STUDY ON BISTATIC SAR OCEAN WAVE IMAGING MECHANISM

Yu Ying, Wang Xiaoqing, Zhu Minhui, *Chong Jinsong**

National Key Lab of Microwave Imaging Technology, Institutes of Electronics,
Chinese Academy of Sciences, Beijing 100190, P.R.China
* presenting author   Email: yyxk720@sina.com; lily@mail.ie.ac.cn

1. INTRODUCTION

Since the SEASAT mission in 1978, monostatic SAR has been used for a variety of ocean applications. In recent years, with the fast development of phase and time synchronization technology, bistatic SAR has gained much more attention. Many researchers over the world have begun exploiting bistatic SAR systems and studied bistatic SAR imaging theory [1]. It is believed that bistatic SAR can offer extra ocean information because of its complex geometry. This paper focuses on bistatic SAR ocean wave imaging mechanism. The intensity expression in the bistatic SAR image plane is derived first. The expression describes the displacement of the scatter elements in the image plane and degradation in radar resolution in azimuthal direction. Then it concludes platform observation conditions under which bistatic SAR can map ocean waves linearly into SAR images. This observation condition can provide theory basis for ocean bistatic SAR system design. It also helps carry out bistatic SAR ocean applications, such as ocean wave spectrum retrieval and wave information analysis.

2. THEORY AND RESULTS

Ocean surface is a time-variant random rough surface. It has apparent movement in SAR integration time. In monostatic SAR case, the heaving of the short waves at the orbital velocities of the long waves results in the scattering elements being shifted in azimuth of the SAR image. Since this orbital velocity is a quasi-periodically varying quantity in space, the scattering elements shift in different directions, resulting in bunching at certain phases of the long wave and dilation at others. This produces a modulation of the image and is known as "velocity bunching" [2]. This also happens in bistatic SAR case. Now we consider the situation that transmitter and receiver platforms fly parallel to each other with the same platform velocity V, and suppose that the azimuthal antenna pattern is a Gaussian function. By using a least square fit to the phase history which includes the long wave orbital velocity, we derive the power density in the bistatic SAR image plane [3]:

$$\left\langle \left| e(x,x_0)\right|^2 \right\rangle = \frac{\pi}{2}T^2\sigma\frac{\rho_a}{\rho_a{}'}\exp\left[-\frac{\left(R_{tc}\sin\alpha_t - R_{rc}\sin\alpha_r\right)^2}{V^2T^2}\right]$$

$$\cdot\exp\left[-\frac{\pi^2}{\rho_a'^2}\left(x-x_0+\frac{\left(\cos^2\alpha_t\sin\alpha_t+\cos^2\alpha_r\sin\alpha_r\right)R_{tc}R_{rc}}{R_{rc}\cos^2\alpha_t+R_{tc}\cos^2\alpha_r}-\frac{2}{V}\frac{R_{tc}R_{rc}}{R_{rc}\cos^2\alpha_t+R_{tc}\cos^2\alpha_r}\bar{U}_r\right)^2\right] \tag{1}$$

$$\rho_a=\frac{\lambda}{VT\left(\dfrac{\cos^2\alpha_t}{R_{tc}}+\dfrac{\cos^2\alpha_r}{R_{rc}}\right)},\quad \rho_a{}'=\rho_a\left[1+\frac{\pi^2T^4\bar{A}_r^2}{\lambda^2}+\frac{T^2}{\tau_s^2}\right]^{1/2}$$

where ρ_a is the theoretical azimuthal resolution. $\rho_a{}'$ is the azimuthal resolution when long wave movement is considered. $\bar{U}_r$ is the slant range-directed component of the long waves orbital velocity. $\bar{A}_r$ is the corresponding acceleration component. τ_s is the radar coherence time. α_t and α_r are transmitter and receiver squint angle. R_{tc} and R_{rc} are slant range when the transmitter and receiver beam center crosses the target.

