Advanced Sea Surface Target Detection System for Shipborne VHF Radar in Log Periodic Dipole Array Antenna

D. M. K. Chaitanya, G. Santhosh Kumar, D. KhalandarBasha

Abstract: ***While navigating in sea target detection is an important problem in modern era communication. In the ocean to detect moving targets and to analyze active variables such as wind, waves and current we can make use of Very High Frequency Ground Wave Radar (VHFGWR). In shipborne VHFGWR the brag spectra widened by Doppler Effect of the ship motion, due to this vessel echo easily merged.An orthogonal projection method to suppress the extended Brag spectra using a log periodic dipole array is proposed in this paper. The advanced technique majorly covers two stages: 1) by utilizing sea echo parameters calculate the approximation of sea clutter in spatial domain and 2) design multi frequency classification Doppler bins method to suppress the extended Brag spectra. After echo suppression, for target detection we can use different algorithms. Simulation result gives a proof that signal- to- clutter noise ratio (SCR) is developed and sea clutter got removed. This method gives very good target detection for shipborne VHF radar.***

Keywords: Very high frequency ground wave radar (VHFGWR), Signal-to-clutter ratio (SCR), log periodic dipole antenna.

I. INTRODUCTION

Currents in the ocean are much like wind in the air carrying objects from one place to another.In coastal waters, knowing the speed and direction of coastal ocean currents [2]-[4] is essential to critical operations such as search and rescue and responding to hazardous spills as well as ongoing applications such as coastal research and management.Operations such as these require data 24/7, 365 days a year. Traditionally, sensors on offshore moorings have been the standard for measuring surface currents. In the last decade, Very high-frequency radar known as "VHF radar [1]" has been increasingly used to complement these single point measurements with detailed maps of ocean surface currents. While satellites can provide large-scale ocean circulation patterns, they cannot directly measure currents near the coastline nor can they provide the near-real-time 24/7 data needed for many applications.Two Very high-frequency radar sites [5] can map the current flowing over hundreds of square miles of coastal waters every hour.Additional sites extend the area even further.

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VHFGWR Radar is mounted on the ship in two categories shore-based and shipborne.Shipborne VHFGWR is quite effective in target detection and ocean object detection.

Compared with cross loop array log periodic dipole array [6] have less aperture which is best suitable for deployment on board.

Due to Doppler Effect in ship motion the first order Bragg spectra is broadened due to this the target detection became difficult. With the increase demand in target detection, sea clutter estimation in spatial domain method has become more popular. An improved Subspace based approach, optimal design of sea clutter canceller and Compound Gaussian clutter suppression model used to suppress sea clutter [7]. However, these methods obtained the direction of beamforming rather than multiple frequency classification algorithms. For small aperture like Log Periodic Dipole (LPD) the target estimation become more typical.

In this paper we propose an advanced sea surface target detection system for VHFGWR based Log Periodic Dipole (LPD) array (including two LPDs).Frequency classification algorithm[8] canbe used to calculate the approximation of clutter suppressed [9] data so that we can make better direction of arrival (DOA) efficiency and accuracy for LPD array Antenna.

This article is explained given below. In Section II we describe the features of sea clutter and targets in detail, while Section III develops sea clutter suppression method. In Section IV we present simulation results, where Section V gives conclusions and future scope.

II. FEATURES OF SEA CLUTTER AND TARGETS

The basic feature or observation from sea surface can be categorized in to three parts for 'large scale structure' i.e.
1. Superimposing ripple 2. Foam 3. Splashing spray. Where for small scale structure splashing ripple and spray are considered. On sea surface different types of swell and wind waves will generate, this may lead to irregular pattern of sea surface.
When VHF radar [9] operating in X- band, the sea clutter data can be analyzed as the current emits from different directions in form of wind and air. This emits pulses in radial direction; sea clutter is recorded in time domain and frequency domain, which are shown in fig 1 and fig 2 respectively.

III. SEA CLUTTER SUPPRESSION METHOD

Shipborne VHF radar systems with two LPD array antennas are studied here.

