SAR RAW SINGAL SIMULATION ACCOUNTING FOR ANTENNA ATTITUDE VARIATIONS

Tang Xiaoqing [1], Xiang Maosheng [1], Wei Lideng [1], Wu Yirong [1]*

[1]Institute of Electronics, Chinese Academy of Sciences，National Key Laboratory of Microwave Imaging Technology，No.19, BeiSiHuanXiLu, Beijing, P.R.China, 100190
[*]Email: xqtang18@163.com

1. INTRODUCTION

The antenna attitude variations exist in both the airborne SAR systems and the spaceborne ones. It may degrade the SAR imaging qualities, and will reduce the height accuracy of InSAR systems especially the repeat-pass ones. Therefore, it is necessary to set restriction of the antenna attitude variation in mission planning and to reduce its effects in postprocessing. An efficient SAR raw signal simulator able to deal with extended scenes in case of antenna attitude variations is very useful in mission planning, system design and algorithms verification. However, no existing simulation algorithm is suitable for such case. Time-domain simulation of extended scenes is enormously time consuming and therefore not practical, so efficient Fourier domain simulator in case of an ideal straight line sensor flight path was presented [1,2]. Later, an improved Fourier domain simulation scheme able to include the effects of trajectory deviation was presented [2], whereas the effects of antenna attitude variations are not taken into account.

In this paper, the 2-D Fourier domain simulator will be extended to include the effects of antenna attitude variations. The 2-D Fourier domain formulation of SAR raw signal is derived, which can be separated into the primary signal and paired echoes as long as the amplitude of attitude variation is limited in certain extend. Then the 2-D Fourier domain simulation scheme is presented and its validity limit is analyzed. Finally, the simulation results are presented to verify its effectiveness.

2. 2-D FOURIER DOMAIN FORMULATION OF SAR RAW SIGNAL

SAR raw signal is a convolution of the reflectivity map and the SAR system two-dimensional (2-D) pulse response. In order to evaluate raw signal efficiently via fast Fourier transfer(FFT) codes, its 2-D Fourier domain formulation must be evaluated. The antenna attitude variations may cause boresight shifts in both azimuth and range dimensions. Since the SAR raw signal is relatively insensitive to range shift due to the large antenna beamwidth in elevation [3], so we will focus on the azimuth shift. It is known that the antenna boresight shift leads to gain reduction, which appears as the amplitude modulation. The expression of raw signal differs from equation(5) of [2] only in the azimuth envelope, which turns into $W(\frac{x'-x-\delta_{az}\cdot r}{X})$ [3]. Since antenna boresight shift $\delta_x = r\cdot\delta_{az}(x')$ depends on the azimuth position of sensor and the range coordinate of target, the 2-D Fourier domain formulation can not be derived straightforward. When the attitude variation is small enough compared to the beamwidth, an approximation can be made as follows:

$$W\left(\frac{x'-x-\delta_x}{X}\right) \simeq W\left(\frac{x'-x}{X}\right) - W^{(1)}\left(\frac{x'-x}{X}\right)\cdot r\cdot\delta_{az}(x') + \frac{1}{2}W^{(2)}\left(\frac{x'-x}{X}\right)\cdot r\cdot\delta_{az}{}^{2}(x') \tag{1}$$

where $W^{(n)}$ denotes the nth order derivative of the two-way antenna radiation diagram. As to equation (1), SAR raw signal spectrum can be separated into 2 parts as: $H(\xi,\eta) = H_0(\xi,\eta) + H_1(\xi,\eta)$. $H_0(\xi,\eta) = \iint \gamma(x,r)\cdot G(\xi,\eta,r)\cdot W\left(\frac{\xi}{2\Omega_x}\right)\cdot dx\cdot dr$ [1] is the standard raw data spectrum in absence of attitude variation, which is known as the primary signal. $H_1(\xi,\eta)$ corresponds to the latter two items in (1), which is caused by the attitude variations and appears as paired echoes in the case of sinusoidal oscillation. $H_1(\xi,\eta) = \mathrm{FT}\left[\delta_{az}(x')\right]\otimes \bar{H}_1(\xi,\eta) + \mathrm{FT}\left[\delta_{az}{}^{2}(x')\right]\otimes \bar{H}_2(\xi,\eta)$ (2)

where , $\bar{H}_1(\xi,\eta) = \frac{Prf}{v}\cdot\iint r\cdot\gamma(x,r)\cdot G(\xi,\eta,r)\cdot\left[W\left(\frac{\xi-\Delta\xi(r)}{2\Omega_x}\right) - W\left(\frac{\xi}{2\Omega_x}\right)\right]\cdot dx\cdot dr$

$\bar{H}_2(\xi,\eta) = \left(\frac{Prf}{v}\right)^2\cdot\iint \frac{1}{2}r^2\cdot\gamma(x,r)\cdot G(\xi,\eta,r)\cdot\left[W\left(\frac{\xi}{2\Omega_x}\right) - 2W\left(\frac{\xi-\Delta\xi(r)}{2\Omega_x}\right) + W\left(\frac{\xi-2\cdot\Delta\xi(r)}{2\Omega_x}\right)\right]\cdot dx\cdot dr$, $\Delta\xi = \frac{4\pi v}{\lambda r\cdot Prf}$

