A High Resolution Radar Range Profile Simulator for Low Flying Target above Sea Surface with Multipath Effect

P. Peng* (1)(2), L. X. Guo (1), C. M. Tong(2) and B. Chen(2)
(1) School of Physics Optoelectronic Engineering, Xidian University, Xi'an, 710071, China
(2) Air and Missile Defense College, Air Force Engineering University, Xi'an, 710051, China
Email: pengpengxidian@163.com

***Abstract*—To theoretically evaluate multipath effect on radar characteristics of low flying target. This letter presents an applicable method in description of multipath coupling between target and ocean surface. It illustrates a composite scale scattering description over physically modelled ocean surface. Then it introduces a facet-based imaging thought in coupling consideration. The method is well suitable in application of the multipath evaluation in electrically large scale scenes and has the advantage to reflect both specular and diffuse scattering effects over complex surface profile. The HRRP simulation results are also presented and discussed, which show multipath effect clearly.**

Keywords—component; formatting; style; styling; insert (key words)

I. INTRODUCTION

Great attentions are paid on ocean securities nowadays. In radar detection of low flying targets above the ocean surface, problems such as range measurement errors and angle tracking errors are often encountered. The source of these errors is regarded to come from the coupling electromagnetic interactions between the low flying target and ocean surface, which is referred to as multipath [1]. Since real data is often inconvenient to obtain, a reliable theoretical model to evaluate multipath and its influence on radar returns is of crucial importance. The available empirical model treats underlying environment as infinite plane modified with roughness factors [2], while it cannot actually reflect the properties of multipath over environments with complex surface structures, which is often encountered in the real scene. This letter has proposed a novel imaging thoughts upon physically modelled ocean surface with composite scale surface profile descriptions. The following HRRP simulator can clearly reflect multipath effect.

II. THEORETICAL MODEL AND FORMULATIONS

A. Facet-based ocean surface scattering descriptions

Ocean surface profile is a time-varying spatially random function. At a given moment, it has a deterministic realization with composite structures. As in Double Superimposition Model (DSM) [3], it can be decomposed in large scale facet structure with small ripples. The Bragg scattering field from each facet can be obtained by Fuks' model, with a feasible approximation that the Bragg wave is a single frequency sinusoidal wave to simplify the computation as shown in Fig.1, and the polarization factor is modulated by the gravity wave. We assume the sinusoidal wave is expressed by $\xi = 0.015\cos(2\pi x_g / \Lambda)$, where $\Lambda = \lambda / (2\sin\theta_i)$ is the spatial wavelength satisfying the Bragg resonance. The facet scattering field can be expressed as:

$$\vec{E}_{pq}^{facet}(\hat{k}_i, \hat{k}_s) = 2\pi \frac{\exp(ikR)}{iR} S_{pq}(\hat{k}_i, \hat{k}_s) \tag{1}$$

$$S_{pq}(\hat{k}_i, \hat{k}_s) = \frac{k^2(1-\varepsilon)}{8\pi^2} F_{pq} \iint \xi(\vec{r}) \exp(-i\vec{q} \cdot \vec{r}) d\vec{r} \tag{2}$$

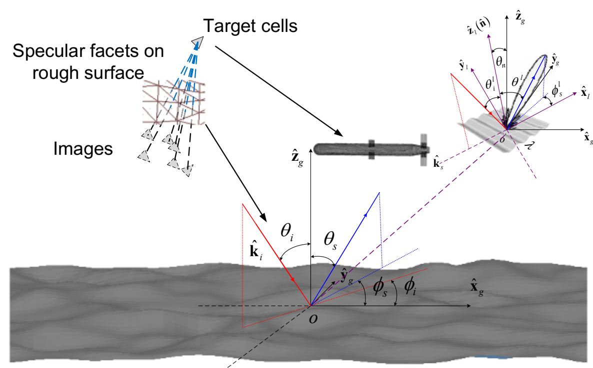


Fig. 1 *Low flying target above ocean surface with Two-scale profile*

B. Coupling mechanisms consideration

In high frequency approximations, EM scattering from target is evaluated by induced currents on meshed planar triangular cells independently, whose form is given by.

$$\boldsymbol{J}_s(\boldsymbol{r}') = 2\delta(\theta^i, \theta^s)\boldsymbol{n} \times \boldsymbol{H}_i(\boldsymbol{r}') \tag{3}$$

$\delta(\theta^i, \theta^s)$ is the shadowing judgement function, $\boldsymbol{H}_i(\boldsymbol{r}')$ is the incident magnetic field upon illuminated facets. In Facet-based coupling considerations, each target cell would have their corresponding image profile against localized mirror-liked facets of ocean surface, as illustrated in Fig. 1. Induced currents include two parts since incident wave would also have images and induce currents on target which is denoted as $\boldsymbol{J}_s'(\boldsymbol{r}')$. It can be expressed as

$$\boldsymbol{J}_s'(\boldsymbol{r}') = 2\delta(\theta^i, \theta^s)\boldsymbol{n} \times \boldsymbol{H}_{iimage}(\boldsymbol{r}') \tag{4}$$

$\boldsymbol{J}_s(\boldsymbol{r}')$ and $\boldsymbol{J}_s'(\boldsymbol{r}')$ have images $\boldsymbol{J}_s(\boldsymbol{r}'_{image})$ and $\boldsymbol{J}_s'(\boldsymbol{r}'_{image})$ at their corresponding image profile locations. Besides, both image incident wave and currents values need to be multiplied by a modification factor to involve the localized ocean surface scattering effect, as given by