The two LPD array with VHF radar is shown in fig 3.
The steering vector for two LPD array antenna is given by,

$$a(\theta)=[1,\cos\theta,\sin\theta,e^{i2\pi\frac{r}{\lambda}\sin\theta},\times e^{i2\pi\frac{r}{\lambda}\sin\theta}.\cos(\theta+90),\times e^{i2\pi\frac{r}{\lambda}\sin\theta}.\sin(\theta+90)] \text{ ------- } (1)$$

Where the distance between two LPD array is r, *where* $r \geq \frac{\lambda}{2}$

Where λ=wavelength of the VHF radar
θ=incident angle.

The normalized LPD in Doppler domain for some distance is given by,

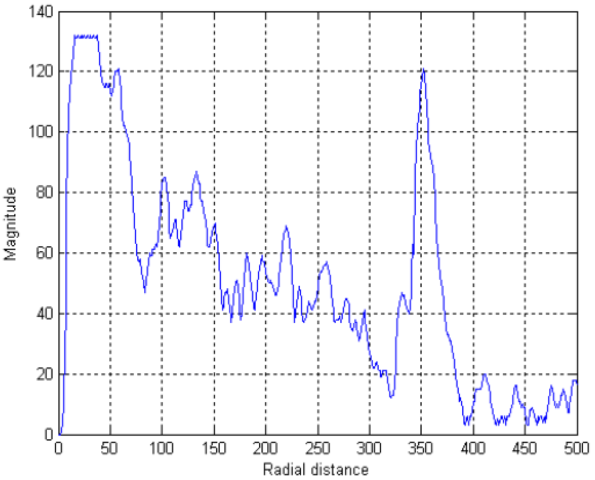


Fig1: Amplitude data of sea clutter

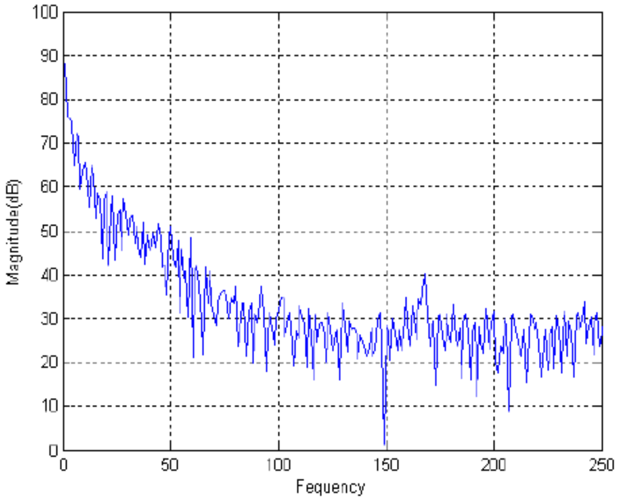


Fig 2: Frequency spectrum of sea clutter

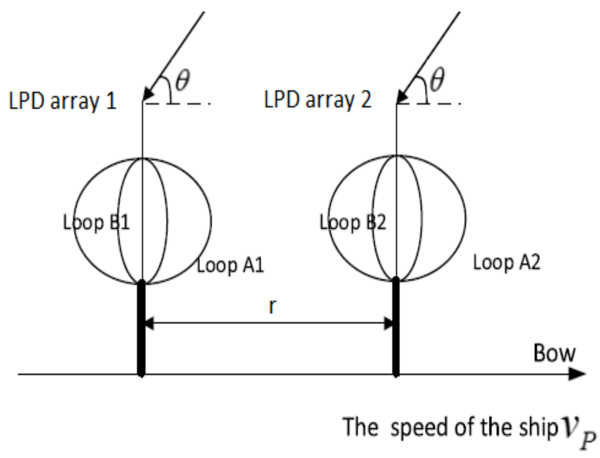


Fig 3: Two-element LPD array mounted on the ship.

$$X_d(f_t)=\sum_{i=1}^{m} a(\theta_{ci})s_{ci}+\sum_{j=1}^{n} a(\theta_{tj})s_{tj}+N--(2)$$

N – Noise vector (Rayleigh noise model used)
m - Sea clutters
n – Targets in a Doppler bin
d – d^{th} element distance.
f_t – Doppler bin frequency
θ_{ci} and $\theta_{sj}$are the direction of arrival of the i^{th} sea clutter, j^{th} target.
a(θ) – steering vector.
S_{ci}, S_{tj} are the complex amplitudes.

