Performance Assessment of SFM Pulse in Reverberation Environment

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Abstract: In shallow water, the performance of the operating active sonar systems is usually limited by reverberation. One of the measure to overcome the negative effect of reverberation is of selecting an adequate transmission pulse. SFM(Sinusoidal Frequency Modulation) pulse has been received a considerable attention as a candidate for suppressing the reverberation effect. In this paper, we analyze the detection performance of SFM pulse with respect to modulation frequency and bandwidth. To conduct the analysis, we synthesize the signal at the receiver considering, the transmitter, the receiver, and the propagation medium characteristcs. The simulations provide the optimum modulation frequency and bandwidth under the given situation.

About Reverberation, Active Sonar, SFM pulse, Performance, Simulation

1. INTRODUCTION

In passive sonar the DOA(Direction of arrival) of target is estimated using the noise emanating from the target. As submarine noise is decreasing, recently target detection becomes difficult in passive sonar systems. Therefore, it is necessary to use active sonar such as HMS(Hull Mounted Sonar), VDS(Variable Depth Sonar), and Active TASS(Active Towed Array Sonar Systems) which detect a target by return signal. The detection performance in reverberation limited environment is affected by the several parameters such as transmission pulse shape, transmitter and receiver type, and medium condition.
However the processing gain against reverberation usually depends on the transmission pulse shape. So the new waveform such as Comb pulse has been received a considerable attention in reverberation limited environment instead of CW or LFM pulse. The SFM(Sinusoidal Frequency Modulation)pulse which is one of the Comb pulses could be used in active sonar systems for improving target signal to reverberation ratio in reverberation limited environments. It is necessary to analyze the performance of SFM pulse with respect to each parameter used in real active sonar systems. However the real experimentation is restricted by resources such as time, space, and so on. In this paper, the performances of SFM pulse is analyzed under several simulation environments. The real reverberation environments were considered in the simulator to analyze the performance of SFM pulse. Plus the parameters such as type of sensor, center frequency, pulse length, bandwidth, own ship velocity, and modulation frequency are also parameterized in the simulator. The receiving signal was synthesized considering environments such as sea states, water depth, and sound velocity profile and movements of the own ship and target. Through the repeated simulation, the modulation frequency and frequency bandwidth for the best detection can be decided under the given environment.

2. REVERBERATION LIMITED ENVIRONMENTS IN ACTIVE SONAR SYSTEMS

Reverberation is a phenomenon which is due to reflections of the transmitted acoustic signals from the ocean bottom, the sea surface, and within the ocean volume.
Fig. 1. gives an overview of space-frequency characteristic in reverberation limited environments when CW pulse is used. Due to platform motion, the received signals from the sea surface or the ocean bottom are Doppler shifted by a value which is proportional to the cosine of the angle θ between the platform velocity vector and the velocity vector of the individual scatterer. The Doppler band depends on parameters like beam direction, beam width, platform velocity, bandwidth of the transmitted pulse, and frequency. The Doppler shift for a stationary scatterer is approximately given by:

$$f_D = f_c(1 + \frac{2V}{c}\cos\theta) \qquad (1)$$

where V and c denote the magnitude of the platform velocity and the sound velocity, respectively. f_c is the transmitted center frequency[1].
In region A, part of the cross-spectrum between the replica and the reverberation signal falls in the mainlobe of the beam directivity pattern(mainlobe is considered between its first zeros). It means that the corresponding Doppler channels are associated to scatterers in the direction of the beam. These scatterers are rejected neither by the directivity function, nor by the Doppler filter. It is considered that performance in reverberation limited

conditions is very poor in this region.

In region B, the cross-spectrum between the replica and the reverberation signal falls in the sidelobe beampattern. There are two main contributions to the reverberation intensity. The first contribution comes from scatterers in the mainlobe of the beam pattern, but at different frequencies. These scatterers are rejected by the spectral analysis(or Doppler filter) and this contribution is usually negligible with respect to the other. The second contribution corresponds to scatterers at the same frequency of the target, but rejected by the sidelobes of the beampattern. To assess reverberation intensity associated to this contribution, the angular interval θ corresponding to the overlap between replica and reverberation spectra must be worked out. This interval corresponds to scatterers whose frequencies match the frequencies of the target Doppler channel. In this region, SFM pulse which is one of the Comb pulses is used for improving signal to reverberation ratio.

In region C, there are no scatterers at the frequency of the target Doppler channel. The CW pulse is used for target detection [2].

