Analysis of the Waveform of the High Frequency Surface Wave Radar

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Abstract: The waveform characteristic of the high frequency surface wave radar (HFSWR) in the detecting target on the sea has been discussed. Principle of HF radar modulation is analyzed and the derivation of range and velocity detecting is given. Moreover, the actual data from sea echoes are simulated. The results are shown that the range and velocity resolution of FMICW is improved. The study has some values in the waveform design and the application of HFSWR.

Key words: high frequency, waveform, range resolution

1 Introduction

HFSWR can detect slow moving targets over the horizon at sea, called "hard target " detection. It works on the high-frequency band and its wavelength is larger than microwave radar by three orders of magnitude. The shore-based radar receiving station use the antenna array, which size is often relatively large. These large array brings many difficulties in management, such as high maintenance costs, poor mobility performance, restricted sites and many unfavorable factors. Therefore, in order to be more flexible, the antenna array is required miniaturization.. It becomes an important issue considering both maximum detection range and range resolution that how to design waveform parameters and optimize the transmitted waveform[1-4] .

Currently HFSWR have realized digitizing, transmitted waveform using frequency modulation, phase encoding, linear FM,etc, to resolve conflicts between the ranging ambiguity and transmitter peak power[5-7] . U.S. high-frequency ground wave radar network used continuous wave frequency modulation (FMCW). The advantages are a wide range of Doppler frequency change. The FMICW (FMICW: frequency-modulated interruptive-continuous wave) were more widely used, which advantage were that the radar has higher average power and co-location transceiver. FMICW was favorable in solving the problem of distance aliasing and Doppler aliasing. Wuhan University of OSMAR2003 ground radar also used it. Canadian Northern Radar Company researched frequency-modulated continuous wave interrupted by uniform pulse (FMPCW) and had got it practical [1-3] . In this paper , analysis on the FMICW waveform is given and the actual data from sea echoes are simulated. Waveform parameters design is for discussion, and the design principles of distance and speed to avoid ambiguity is discussed.

2 Echo signal processing

Setting target is the ideal point target and transmitting signal is FMICW, its echo expression can be written as:

$$\begin{aligned} S_R(t) = A * \sum_{n=-\infty}^{+\infty} \mu_1(t-T_r) * \exp\{ j2\pi[f_0(t-t_r) \\ + f_b(t-t_r-nT_r) + \frac{k}{2}(t-t_r-nT_r)^2 + \phi_0] \end{aligned} \quad (1)$$

Wherein, A is the gain factor.

Its instantaneous phase is:

$$\psi_R(t) = 2\pi[f_0(t-t_r) + f_b(t-t_r-nT_r) + \frac{k}{2}(t-t_r-nT_r)^2 + \phi_0] \tag{2}$$

Where $t_r \le t - nT_r < T_r$ 。

Then time delay Tr may then be expressed as:

$$t_r = \frac{2(R_0 + vt)}{c} = \Delta f \frac{T_r}{B} \tag{3}$$

Where c is the speed of light, R_0 is the distance between the target and the radar when $t = 0$. The distance to the target can be obtained by the delay. Δf is the frequency shift that the receivign frequency is relative to the transmitter frequency, B is the bandwidth of the modulated signal.

The distance extracted from the echo is expressed as:

$$R = t_r \frac{c}{2} = \Delta f \frac{T}{B}\frac{c}{2} \tag{4}$$

A FFT is done to the linear FM signal and the quantitative computation is as:

$$\frac{1}{T} = \Delta f = \frac{B}{T}\frac{2r}{c} \tag{5}$$

Whereby the distance is $r = \frac{c}{2B}$.

Speed information can not be obtained from a single echo pulse frequency offset, so the velocity information result should be obtained through accumulating by transmitting multiple pulses. When target is in low-speed movement, target moving distance does not exceed the distance unit length during the L sweep cycles, speed will be reflected in the corresponding distance on the Doppler spectrum.

The Doppler spectrum on the distance can be obtained by DFT with L points:

$$Y_m(k) = \sum_{l=0}^{L-1} F_l(m) W_L^{kl} \tag{6}$$

So the speed solution can be gotten by the Doppler offset directly. During the time between the radio waves transmitted and returned from target, the echo frequency has a frequency conversion compared with the transmitting, so the voltage difference will arise at the output of the mixer frequency. Since the target distance is related with the voltage difference frequency, the target distance can thus be solved. This general method is to extract the distance and speed of information through twice FFTs.