Doppler bin for first LPD array is given by

$$X_1(f_t)=D_c+D_t+N \;---(3)$$

where, $D_c[D_c=a(\theta_c)S_c]$ vector of the sea clutter
$D_t[D_t=a(\theta_t)S_t]$ vector of the target.

For the second LPD array signal is given by

$$X_2(f_t)=D_1S_c+D_2S_t+N---(4)$$

where,
$D_1=\exp[j2\pi\frac{r}{\lambda}.\sin\theta_c]$ is phase difference between two subarrays of the sea clutter
$D_2=\exp[j2\pi\frac{r}{\lambda}.\sin\theta_t]$ is phase difference between two subarrays of the target.
These are defined from steering vector of LPD arrays.

The output after the first LPD is given by,

$$\dot{s}_{s1}=D_t-P_cD_t+S_c-\dot{S}_c+N^l---(5)$$

N^1 – Noise matrix after projection
P_c–projection matrix after sea clutter

After passing through second LPD is given by,

$$\dot{s}_{s2}=D_2(D_t-P_cD_t)+D_1(S_c-\dot{S}_c)+N^l---(6)$$

Considering the ideal case, estimated sea clutter is same as sea clutter so that we can write$S_c=\dot{S}_c$. The clutter will be eliminated after passing through projection.
To get $\dot{S}_c$, the sea clutter distribution of the broadened first order spectra in a spatial domain is used. The distribution can be defined by,

$$f_d=\pm f_B+\frac{2v_p}{\lambda}\cos\theta---(7)$$

where f_d – Doppler frequency
f_B – Bragg frequency
θ -- Incident Direction
V_p – Speed of the ship
For sea cluster estimation the Doppler bin configuration in shown in figure 4. The four protection bins that are close to the detection bins in direction of arrival are designated to deal with the spectrum leakage. The maximum likelihood matrix of the sea clutter covariance R can be expressed as

$$R = \frac{1}{L}\sum_{m=1}^{L} X_{1,m}\, X_{1,m}^{\pi} \; --- \; (8)$$

Where, $X_{1,m}$ is the m^{th} reference vector bin of the first LPD array and L is the number of reference bins.

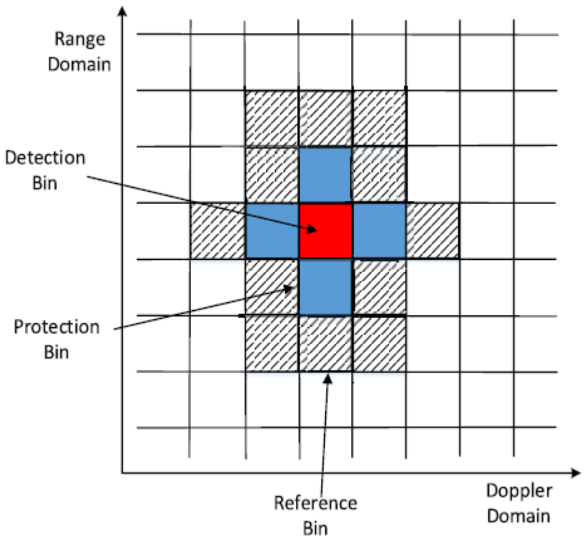


Fig 4: Estimation of sea clutter Blue block: protection bin Gray block: reference bins used to estimate the sea clutter. Red block: Detection bin.

For better suppression efficiency and performance, many Doppler frequency bins can be used to build the orthogonal projection matrix. This is best suitable method for LPD array antenna. If the multiple Doppler bins are applied, then the vector bin is given by,

$$X_R = [X_r(f_{t-1})X_r(f_t)X_r(f_{t+1})]^T \; --- \; (9)$$

where,

f_{t-1} – with reference to detection bin left sided Doppler bin
f_{t+1} – with reference to detection bin right sided Doppler bin
f_t – reference detection bin

The sea clutter is suppressed. However, the direction of arrival of the target and the sea clutter are closer. But, after suppression the output signal will become weaker. To develop Signal- to- clutter ratio (SCR), multi frequency classification algorithm will be used.