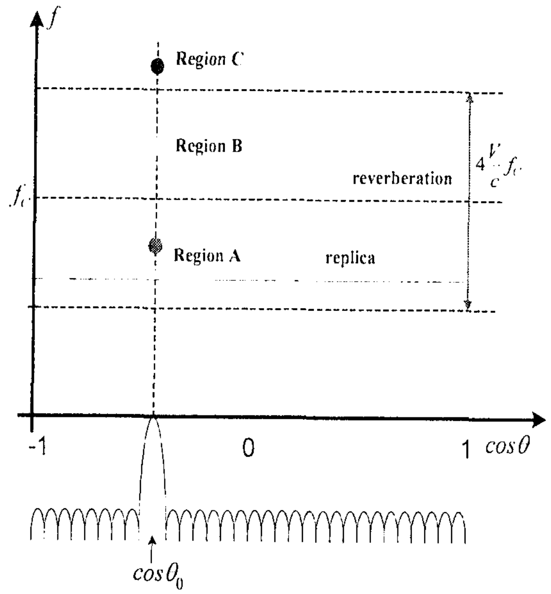

Fig. 1. Space-frequency characteristic in reverberation limited environments.

3. CHARACTERISTIC OF SFM PULSE

One of the most familiar types of comb-spectrum waveforms is a periodically frequency modulated sinusoid. The simplest case is a sinusoidal frequency modulation (SFM) where the modulating waveform itself is also a sinusoid

$$s(t) = w(t)\exp[2\pi f_c t + j\beta(2\pi f_m t)] \qquad (2)$$

$w(t)$ is the amplitude window of the pulse. f_c is the center frequency, f_m is the modulation frequency and β is the modulation index which defines the bandwidth of the pulse. Using Carson's rule the bandwidth can be approximated[3] as

$$B \cong 2f_m(1+\beta) \qquad (3$$

The power spectrum of a sinusoidal frequency modulated pulse will be a symmetrical comb, centered around f_c and with frequency spacing of f_m. The magnitudes of the peaks will not be uniform but it can be calculated using Bessel functions. By comparison with a CW pulse the energy in the pulse is now distributed to several peaks instead of all being concentrated in a single frequency. But the number of peak can not be continuously increased. The SFM pulse has a uniform amplitude envelope and has power spectra consisting of a series of uniformly spaced narrow peaks. The spacing of the peaks in the spectrum is a vital design parameter. If these are too close together, large Doppler ambiguities appear for adjacent 'teeth' in the comb to overlap. This situation is called blind-speed. If they are placed too far apart, on the other hand, the processing advantage over CW pulses is diminished as there are fewer peaks within the available bandwidth amongst which the energy of the train can be spread. If the total duration of the train is T seconds and it is split into $f_m \cdot T$ sub-pulses then the blind speed can be approximated as

$$V_B = k\frac{c \cdot f_m}{2f_c} \qquad (4)$$

with integer k reflects a signal with same frequencies as reverberation in target direction. c is the speed of sound and f_c is the center frequency of the pulse train. If V_B is set to be outside the range of velocities of interest, equation (4) can be used to calculate the minimum value of f_m allowable[4].

4. SIMULATION AND RESULTS

The received signal is synthesized by signal synthesizing model in Fig. 2. Next target velocity and range are estimated by signal processing model in Fig. 3.

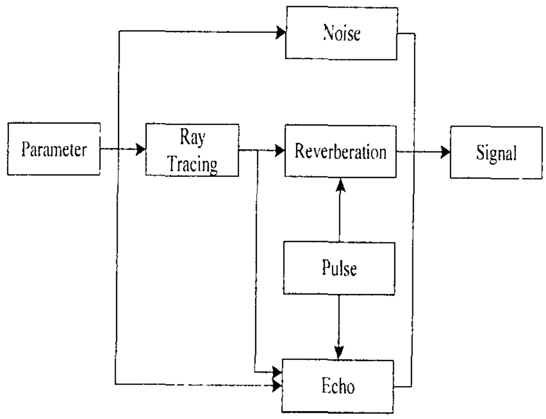

Fig. 2. Signal Synthesizing Model

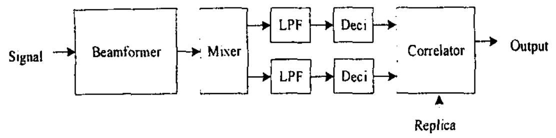

Fig. 3. Signal Processing Model

Simulations are conducted for variable modulation frequencies f_m and frequency bandwidths of SFM pulse in reverberation limited environment.

