Detecting low-speed targets such as underwater unmanned vehicles (UUVs) by using active sonar is becoming attractive. Recently, binary phase shift keying (BPSK) pulse is taken as active waveform because it has both high doppler and range resolution. However, its doppler sensitive property limit the application of BPSK heavily. In this paper, we focus on discussing the application area which is suitable for BPSK waveform. It is proved by simulation that shorter time duration of waveform could avoid time distortion of pulse and energy lose of matched filter. BPSK is more suitable for short range detection on high frequency sonar than low frequency sonar. The small doppler tolerance of BPSK could help to suppress clutters which arise from physical objects in the ocean (e.g. rocks, shipwreck, or fish). It is effective to detect low-speed target by BPSK in clutter-filled environment such as harbor and littoral area. Compared with linearly frequency modulation (LFM) waveform, the experiment results testify the benefit of applying BPSK to detect low-speed target in clutter-filled area on HFAS.

Keywords: clutter suppression, BPSK, active sonar, low-speed target

1. Introduction

Nowadays, the detection of low-speed equipments such as unmanned vehicles (UUVs) is highly required. The UUVs often sail in harbor and littoral environment which are clutter-filled when using high
frequency active sonar (HFAS) system [1]. The clutters are false alarms arising from underwater physical objects, e.g., rocks, fish, shipwreck, or seaweed [2]. Traditionally, the large bandwidth-time duration (BT) classical frequency modulation (FM) waveform is selected for low-speed target detection [3-4]. However, the insensitive doppler property leads to well correlation of both target and clutters. In recent years, many complex waveforms such coded pulse, Costa, comb pulses, pulse trains of FM have been employed to improve the performance, but they still have problems in practical engineering [5-8]. The binary phase shift keying (BPSK) waveform is a type of coded waveform with ideal ambiguity function shaped as a thumbtack [9]. It has both high doppler and range resolution, but it is too sensitive to be applied in reality [10]. This paper discusses on the application condition of BPSK waveform. It is proved that BPSK is suitable for detecting low-speed targets in clutter-filled environment on HFAS system.

2. Waveform Property

This section introduces BPSK waveform property and analyses its application characters. Compared with FM waveform, BPSK has the ability of suppressing clutters to reduce false alarms when detecting low-speed target [11]. Even though BPSK is sensitive which may leads to energy loss of matched filtering, simulation will testify that it is negligible when time duration of pulse is short by using high frequency sonar for short range detection.

2.1 Clutter Suppression Capacity

BPSK waveform could be described as

\[ s(t) = \sin(2\pi f_c t (2b(t) - 1)), \]  

where \( b(t) \) is a binary sequence of \( N \) bits. The Woodward ambiguity function (WAF) of \( s(t) \) which is always used for waveform analysis is

\[ \chi_s(\tau, k) = \sqrt{k} \int s(t)s[k(t - \tau)]dt, \]

where \( \tau \) and \( k \) is the time delay and doppler scale factor of replica. The 3dB bandwidth of BPSK waveform is

\[ B = \frac{N}{T}. \]

The WAF contour of LFM and BPSK waveforms are shown in Fig. 1.

As the figure shown, the black area is the region of 3dB contour which defines the doppler tolerance. If the difference of clutter velocity and target velocity is smaller than the waveform doppler tolerance, the target echo will be blended with clutters. Thus, the doppler sensitive waveform such as BPSK is more easily to distinguish target and clutter. It means that clutters will be suppressed by the waveform when target is matched filtered well.

2.2 Sensitivity

The oscillation of source and receiver because of high sea state or platform fluctuation may leads to a time-varying doppler shift which seems to be harmful to the doppler sensitive signal [10]. It will leads to waveform distortion and energy loss of matched filtering which is essential for the detection performance. Assuming the perturbation is a sinusoidal process for simplicity, a typical wave period is 4 ~ 6s [12].
During the transmitting and receiving process, the waveform might be distorted with continuous non-linear both positive and negative doppler shift as the perturbation is heavy. The distortion will leads to mismatch and matched filter peak energy loss. Following the perturbation model of paper [10], the BPSK time function \( p(t) \) and the perturbation transform function \( p_\alpha(t) \) are as follows:

\[
p(t) = \sin(2\pi f_c t(b(t) - 1)) \tag{4}
\]

\[
p_\alpha(t) = p(t + \alpha \sin 2\pi \frac{t}{C}(1 - \cos 2\pi \frac{t}{C})) = \sin(2\pi f_c u(t)(t + \alpha \sin 2\pi \frac{t}{C}(1 - \cos 2\pi \frac{t}{C}))), \tag{5}
\]

where \( b(t) \) is the \( N \)-bit binary sequence of during \( T/N \) and \( u(t) \) is the phase modulating sequence contains \( \pm 1 \), \( C \) is the wave period, \( \alpha \) is the amplitude of the distortion. Applied with a matched filter process, we can get the delay-doppler matrix \( \chi_\alpha(\tau, d) \) and find that the time distortion leads to energy loss of matched filtering. Consider from the physical process of the distortion, the ratio \( R_\tau = \frac{T}{C} \) is decisive because the instantaneous transmitting and receiving process will not be influenced by a long period perturbation. So we simulated the distortion loss at different \( R_\tau \) when we set \( f_c = 1500 \text{Hz} \) by LFAS and \( f_c = 30 \text{kHz} \) by HFAS. The loss curve at different \( R_\tau \) is shown in Fig. (2).

As shown in Fig. (2), the distortion loss could be neglected when the \( R_\tau = \frac{T}{C} \) is quite small. For example, when \( T = 200 \text{ms}, C = 4s \) and \( R_\tau = 0.05 \). Compared with LFAS, the \( T \) of HFAS is much smaller and the \( R_\tau \) could be quite small. The problem of WAF Peak-Loss could be neglected in the situation.

3. Experiment

The experiment is taken in a lake. LFM and BPSK waveforms were used by HFAS to detect target of about 1 knot speed. The frequency, bandwidth and time duration of LFM and BPSK are all the same. The doppler tolerance of LFM is quite large and of BPSK is about 0.6 kn. Multi-doppler channels are employed to the received data, the multi-doppler gram of LFM and BPSK is shown in Fig. 3.

As the figure shown, target and clutters could be distinguished by doppler sensitive BPSK waveform, but there is few difference by using multi-doppler channels matched on LFM data. In Fig. 4 it is proved...
Figure 2: The simulated WAF Peak-Loss when $R_r$ ranging from 0.1 to 0.4.

Figure 3: Multi-doppler matched filter gram with replicas doppler from $-2$ kn to 2 kn for one ping.
that BPSK help to reducing false alarms better than LFM.

4. Conclusion

In this paper, we applied BPSK pulse to detect low-speed target in clutter-filled environment. BPSK is doppler sensitive what limit its application on active sonar. We discussed the application area which is suitable for BPSK waveform by simulation. It is proved BPSK is more suitable for short range detection on high frequency sonar than low frequency sonar. BPSK is helpful on suppressing clutters which arise from physical objects (e.g. rocks, shipwreck, or fish). Compared with LFM pulse, we took experiments to testify the benefit of applying BPSK on detecting low-speed target in clutter-filled area on HFAS. It is effective to detect low-speed target by BPSK in clutter-filled environment.

REFERENCES


