Modeling and Characteristics Analysis of Clutter for Passive Radar on Moving Platform

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Abstract

In the latest years, the investigation of passive radar on moving platform (PRMP) for surveillance purpose has received a new interest. The problem of direct path interference and ground (sea) clutter is encountered in PRMP. This paper studies the modeling and characteristics of the clutter in PRMP which employs digital radio and television illuminators based on Single Frequency Network (SFN) configuration. The clutter model of PRMP is established firstly, and then the space-time characteristics are elaborately analyzed. The experiment performed with the newly-developed multi-channel passive radar system validates the correctness of the proposed model. The study provides the underlying theory for clutter suppression and target detection in PRMP.

1. Introduction

Passive radar systems present a novel approach for target detection, localisation and tracking. They use the illumination by third-party transmitters. The passive radar is resistivity against stealth targets because of the bistatic/multistatic system architecture and the low frequency bands of the illuminator signal. Passive radar doesn't need to transmit signals by itself, so the system is greatly simplified and the cost is reduced. It may be also undetectable by electronic warfare systems because of the silence feature [1-3]. In recent years, many kinds of illuminators have been explored in passive radar, such as FM radio, DVB-T, GSM, GPS or WiFi. China has also presented its independent intellectual proprietary digital terrestrial TV standard called China Mobile Multimedia Broadcasting (CMMB), which provides a new opportunity for passive radar study in China.

From the open literature, the passive systems studied are most ground-based static systems such as Silent Sentry (USA), CELLDAR (UK) and Homeland Alerter (France) systems. Besides the advantages mentioned above, there will be many additional benefits if the passive receiver is mounted on moving platforms like aircrafts, balloons, warships, vehicles and even satellites. For example, the mobility of PRMP is greatly improved comparing with that of the ground-based static systems. Moreover, it is more favorable for wave propagation if the receiver is equipped on aircraft because of the increased elevation which implies a reduction of the terrain masking effect.

Research work on PRMP is still at an early exploration stage from the published literature. A series of related papers from Warsaw University of Technology [4], Nanyang Technological University [5] and University College London [6] present the associated work that had been conducted, suggesting that passive radar on a moving platform is indeed a novel and feasibility concept. To the best of the authors' knowledge, the research on PRMP based on CMMB has not been discussed. The research on clutter of PRMP is the foundation of all kinds of clutter suppression technologies, playing an important role in target detection, localisation and tracking. The paper describes the study on clutter characteristics of PRMP based on CMMB and the latest progress of experiments conducted by the radio propagation laboratory in Wuhan University. A simple sketch is represented in Fig.1 and the geometry of it is represented in fig.2.

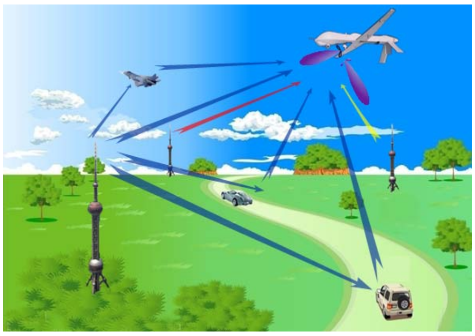

Fig.1. A sketch of passive radar on UAV

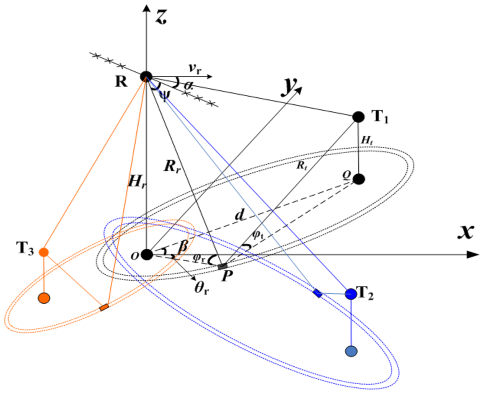

Fig.2. The geometry of PRMP based on SFN

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2. The Geometry of PRMP and Characteristics Analysis of Clutter

