Evaluation of Spatial Diversity Technique from Experimental Results using Multiple Array Sensors in Underwater Acoustic Communication

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1. Introduction

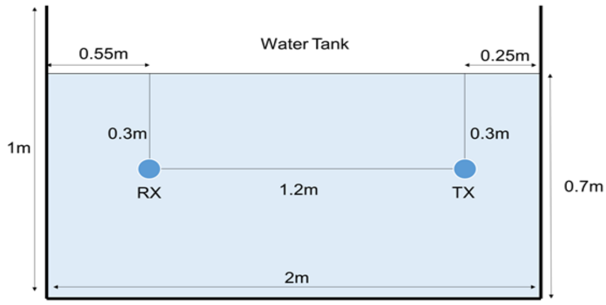
The underwater acoustic communication channel is known to exhibit a frequency selective channel by multi-path delay spread in a multipath channel such as the shallow water. The inter-symbol interference (ISI) occurs due to multiple reflections from the water surface and the seabed affected by the reflected waves, resulting in degradation of underwater acoustic communication performance in the shallow water.[1-2] As the channel's bandwidth becomes narrow due to the influence of the ISI, it shows the frequency selective channel.[3-4]

For the proper underwater acoustic communication in these situations, we concentrated on space diversity technique which is known helpful to communicate with the more proper channel among varying channels. It was investigated the effect of the space diversity technique with array sensors on the receiver in the water tank. We used the selection technique among processing techniques with multiple sensors. We experimented and evaluated on the QPSK modulation and demodulation system in water tank.

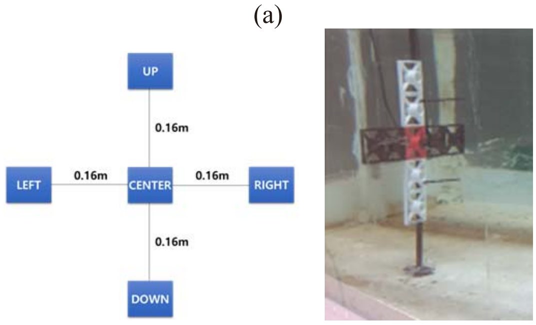
2. QPSK system and the experimental conditions

The QPSK modulation and demodulation system is one of the digital communication systems with two channels – I channel and Q channel. The transmitted signals are demodulated to two output signals using cosine signal or sine signal with same carrier frequency of modulation system and synchronization. Then output signals are converted to 4 states sequences [00 01 10 11] through the decision processor for each channel.

Figure 1 shows the experimental configuration in a water tank on (a) and the receiver sensors' structures on (b). The size of the water tank is 2m×1.5m×1m in length, width and height respectively. The depth of the transmitter and the center of the receivers are set to be 0.4m from the bottom. Five sensors are constructed in the form of crosses, horizontally and vertically. The distance from each sensor is 0.16m from center in width and height, respectively. The carrier and sampling frequency are respectively chosen as 16 kHz and 128 kHz. The transmission rates are set to be 100, 200, and 400 bps. The transmitted image is the standard Lenna image consisting of 9,800 bits of data. The specific experimental parameters are given in Table I.



(a)



(b)

Fig. 1 The experimental configuration in water tank on (a) and the receiver sensors' structures on (b).

Table I. Simulation and experimental parameters

Mod/Demod. System	QPSK
Carrier frequency (kHz)	16 kHz
Sampling frequency (kHz)	128 kHz
Symbol rates (bps)	100, 200, 400
Data Transmission Type	Packet
Tx and Rx range (m)	1.2m
Tx and Rx depth (m)	0.3m
Depth (m)	0.7m
Data (bits)	Image 9,800 bits

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3. Experimental results and discussion

Before transmitting QPSK image signal and making frame structure for packet data transmission, linear frequency modulated (LFM) signal is transmitted to measure the channel impulse response with frequency ranges from 13 kHz to 23 kHz as shown **Fig. 2**. From this result, a reverberation time of the water tank is given by about 31 msec.

Next, for the check of each channel's characteristics, each received LFM's amplitude response was divided by the transmitted LFM's amplitude responses calculated, and shown in **Fig. 3**. The dotted lines show each bandwidth according to 100, 200 and 400 bps. From each result, several deep fading near to the carrier frequency were founded in channel CENTER and RIGHT. It can be expected that the communication quality can be degraded.

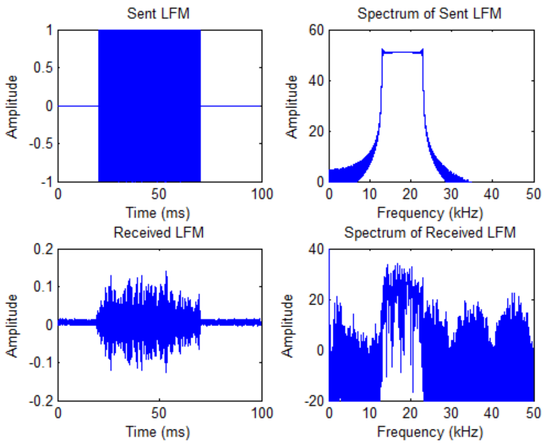

Fig. 3 A LFM signal ranges from 13 kHz to 23 kHz and its frequency characteristics.

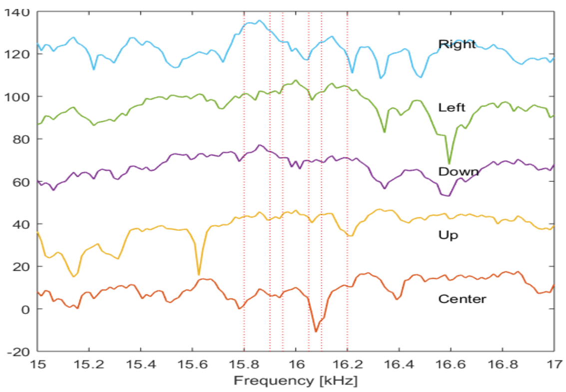

Fig. 3 Channels' frequency responses.

To select the proper channel, it was calculated the standard deviation in each channel's constellation shown as Table II. The bold indicates a channel with higher than the average of all the channels, and means a channel estimated to have less error as shown Table III.

Table II. Channel's standard deviations in constellation according to bps.

channel \ bps	100	200	400
LEFT	**4.320**	**1.882**	**0.801**
RIGHT	0.929	0.705	0.451
CENTER	0.945	0.453	0.222
UP	**2.810**	**1.263**	**0.557**
DOWN	**4.404**	**1.101**	**0.519**
Average	2.681	1.081	0.510

Table III. Channel's bit error rate according to bps.

channel \ bps	100	200	400
LEFT	**0.000**	**0.000**	**0.013**
RIGHT	0.000	0.246	0.196
CENTER	1.E-04	0.167	0.102
UP	**0.000**	**0.000**	**0.000**
DOWN	**0.000**	**0.000**	**0.000**

4. Conclusions and further study

We investigated the effect of space diversity on the underwater acoustic communication. For the choosing of the proper channel, we calculated the standard deviation in constellations on each channel. As results, those standard deviations are related to the bit error rate on each channel. When the standard deviation value on the constellation was large, it was found that the fading was low and the frequency characteristics were flat.

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