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Analysis of Doppler shift and phase error according to the movement of underwater vehicles in the underwater phase modulation method

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1. Introduction

The underwater acoustic communication channel is a time-varying channel according to a change in boundary surface of sea surface and bottom. In this channel, the acoustic communication of Remotely Operated Vehicles (ROV), Autonomous Underwater Vehicles (AUV) and underwater vehicles is degraded performance by symbol interference of signal and Doppler shift of transmitter frequency. The movement of these underwater vehicles affects the delay time of the received signal. Also, it causes delay spread, symbol interference, and time-varying homogeneity of the channel band. [1)]

Alos, the frequency of transmitted signals is also significantly distorted by transient Doppler effects generated by elongation and contraction of surface reflected transmission path, or Doppler frequency shifts from movement of either the transmitter and receiver. [2-3)]

In this paper, we analyze the Doppler transition characteristic of the transmission frequency and the communication performance by the change of the synchronization pointer of Quadrature Phase Shift Keying (QPSK) of the phase transition method with the movement of the underwater vehicle.

2. Multipath variation and Doppler effect

In underwater acoustic communication, a transmission signal is received through a multipath by reflection of a channel boundary, and has a delay spreading characteristic of the received signal. As shown in **Fig. 1**, the movement of an underwater vehicle in an underwater multi-path environment degrades transmission performance by forming multi-path fluctuations. Therefore, it is necessary to apply the transmission rate and communication method through the analysis of the transmission band according to the characteristics of the channel and the movement in the water to which the underwater vehicle is applied.

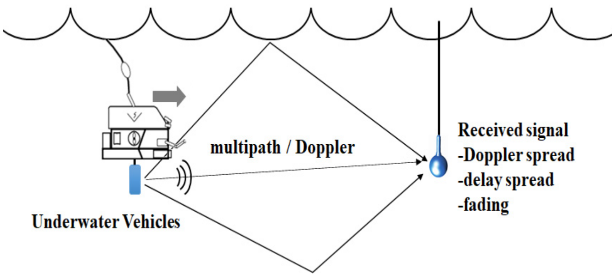


Fig. 1 underwater vehicle in underwater multipath.

There is a special case PSK wherein M=4, and each symbol represents 2bit. The QPSK modulation signal is given by Eq. (1) [4)]

$$s(t) = \sqrt{\frac{2E_b}{T_s}} \cos\left(2\pi w_c t + (2i-1)\frac{\pi}{4}\right) \tag{1}$$

In addition, the Doppler frequency shift is defined as the ratio between the relative velocity between the underwater vehicle and the receiver and the propagation velocity of the signal. The signal with the Doppler transition due to the Doppler effect is expressed as follows.

$$r_D(t) = s((1+\Delta)t) \tag{2}$$

The function for a continuous signal with bandwidth is expressed as

$$r_{sD}(\tau,\Delta) = (1+\Delta)\int s((1+\Delta)t) r(t-\tau) dt \tag{3}$$

Here, τ is the delay time, d Δ is the Doppler transition and $r(t)$ is received signal.

A phase shift method such as QPSK is a synchronous method and is a method sensitive to a change in phase due to a Doppler transition. The Doppler transition frequency is given by[3)]

$$\Delta f_D = \frac{1}{2\pi T} \arg\left(f_D(k) \times f_D^*(k-1)\right) \tag{4}$$

Here, $f_D(k) = a_k^* a_k e^{j(2\pi \Delta f k T + \theta)} + n(k)$ is the signal containing noise and * is complex conjugate.

In Eq. 4, the phase of the synchronization signal is important in the phase modulation method, and in particular, the Doppler shift frequency Δf_D according to the moving speed of the underwater vehicle causes the synchronization pointer mismatch problem of the phase shift method.

3. Experimental Results

The experimental parameters and configuration are shown in **Fig. 2** and **Table I**, respectively. The source and the receiver are located at depth of 5m and distance 50m, respectively.

Table I. The experimental parameters.