According to equation (1), we can see that long wave movement will cause degradation in bistatic SAR azimuthal resolution as monostatic SAR. And there is also a displacement of scattering elements in image plane:

$$x=x_0-\frac{\left(\cos^2\alpha_t\sin\alpha_t+\cos^2\alpha_r\sin\alpha_r\right)R_{tc}R_{rc}}{R_{rc}\cos^2\alpha_t+R_{tc}\cos^2\alpha_r}+\frac{2}{V}\frac{R_{tc}R_{rc}}{R_{rc}\cos^2\alpha_t+R_{tc}\cos^2\alpha_r}\bar{U}_r \tag{2}$$

We can also obtain a bistatic SAR linear imaging limit, under this condition ocean waves can be mapped linearly into SAR imagery [4]:

$$|C_{bist}| = \left|\frac{R_{tc}R_{rc}}{V\left(R_{rc}\cos^2\alpha_t + R_{tc}\cos^2\alpha_r\right)}|\mathbf{k}|\xi_0 w\cos\varphi\cdot g_{bist}\right| \le 0.3 \tag{3}$$

$$g_{bist} = \left[\left(\left(\sin\alpha_t + \sin\alpha_r\right)\cos\varphi + \left(\sqrt{\sin^2\theta_i - \sin^2\alpha_t} + \sqrt{\sin^2\theta_s - \sin^2\alpha_r}\right)\sin\varphi\right)^2 + \left(\cos\theta_i + \cos\theta_s\right)^2\right]^{1/2} \tag{4}$$

In order to analyze conveniently, we define a normalized $|C_{bist}|_{normal}$ as follow:

$$|C_{bist}|_{normal} = \left|\frac{\sqrt{m}}{\cos 40^\circ}\frac{\cos\varphi\cdot g_{bist}}{\left(R_{rc}/R_{tc}\cos^2 a_t + \cos^2 a_r\right)}\right| \tag{5}$$

where $R_{rc} = mR_{tc}$. $|C_{bist}|_{normal} = 1$, when $\theta_i = \theta_s = 40^\circ$, $R_{rc} = R_{tc}$, $\alpha_t = -\alpha_r = 0^\circ$, $\varphi = 0^\circ$ (defined as the angle between long wave and platform flight path). In order to detect waves in all directions, we have to make use of cross section modulation to image ocean waves that vertical to platform flight path, which velocity bunching can't detect. That is to say, Bragg wave direction should be as vertical to platform flight path as possible [5]. This requires $\alpha_t = -\alpha_r$. Based on this requirement, we give simulation results to deduce the observation parameters that make ocean waves imaging process become linear:

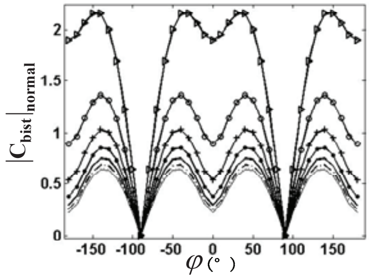

Figure.1

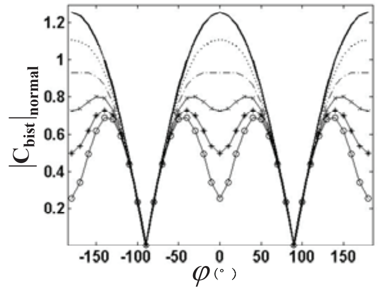

Figure.2

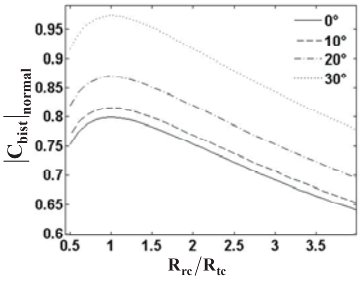

Figure.3

Fig.1. parameters: $\theta_i = \theta_s = 80^\circ$, $R_{rc}/R_{tc} = 1.5$, 8 lines from the bottom up are corresponding to $\alpha_t = -\alpha_r = 0^\circ - \pm 70^\circ$;

Fig.2. parameters: $\alpha_t = -\alpha_r = \pm 20^\circ$, $R_{rc}/R_{tc} = 1.5$, 6 lines from the top down are corresponding to $\theta_i = \theta_s = 30^\circ - 80^\circ$

Fig.3. parameters: $\theta_i = \theta_s = 45^\circ$, $\varphi = 45^\circ$, 4 lines from the bottom up are $\alpha_t = -\alpha_r = 0^\circ, 10^\circ, 20^\circ, 30^\circ$.

These figures show that under the same sea state, with larger θ_i (θ_s), smaller α_t (α_r), and larger difference between R_{tc} and R_{rc}, the linear imaging range of ocean waves by bistatic SAR will be broaden. So we can interpret easily the bistatic SAR imagery, and retrieve wave spectrum linearly.

3. ACKNOWLEDGMENT

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4. REFERENCES

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