The new generation of digital broadcast usually operates in a single-frequency network, where identical waveforms are transmitted from multiple illuminators. Three illuminators are illustrated in this paper. The geometry of PRMP is shown in Fig.2. T_1, T_2, T_3 represents the transmitter station respectively. Without loss of generality, T_1 is described only. The receiver is at point R at height H_r above the x-y ground plane, and the transmitter is at the point T_1 at the height H_t. The receiver moves along the x axis at speed v_r. ∂ is the yaw angle, and d is the distance from origin o to the projection Q of transmitter on the ground. The transmitter signal hits the ground at a stationary point P after passing the transmit slant range R_t and the reflected signal is collected by the receiver after passing the receiver slant range R_r. The sum of two slant ranges represents the bistatic range sum R_{sum}. The angle ψ is cone angle measured with the clutter scattering point to the moving direction of radar platform. The angle θ_r is azimuth angle of the scattering point P measured with respect to the bistatic baseline, and the angle φ_r is elevation angle denoted by the angle between the slant range and the ground surface. β represents bistatic location parameter.

According to the triangle cosine theorem and the geometry illustrated in Fig.2, The relationships of different parameters can be expressed as:

$$R_r = \frac{-R_{sum}B + \cos(\theta_r - \beta)\, d\left(B^2 - R_{sum}{}^2 H_r{}^2 + d^2 H_r{}^2 \cos^2(\theta_r - \beta)\right)^{1/2}}{R_{sum}{}^2 - d^2 \cos^2(\theta_r - \beta)} \tag{1}$$

$$B = \left(H_t^2 - H_r^2 + d^2 - R_{sum}{}^2\right)/2 \tag{2}$$

The Doppler and cone angle of clutter patch on the same ellipse can be expressed as:

$$f_p = \frac{v_r}{\lambda}\cos\theta_r \cos\varphi_r = \frac{v_r}{\lambda}\cos\theta_r \left(1 - \frac{H_r{}^2}{R_r{}^2}\right)^{1/2} \tag{3}$$

$$\cos\psi = \cos(\theta_r - \partial)\cos\varphi_r = \cos(\theta_r - \partial)\left(1 - \frac{H_r^2}{R_r^2}\right)^{1/2} \tag{4}$$

To normalize f_p, the formula 3 is converted to formula 5:

$$\frac{f_p}{f_r} = \frac{v_r}{\lambda f_r}\cos\theta_r \cos\varphi_r = \cos\psi\cos\partial - \sin\partial\sqrt{\cos^2\varphi_r - \cos^2\psi} \tag{5}$$

where $f_r = \frac{v_r}{\lambda}$. In the same way, the Doppler and cone angle of direct wave can be expressed as:

$$f_D = \frac{v_r d}{\lambda}\cos\beta / \sqrt{(H_t - H_r)^2 + d^2} \tag{6}$$

$$\frac{f_D}{f_r} = \frac{v_r d}{\lambda f_r}\cos\beta / \sqrt{(H_t - H_r)^2 + d^2} = d\cos\beta / \sqrt{(H_t - H_r)^2 + d^2} \tag{7}$$

