Radiometric Correction and Calibration for Low frequency UWB SAR System

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***Abstract*- The new peculiarities of the low frequency UWB SAR result in difficulty of radiometric correction and calibration for the system. The calibration techniques developed for common high frequency and narrow band SAR system cannot be applied to the low frequency UWB SAR. In this paper, based on the peculiarities of the system, the system processing model and the electromagnetic scattering model of calibrators are given, and the new radiometric correction and calibration method is proposed. The computer simulation is used to validate the method.**

I INTRODUCTION

The low frequency ultra wide band (UWB) synthetic aperture radar[1] (SAR) is an advanced all-day and all-weather 2-D microwave electric imagery system. This system combines the advantages of SAR and UWB radar techniques, and can detect the targets under foliage with high-resolution imaging. The peculiarities of the system, compared with common high frequency narrow band SAR system, are (1) very low work frequency, (2) very wide frequency band and (3) relatively very wide beam width of antenna pattern.

During the radiometric correction and calibration procedure, some parameters, which need to be corrected or calibrated, cannot be thought to be frequency independent or aspect angle independent, because of the peculiarities of low frequency UWBSAR system, and that is the reason why the existing radiometric correction and calibration techniques cannot be applicable.

In this paper, the radiometric correction and calibration method for the low frequency UWB SAR system is discussed. In section II, the system processing model for the system is given, which is the base of followed discussion. In section III, the electromagnetic scattering model for the calibrators is considered. In section IV, the calibration method is given, and computer simulation is used.

II SYSTEM MODEL

The system model is based on various kinds of focusing algorithms. Because of the Fresnel approximation for signal Doppler history is not valid for low frequency UWBSAR, the common focusing algorithms, such as Range-Doppler algorithm, cannot be used. The exist algorithms for the low frequency UWB SAR system are classified into time-domain focusing algorithm, such as Back-Project algorithm, and frequency domain focusing algorithm, such as $\omega-\kappa$ algorithm. In this paper, the system model is based on the frequency domain.

The geometric relationship between SAR and targets is shown in figure 1. Because of wide processing angle of low frequency SAR system, the dynamic range of angle θ between target and radar is relative very large. The Doppler history of return signal from the target cannot be approximated to be linear FM signal, and as a result, the common SAR processing model cannot be applicable to the large beam width SAR. The system model for low frequency UWB SAR is discussed.

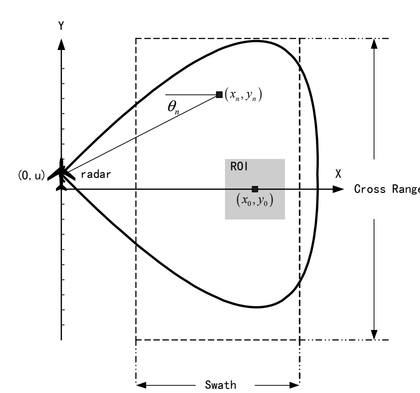

Figure 1. Geometric relationship of the SAR system

In the figure 1, the radar moves along the Y-axis, transmitting and receiving the pulse at a determined frequency (PRF) along X-axis. When the radar is located at the coordinates

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(0,u), the receive signal can be written:

$$s(u,\omega)=P(\omega)E(\omega)\sum_n a(\theta_n,\omega)a_n(\theta_n,\omega)\exp\left(-j2k\sqrt{x_n^2+(y_n-u)^2}\right) \quad (1)$$

where $P(\omega)$ denotes the spectrum of transmitted signal. The $E(\omega)$ denotes the frequency response of the signal channel and the aberration of signal channel. $a(\theta_n,\omega)$ and $a_n(\theta_n,\omega)$ denote the radiate pattern of antenna and an target located at (x_n,y_n). The expression (1) is the sum of echoes, multiplied by antenna pattern and phase term, from all targets illuminated by antenna beam. The angle between radar and target is:

$$\theta_n=\tan^{-1}\left(\frac{y_n-u}{x_n}\right) \quad (2)$$

Using the Principle of Stationary Phase, the Fourier transformation of (1) along azimuth can be obtained:

$$S(k_u,\omega)=P(\omega)E(\omega)A(k_u,\omega)\sum_n A_n(k_u,\omega)\exp\left(-j\sqrt{4k^2-k_u^2}x_n-jk_uy_n\right) \quad (3)$$