4.1. Establishment of simulation environments

Center frequency of SFM pulse : 7.5kHz
Pulse length : 1sec
Water depth : 100m
Sound Velocity Profile : bending downward refraction in shallow water.
Sea State : 3
Bottom State : rough send
Target Strength : 3dB
Target Velocity : -5knots (Submarine)
Target Depth : 50m
Target Direction : 90° (a broad side direction of array)
Own ship velocity : 7knots
Transmitter : Hull Mounted Sonar
Receiver : Towed Array Sonar Systems
Depth of Transmitter : 8m
Depth of Receiver : 50m

4.2. Performance assessment of SFM pulse according to f_m

We analyzed the detection performance of SFM pulse, changing the modulation frequency f_m , for several distances, between own ship and target, 0.8km, 1.0km, 1.2km, and 1.5km. Bandwidth of SFM pulse is set to 400Hz. As the modulation frequency f_m is increased, the number of frequency peak is decreased. In Fig. 4. the solid line presents echo to reverberation ratio with respect to modulation frequency f_m in SFM pulse and the dotted line represents echo to reverberation ratio in CW pulse. As the modulation frequency f_m is decreased up to 60 ~ 70Hz, the echo to reverberation ratio is increased because the energy in the pulse is now distributed to several peaks. The echo to reverberation ratio is decreased for f_m below 60 ~ 70Hz because of the blind speed. This frequency is Doppler frequency corresponding to the double own ship velocity.

4.3. Performance assessment of SFM pulse according to bandwidth

We also analyzed the detection performance of SFM pulse, changing the frequency bandwidth, for several distances between own ship and target, 0.8km, 1.0km, 1.2km, and 1.5km. The modulation frequency f_m is set to 60Hz. In Fig. 5. the solid line represents a echo to reverberation ratio with respect to frequency bandwidth of SFM pulse and the dotted line represents echo to reverberation ratio in CW pulse which has a same center frequency and pulse length. As the frequency bandwidth is increased the echo to reverberation ratio is increased.

5. CONCLUSION

This paper assessed the performance of SFM pulse in reverberation limited environment by simulations using synthesized signal. As a result, as the modulation frequency f_m of SFM pulse is decreasing up to Doppler frequency corresponding to the double own ship velocity and bandwidth of SFM pulse is increasing, the echo to reverberation ratio is increased. The result of simulations is helpful to be guide line in case of using SFM pulse for active sonar operating

References

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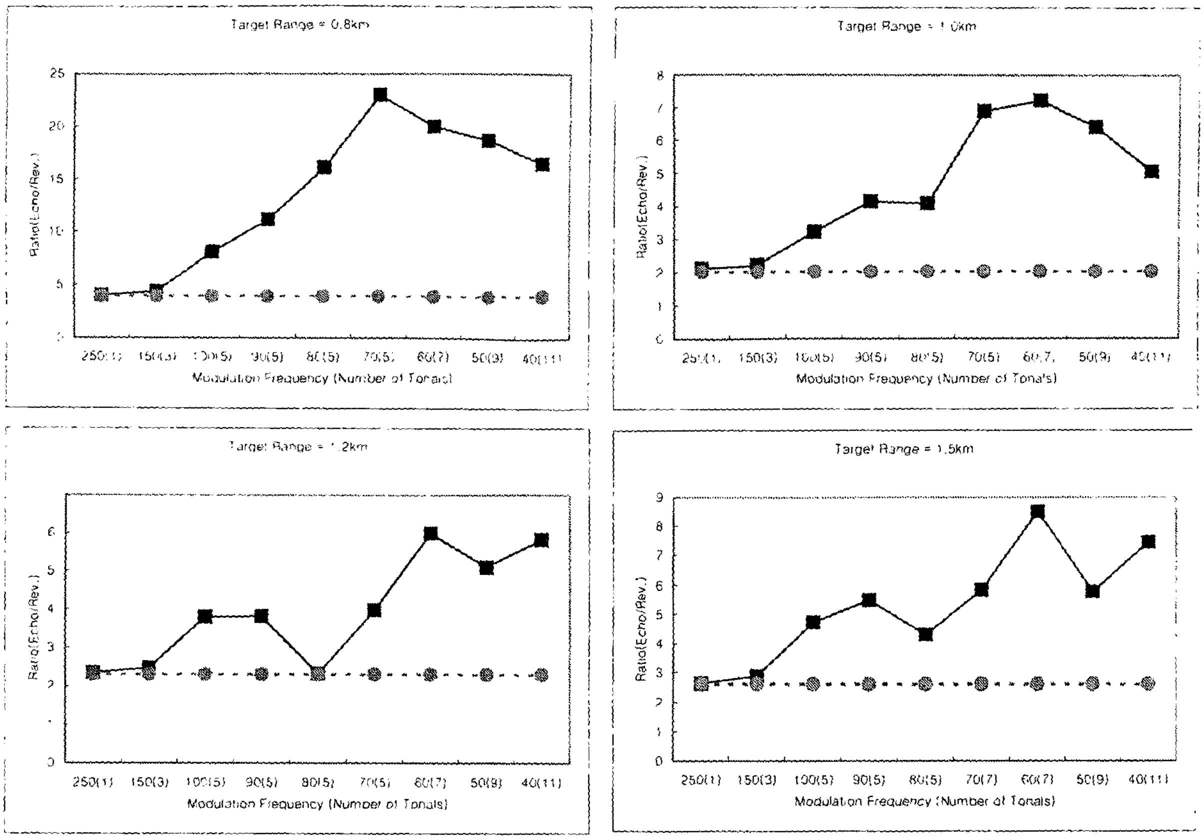