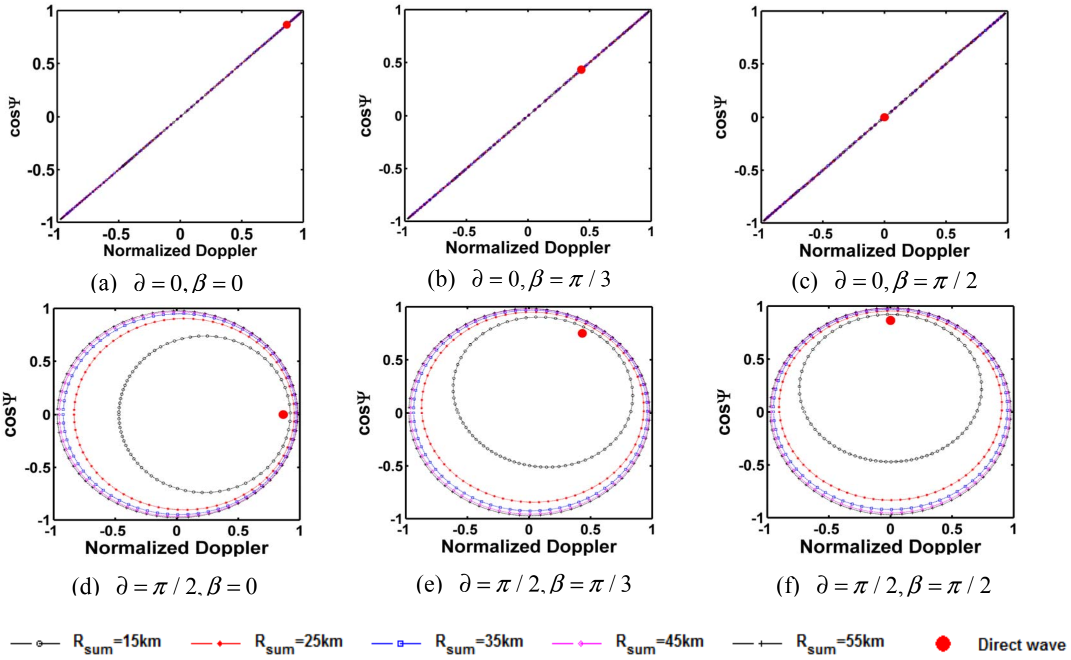
$$\cos\psi_D = \cos(\beta - \alpha)d / \sqrt{(H_t - H_r)^2 + d^2} \tag{8}$$

3. The Simulation of Clutter Space-Time Relationship

The clutter space-time relationship is simulated according to the math deduction above. Suppose that the receiving antenna is an 8-element uniform linear array (ULA). The Receiver element pattern is omnidirectional. The main simulation parameters are shown in Table I.

Table I The main parameters of the simulation

parameter	value
H_t	221 m
H_r	6000 m
v_r	146 m/s
θ_r	$[0:\pi/179:2\pi]$
∂	0, $\pi/2$
β	0, $\pi/3$, $\pi/2$



(a) $\partial = 0, \beta = 0$ (b) $\partial = 0, \beta = \pi/3$ (c) $\partial = 0, \beta = \pi/2$

(d) $\partial = \pi/2, \beta = 0$ (e) $\partial = \pi/2, \beta = \pi/3$ (f) $\partial = \pi/2, \beta = \pi/2$

Fig.3. The angle-Doppler trajectories of different stations and yaw angles

When $\alpha = 0$, the angle-Doppler trajectory is linear, the slope of which is 1. And all the trajectories are coincident from different ranges by comparing Fig.3 (a) (b) (c). This shows the range independence or homogeneous characteristic of clutter spectrum when the ULA is side-looking. The characteristic is unaltered when $\cos\Psi$ is different. So we can conclude that it is homogeneous when the PRMP works on the side-looking mode in the SFN and the covariance matrix of undertest gate can be calculated by averaging its surrounding gates. When $\partial = \pi/2$, the angle-Doppler trajectory is circular and the trajectories are not coincident from different ranges by comparing Fig.3 (d) (e) (f). It means that the clutter spectrum is heterogeneous, i.e. statistical characteristic of the data varies with range gates at a given Doppler gate. Averaging covariance matrices of secondary range gates will lead to an undesirable estimation of range gates under test. The characteristic is altered when β is different. So we can conclude that it is heterogeneous when the PRMP works on the forward-looking mode in the SFN.

4. Experiment of Passive Radar on the Moving Platform

A UHF passive radar system is developed by the radio propagation laboratory in Wuhan University. A series of experiments about passive detection on moving platform were carried out. A great quantity of measured data was obtained. This system consists of 8 receiving channels. The working mode can be configured according to side-looking/forward-looking detection. The system block diagram is described in Fig. 4. The receiving system was mounted on a lorry shown in Fig. 5.