It is necessary to note that the relationship between the radiate pattern of antenna or the target in azimuth space domain and that in Doppler domain is mapping pair, not Fourier transformation pair. The mapping relationship is:

$$k_u=2k\sin\theta=2\cdot\frac{2\pi}{C}\cdot f\frac{u}{\sqrt{X_n^2+u^2}} \quad (4)$$

where the wave number $k=\frac{2\pi f}{c}$. This mapping relationship is nonlinear and is determined by the geometric relationship shown in figure 1. We change the variable $k_x=\sqrt{4k^2-k_u^2}$ of (3), which is so called Stolt interpolation:

$$S(k_u,k_x)=P(\omega)E(\omega)A(k_u,k_x)\sum_n A_n(k_u,k_x)\exp(-jk_xx_n-jk_uy_n) \quad (5)$$

From (5), we found that the frequency response of signal channel $E(\omega)$ and the antenna pattern $A(k_u,\omega)$ are unknown and needed to be corrected and calibrated. We also found that, if the calibrators are used to calibrate the system, the radiate pattern of the calibrator must be known.

III ELECTROMAGNETIC SCATTERING MODEL OF CALIBRATORS

In this section, the computation of the electromagnetic scattering model is discussed. For the low frequency SAR, the dimensions of interesting targets are always closed to wavelength, and that is to say, we should use the low frequency electromagnetic computation method, such as method of moment (MOM)[2][3] to compute the target scattering model.

It is known that the scattering electric field can be computed by solving the electric field integral equation (EFIE), but it is difficult to solve the EFIE for a target of any arbitrary shape. The MOM is a numeric electromagnetic field computation method. With MOM, the integral equation can be converted into the matrix equations:

$$\mathbf{IZ}=\mathbf{V} \quad (6)$$

where **I** is the generic current, which denotes the induced surface current density, and **Z** is the generic impedance, which denotes the geometric structure and physical characteristic of the object, and **V** is the generic voltage, which denotes the incidence electric field.

We find that the generic impedance is aspect angle dependent, and the generic voltage is aspect angle and frequency dependent. That is to say, the scattering electric field can be solved at a given frequency point and a given aspect angle. In order to get the UWB and wide beam width scattering characteristic, computation is time consuming adopted MOM. The AWE[4] technique, developed from the microwave circuit design, can be used for computation of the scattering characteristic over wide band and wide aspect angle. The essence of the AWE is to expand the induced current by

Taylor series on a center frequency point, and wide band scattering characteristic can be evaluated. The convergence region of the Taylor series is not very wide, and cannot be used to compute the UWB scattering characteristic. In this paper, the pade approximation is introduced, which is a kind of rational fraction approximation methods. The three parameters can define the relationship between radar and targets: the distance R between radar and the target, the depress angle and the azimuth angle.

These two angle parameters can be replaced by other two parameters: the radar height h and radar offset y from the target along azimuth. If the radar height h is equal to constant H, the EM scattering model is the function of frequency and offset y.

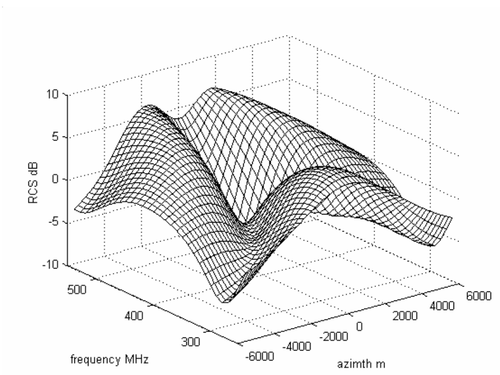


Figure 2. Electromagnetic scattering model of trihedral triangle reflector.

The electromagnetic scattering model of a trihedral triangle reflector is given in figure1. The scattering model is function of frequency and azimuth offset y. With the equation (4), the target radiate pattern $a_n(\theta_n,\omega)$ or $A_n(k_u,k_x)$ can be calculated.

IV RADIOMETRIC CORRECTION AND CALIBRATION PROCEDURE

The ultimate goal of the radiometric correction and calibration is to compensate the unknown parameters: the frequency response of signal channel $E(\omega)$ and the non-ideal antenna pattern $A(k_u,\omega)$ in equation (5). The SAR data is the sum of all backscattering of the targets located in the antenna beam illuminating area, so the first step is to extract the return from the calibrator located at (x_0,y_0). The 2D digital focusing algorithm[1] is implemented to received data, and the clutter around the calibrator can be restrained. The equation (5) can be approximated to be:

$$\begin{aligned} S_0(k_u,k_x) &= P(\omega)E(\omega)A(k_u,k_x)\times \\ & A_0(k_u,k_x)\exp(-jk_x x_0 - jk_u y_0) \end{aligned} \tag{7}$$

where the radiate pattern $A_0(k_u,k_x)$, shown in Figure 4, can be compute using mapping relationship (4) and the method discussed in section III.