3. Simulation results and analysis

Parameter settings for simulation are: radar center frequency 11.08MHz, the transmitted waveform pulse period is 3.2ms, pulse transmission time is 1.6ms, FM bandwidth is 30kHz. Sweep period is 0.652s. SNR is set as 30dB.

Figure 1 is the plot ,the power of the echo signal is related with the distance, through the mixer after the filtering process, the horizontal axis is the distance, the vertical axis is the normalized power. There is a peak at the point of 12 kilometers, which is consistent with the preset target position and verify the effectiveness of the method. Figure 2 the resulting simulation when the chirp rate increases to 3.66e +07.It is seen in the same distance range that the pulse is narrower and sharper.

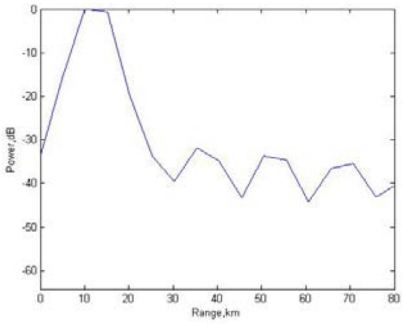

Fig.1 Waveform Output of echo including simulated target, k= 3.66e+05

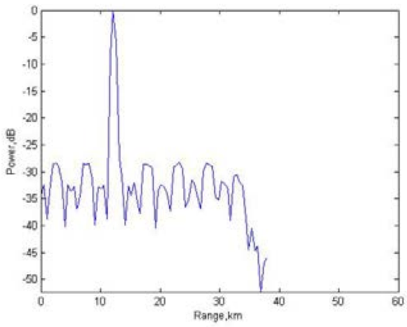

Fig.2. Waveform Output of echo including simulated target, k= 3.66e+07

To extract rate, repeated sampling for several times, the second Fourier transform matrix is constructed and a second FFT transformation is carried on. The radial doppler velocity v can be calculated through the peak frequency $f_d = \frac{2f_0}{c} v = \frac{2v}{\lambda_0}$ and then reversed by moving target velocity.

4.Actual echo data analysis

The actual received echo data analysis and simulation studies were compared. Experiments is carried on during April 2012, located in some harbor of the East China Sea. Based on the above simulation results, the radar waveform parameters are initialized as: Operating frequency 11MHz, pulse width is 1.6ms, transmitting time is 3.2ms, sweep period is 0.6s, the transmitted signal bandwidth is 30kHz. Figure 3 is the output waveform during a time after matched filtering to the actual echo signal. The horizontal axis is distance and the vertical axis is the normalized signal power.

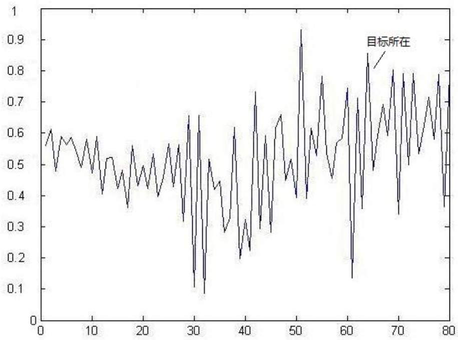

Fig.3. Waveform of the Output after matched filtering

Seen from Figure 3, a significant peak is showed at about 63.7km distance. To verify the validity of the method ,the ship-borne Automatic Identification System data are used to further validate the test results, as shown in Fig4 . The ship is indicated at 65.6km by using this AIS data, which compared with the simulated result the conclusion is obtained that the radar ranging error is 1.9km, error rate is about

3%.

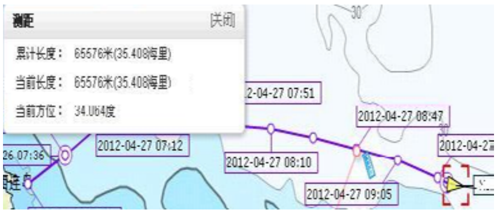

Fig 4. The AIS for target tracking

5.Conclusion

Based on the request of the small antenna arrays of HFSWR in target detection, it is mainly discussed that the FMICW waveform characteristics and the principles and methods of maritime target distance and speed information extraction. FMICW signal formula derivation is given. And simulation and the actual echo data analysis are used for extracting the distance and speed. The experiment results show that the waveform with designed parameters improve the waveform performance than the pulse modulation waveform with low transmission power, distance ambiguity. The work is an important part on the application of the HFSWR to improve detection performance after miniaturization of the antenna array.

6.Acknowledgment

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7.References

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