Fig. 4. Echo to Reverberation ratio vs f_m

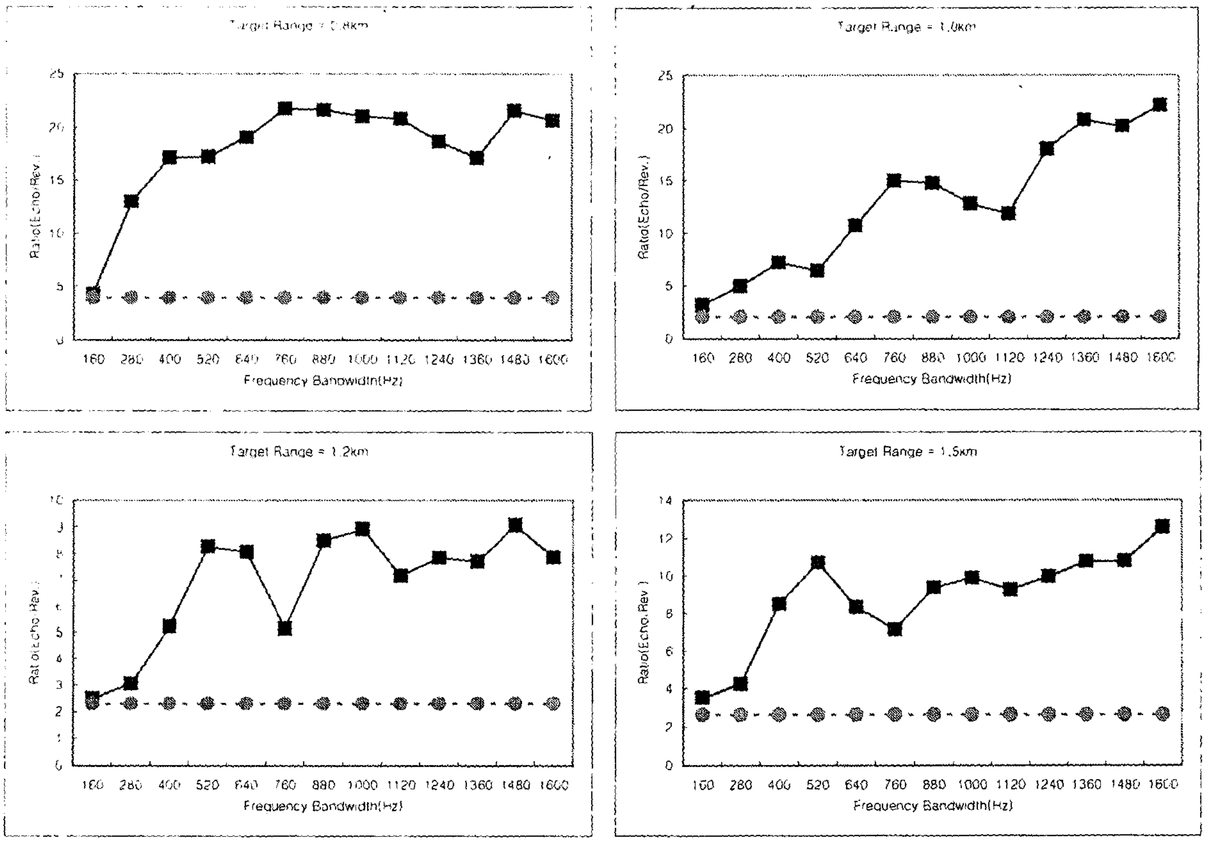

Fig. 5. Echo to Reverberation ratio vs Bandwidth