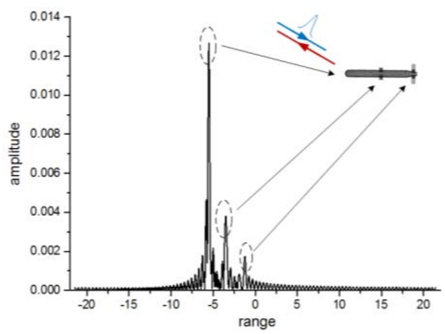
$$\rho = S_{pq}(\hat{k}_i, \hat{k}_s)\frac{e^{ikR}}{R} \tag{5}$$

The final scattering field can be obtained by

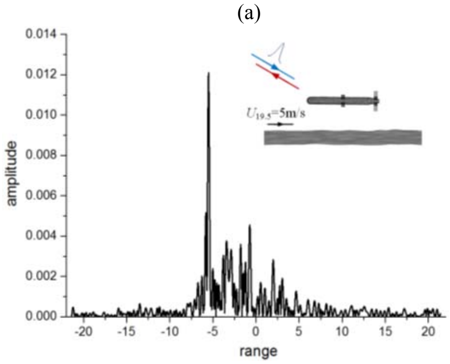
$$\boldsymbol{E}_s = i\omega\mu\int_V \bar{\bar{\boldsymbol{G}}}(\boldsymbol{r},\boldsymbol{r}')(\boldsymbol{J}_s(\boldsymbol{r}') + \boldsymbol{J}_s'(\boldsymbol{r}') + \boldsymbol{J}_s'(\boldsymbol{r}'_{image}) + \boldsymbol{J}_s(\boldsymbol{r}'_{image})\,\mathrm{d}\boldsymbol{r}' \tag{6}$$

III. *HRRP SIMULATION RESULTS*

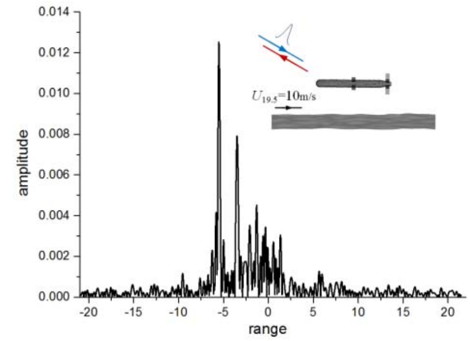
HRRP can distinguish scattering parts at different range distances from radar with corresponding return intensities. We employ the stepped frequency continuous wave (SFCW) with sufficient frequency bandwidth as incident signal, then the range profile can be characterized by (Inverse Fourier Transformation) IFT of the backward scattering field. Fig. 2 shows the simulated HRRP of a typical low-flying missile like target with full length of 5m, diameter of 0.527m, and wing span of 2.65m.



(a)



(b)



(c)

Fig. 2 *HRRP simulation* (*a*) target in free space.(*b*) target above ocean surface when wind speed at 19.5m is 5m/s. (*c*) target above ocean surface when wind speed at 19.5m is 10m/s.

In this simulation, radar is working at 14GHz (Ku band) with bandwidth of 350MHz. Radar incident angle is set as 45°. Strong scattering parts at head, wing and rear can be clearly identified in Fig. 2(a), which shows HRRP of the target in free space. Fig. 2(b) shows HRRP with multipath effect when the target is 5m high above ocean surface and $U_{19.5}$=5m/s. It can be seen that the returns from weaker scatterers have been covered. Fig. 2(c) shows HRRP when $U_{19.5}$=10m/s. Multipath is more severe in -5m-0m zone, but is lowered in other area.

IV. CONCLUSION

This paper presents a novel HRRP simulator to show radar multipath effects of low flying target above ocean surface. The simulator can help better understanding and evaluating multipath effect, which is important in radar detection of low flying target. The conclusion shows multipath is more severe for low level sea state level.

REFERENCES

[1] Berizzi, F., and Diani, M.: ‘Multipath effects on ISAR image reconstruction’, IEEE Trans. Aerosp. Electron. Syst., 1998, **34**, (2), pp. 645–653.

[2] G. Ogden,S. Matzner, L. M. Zurk,D. Blejer, ‘Multipath return for radar targets over a rough surface’ in IEEE Antennas and Propag. Society International Symposium, Honolulu, HI., June. 2007, pp. 4825 – 4828..

[3] S. J. Joung and J. Shelton, “3 Dimensional ocean wave model using directional wave spectra for limited capacity computers,” in *Proc. IEEE OCEANS ‘Ocean Technologies and Opportunities in the Pacific for the 90’s*, 1991, **1**, pp. 608–614..

[4] A. P. Wallenberger and D. R. Lyzenga, ‘Measurement of the surface tension of water using microwave backscatter from gravity-capillary waves,’ *IEEE Trans. Geosci. Remote Sens.*, 1990, **28**, (6), pp. 1012–1016.

[5] F. T. Ulaby, R. K. Moore, and A. K. Fung, Microwave Remote Sensing: Active and Passive, vol.II. Norwood, MA: Artech House, 1996.

[6] Y. I. M. Fuks, “Wave Diffraction by a Rough Boundary of an Arbitrary Plane-Layered Medium,” *IEEE Trans. Antennas Propaga.*, 2001, **49**, (4), pp. 630-639.

[7] H. Chen, M. Zhang, and H. C. Yin, “facet-based treatment on microwave bistatic scattering of three-dimensional sea surface with electrically large ship,” *Prog. Electromagn. Res. (PIER)*, 2012, **123**, pp. 385–405