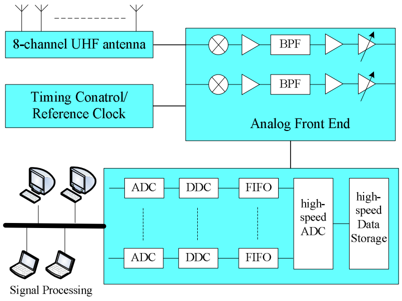
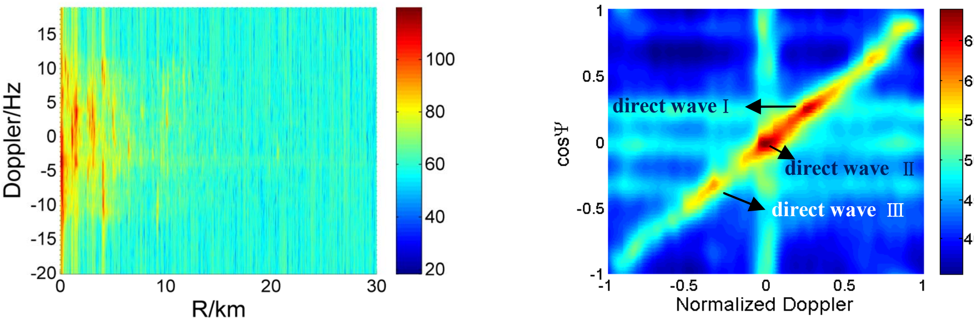


Fig. 4. System block diagram

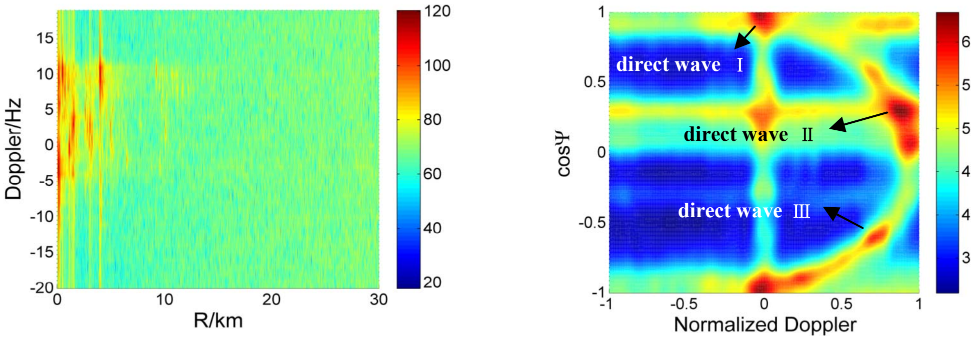
Fig. 5. Photograph of the experiment scene

Fig.6 and Fig.7 depict the processing results when the ULA is side-looking and forward-looking respectively. Because of the moving of the receiving platform, the Doppler is obviously spread as showed in Fig.6 (a) and Fig.7 (a). Fig.6 (b) and Fig.7 (b) show the space-time power spectrum of the clutter scenario. As we can see in Fig.6 (b), the space-time power presents a straight line, the slope of which is 1. Three Doppler ridges can be seen obviously as marked in the figure, causing by the direct wave interference from three stations nearby in the SFN. Fig.7 (b) shows that the space-time power presents a semicircle (The gain of the ULA backlobe is low). And likewise, three Doppler ridges can been seen obviously as marked in it. The results are consistent with the simulation and analysis in part 3, proving the validity of the clutter model.



(a) range-Doppler spectrum of channel 1 (b) space-time power spectrum of clutter

Fig.6. side-looking configuration



(a) range-Doppler spectrum of channel 1 (b) space-time power spectrum of clutter

Fig.7. forward-looking configuration

5. Conclusion

In this paper, a clutter model for passive radar on moving platform is established. The characteristics of the clutter are analysised in detail. The experiment about passive detection on moving platform was carried out. The processing results of the measured data prove the validity of the clutter model, which lays the groundwork for clutter suppression and further research on PRMP.

6. Acknowledgments

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