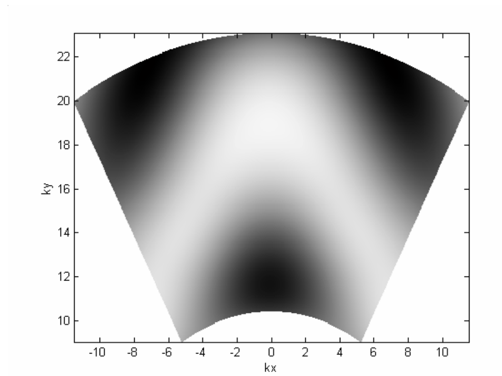


Figure 4. The radiate pattern of the calibrator in transformed domain

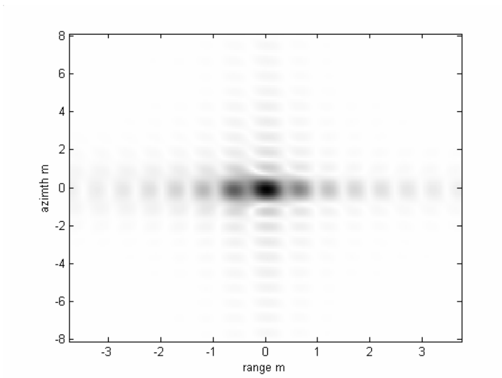
The radiometric correction and calibration for received data in equation (5) is obtained:

$$S_{cal}(k_u,k_x) = \frac{A_0(k_u,k_x)\exp(-jk_x x_0 - jk_u y_0)}{S_0(k_u,k_x)} S(k_u,k_x) \tag{8}$$

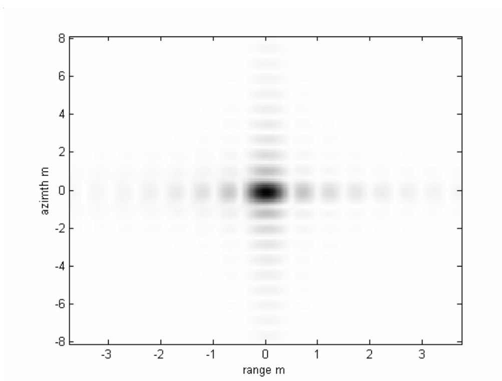
Computer simulation[5] is used to validate the calibration method. Firstly, we obtain the SAR image of a trihedral triangle reflector, using formula (5), and 2D digital focusing algorithm is implemented. Using formula (5), we obtain the uncalibrated SAR image, and the calibrated image is obtained by equation (8). The simulation result is shown in figure 5. We can conclude that the side lobes are depressed when the image is calibrated, and the image quality is enhanced.

V CONCLUSION

Radiometric calibration is a complicated project. In this paper, based on the three peculiarities of the system, we discuss the calculation of the scattering characteristics of the man-made targets. From the theory of SAR focusing algorithm, we obtain the relationship between the scattering characteristics and SAR image of the man-made target. Used the relationship, the UWB SAR images can be calibrated.



(a) SAR image using equation (5)



(b) SAR image using equation (8)

Figure 5. Comparison between before and after calibration

REFERENCE

[1] M.Soumekh, Reconnaissance with UWB UHF SAR, IEEE Signal Processing Magazine,July,1995.

[2] Norbert Geng, Marc A. Ressler, Lawrence Carin, “Wide-band VHF Scattering from a Trihedral Reflector Situated Above a Lossy Dispersive Halfspace,” IEEE Trans. GeoSci. Remote Sensing, vol. 37, NO. 5, pp2609-2617, Sept 1999.

[3] S.M.Rao, D.R.Wilton and A.W.Glisson, Electromagnetic Scattering by Surfaces of Arbitrary Shape, IEEE trans. AP.1982,AP-30:409:418

[4] C.R.Cockrell and F.B.Beck, Asymptotic Waveform Evaluation (AWE) technique for frequency domain electromagnetic analysis. *NASA Technical Memorandum 110292*. 1996.

[5] Axelsson, and Sunc.R.J. Frequency and azimuthal variations of radar cross section and their influence upon low-frequency SAR imaging. IEEE Trans. GeoSci. Remote Sensing, vol. 33, NO. 5, pp1258-1265, Sept 1995