Modulation	QPSK
Carrier frequency	30 kHz
Bit rate	200 sps
Transmission bit	20000 bit
Distance	50 m
Transmitter / receiver depth	5 m, 5 m

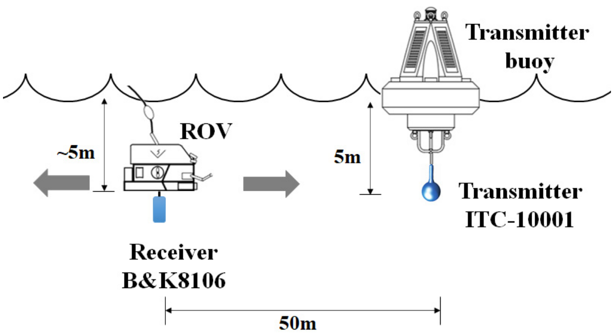


Fig. 2 The experimental configuration.

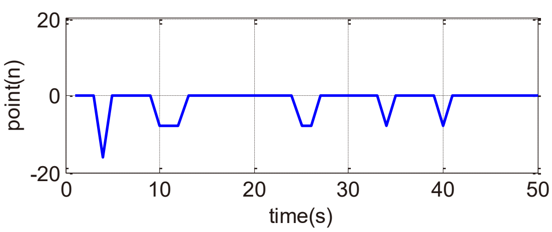


Fig. 3 ROV approaches the receiver(point).

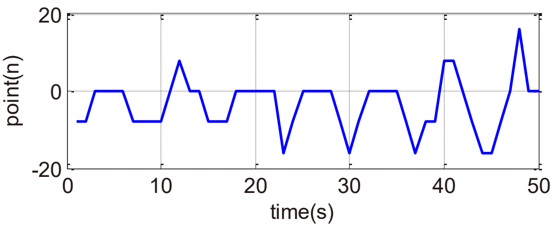


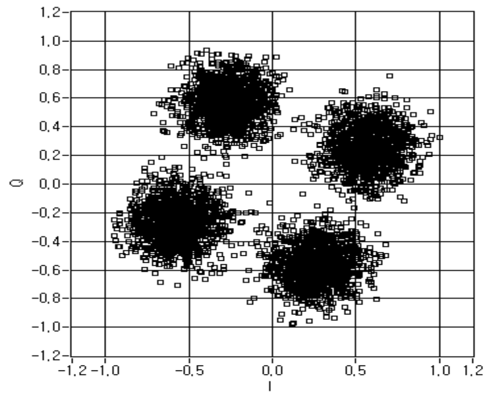
Fig. 4 ROV leaves the receiver(point).

Figure 3 shows the change of synchronization pointer when ROV approaches the receiver. **Fig. 4** shows the change of sync pointer when ROV leaves the receiver. **Fig. 5** is a constellation diagram of QPSK received signal according to ROV movement.

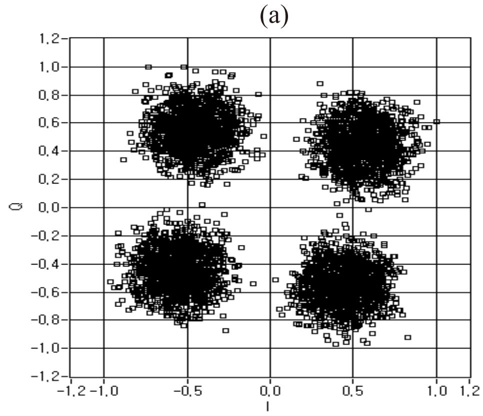
4. Conclusions

In this paper, the effect of the Doppler shift according to the ROV movement on the synchronization pointer of the phase modulation method was analyzed. In the experiment, the pointer fluctuation occurred when the ROV approached or leaves the receiver.

As a result, a position error of the demodulation occurred like the constellation of the QPSK received signal.



(a)



(b)

Fig. 5 The constellation diagram of QPSK, (a) ROV approaches, (b) ROV leaves.

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