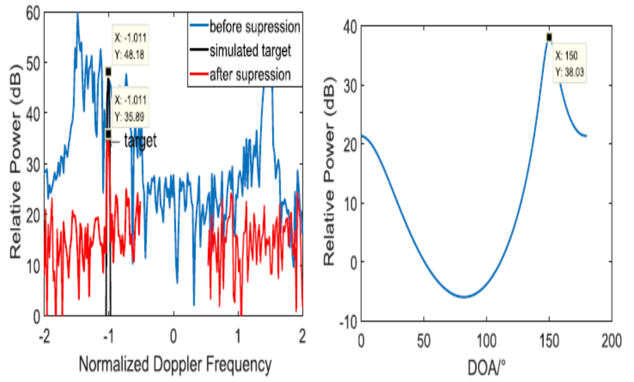
IV. SIMULATION RESULTS

Sea clutter suppression method explained clearly in previous section III. Now in these section simulations of sea clutter suppression method will be studied with the help of attenuation function i.e. S_t-P_cS_t has to reduce.

For simulation model, the simulation parameters are considered as follows,

→Antenna – two LPD array antennas
→Radar bandwidth – 80 kHz at 13 MHz
→Doppler frequency – 0.00027 Hz
→Incident angle ranges from 0^0 to 180^0
→Distance between two LPD's – 18m
→Velocity of the ship – 2m/s
→The target is set at the 9^{th} range bin with Doppler frequency of -1.

The simulation results of the LPD arrays sea clutter method is shown in figure 5. At Doppler frequency the direction of arrival (DOA) for simulated target and sea clutter are 160^0 and 100^0, respectively.

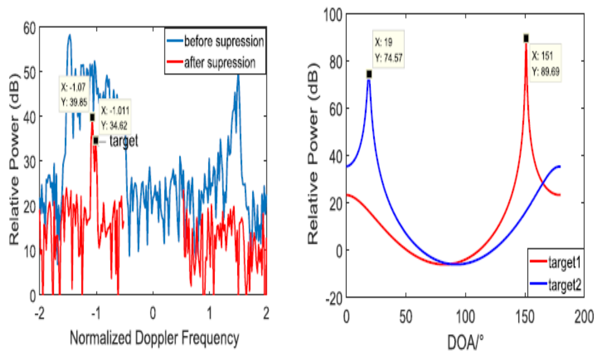


(a) (b)

Fig 5: Simulations of sea clutter suppression. The direction of arrival is 1600 and Doppler frequency -1. (a) Comparison of Doppler spectra before and after suppression. (b) Multi frequency classification algorithm spectrum after suppression.

In figure 5(a), it is obvious that the detection of the target is highly improved, where sea clutter is suppressed and noise removed. Due to attenuation i.e. S_t-P_cS_t the signal to clutter ratio (SCR) is 13.2 dB, but after suppression of clutter SCR greatly improved to 18dB. The direction of arrival(DOA) estimation is given in fig 5(b), which means it is effective to use the phase difference of the two LPD's to estimate DOA of the target.

Figure 6 shows, are two there are two targets added into echo. The direction of arrival (DOA) is 150^0 and normalized Doppler frequency -1, and another one 20^0 and -1.07 respectively and SCR id 0dB.



(a) (b)

Fig 6: (a) Simulation results for Doppler spectra comparison. (b) Multi frequency classificationazimuth angle of 1500 and 200 after removing the clutter.

V. CONCLUSION

In this paper, we conducted an experimental study to suppress clutter of VHFGWRradar with LPD array antennas. The detection of target can be achieved more effectively. Hence, simulation results show that this is the best method to find surface target detection with the improved signal to clutter noise ratio. Multiple LPD array have better clutter suppression performance and efficiency in practically.

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