longer ranges. PDFs of the magnitude demonstrate Rayleigh or Rician fading channels. A few multi-paths are observed in the short range channel (1 km) and the delay spread is less than 35 ms. As the horizontal range increases the number of multi-paths decreases in the channel impulse responses.

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REFERENCES

[1] J. L. Spieberger and D. Green, “Statistical characterization of very low frequency communication channels at ocean basin-scales,” IEEE Oceans ’06

[2] W.-B. Yang and T. C. Yang, “Characterization and modeling of underwater acoustic communications channels for frequency-shift-keying signals,” IEEE Oceans ’06

[3] A. Radosevic, J. G. Proakis, and M. Stojanovic, “Statistical characterization and capacity of shallow water acoustic channels,” IEEE Oceans ’09 Bremen

[4] B. Borowski, “Characterization of a very shallow water acoustic communication channel,” MTS/IEEE Oceans ’09 Biloxi.

[5] W. S. Hodgikiss and J. C. Preisig, “Kauai acomms MURI 2001 (KAM11) experiment” Proceedings of the 11th European Conference on Underwater Acoustics, 2012, pp. 993-1000.

[6] S.-M. Kim, S.-H. Byun, S.-G. Kim, and Y.-G. Lim, “Experimental analysis of statistical properties of underwater channel in a very shallow water using narrow and broadband signals,” MTS/IEEE Oceans ’09 Biloxi.

[7] S.-M. Kim, S.-H. Byun, S.-G. Kim, and Y.-G. Lim, “Temporal variations of the statistical properties of an underwater acoustic channel measured at a shallow water in 2009,” IEEE Oceans ’10 Sydney.

[8] F. B. Jensen, W. A. Kuperman, M. B. Porter, and H. Schmidt, Computational Ocean Acoustics, Springer-Verlag, 2000, pp. 3–5.

[9] B. K. Choi, B.-C. Kim, C. Kim, and B.-N. Kim, “Analysis of dependence on wind speed and ship traffic of underwater ambient noise at shallow sea surrounding the Korean Peninsular,” J. of Acoust.ical Society of Korea, vol. 22, pp. 233–241, April 2003, (in Korean).

[10] M. Patzold, Mobile Fading Channels, John Wiley & Sons, 2002.