3. RAW DATA SIMULATION SCHEME

According to the 2-D Fourier formulation, the primary signal and paired echoes can be generated separately. The former can be evaluated by the efficient simulator as in [1], the latter can be obtained by multiplying $\bar{h}_n(x',r)$ with the attitude variation function, so the key problem becomes the evaluation of $\bar{h}_n(x',r)$. There are two differences between $\bar{h}_n(x',r)$ and the primary signal: the multiplication factor r and the azimuth envelope, which are both range dependent. By multiplying the reflectivity map with the two factors in the range time domain and azimuth Fourier domain, $\bar{H}_n(\xi,\eta)$ can be transferred into the same form as $H_0(\xi,\eta)$ and be evaluated by the same procedure as $H_0(\xi,\eta)$. Fig. 1 is the flow chart of the improved 2-D Fourier domain simulation scheme. The 2-D Fourier domain simulator in Fig1 is same as the one presented in [1].

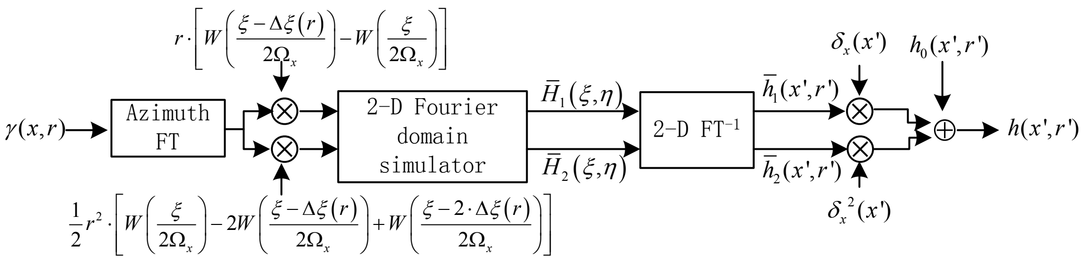

Fig.1 simulation scheme accounting for antenna attitude variations

As long as the attitude variation is small enough to satisfy the approximation in equation (1), the approach presented in this paper is valid. Further analysis shows that the simulator is practical even that such validity limit must be set. The computational load of this approach is of the same order of magnitude as the original 2-D Fourier-domain simulator.

4. SIMULATION RESULTS

The simulation results of range time domain pulse coherence algorithm (RTDPC) are used to evaluate the accuracy of our approach. The raw signals of targets placed at different range in presence of sinusoidal attitude oscillation are simulated. The amplitude is 1/20 of the beamwidth and its oscillation period is 1/10 of the integration time. The amplitude and phase of raw signals and images simulated by RTDPC and our approach are compared respectively in Fig.2 and Fig.3. (Limited to the length of article, only the result of target placed at reference range is presented.) The accuracy of this approach is verified.

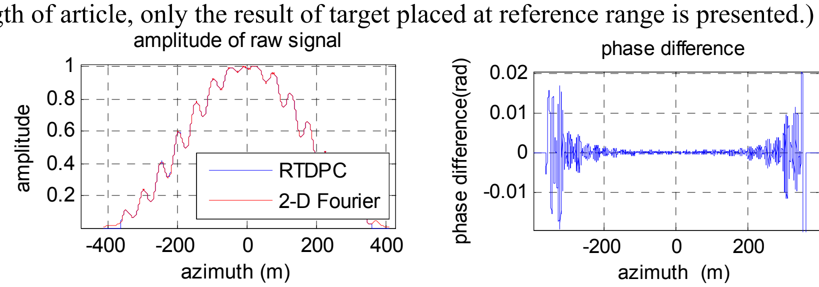

Fig.2 Raw signal comparison

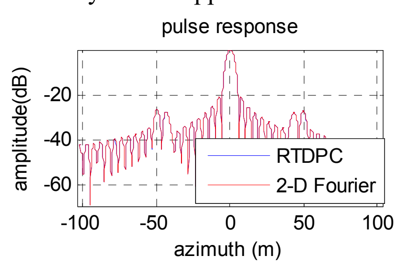

Fig3 Image comparison

5. CONCLUSION

In this paper, an efficient SAR raw signal simulator including the effects of antenna attitude variations is presented based on the deduction of 2-D Fourier-domain formulation of raw signal. Under some reasonable assumption, the raw signal is separated into the primary signal and the paired echoes. The simulation scheme to evaluate 2 components separately in Fourier domain is presented. The validity limit of this approach is analyzed. Simulation results are presented to verify its accuracy. The approach presented here can deal with the extended scene in case of antenna attitude variations efficiently, so it is practical and useful in the mission planning and testing processing algorithms related to attitude variations.

6. REFERENCES

[1] G. Franceschetti, M. Migliaccio and D. Riccio, et al., “SARAS: A SAR raw signal simulator,” IEEE Trans. Geosci. Remote Sens., vol. 30, no. 1, pp. 110–123, Jan. 1992.

[2] G. Franceschetti, A. Iodice and S. Perna, et al., “SAR Sensor Trajectory Deviations: Fourier Domain formulation and Extended Scene Simulation of Raw Signal”, IEEE Trans. Geosci. Remote Sens., vol. 44, no. 9, pp. 2323-2334, Sept. 2006.

[3] L.P. Zhu, G. F. Qiu, J. Pan, “Analysis of Antenna Boresight Pointing Instability Effect on SAR Image Quality”, Modern Radar, vol. 28, no. 1, pp. 61-64, Jan. 2006. In Chinese.