EFFECT OF SQUINT IMAGING ON BEAM POSITION DESIGN OF SPACE BORNE SAR

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1. INTRODUCTION

Beam position design is a key technique in system design for the space borne Synthetic Aperture Radar (SAR). The parameters of beam position, which involves the Pulse Repetition Frequency (PRF) and the looking angle [1], directly affects the performance of the SAR system such as ambiguity [2][4], Signal Noise Ratio (SNR)[3], coverage and other factors. Drawing the zebra map and calculating the swath width are two most important aspects of beam position design under the condition of squint imaging. For the traditional zebra map drawing method, the receiving time of the beam pointing direction is considered only. It is available for the broadside SAR and the slightly squint-looking SAR because its slant range changes little. However, as the squint angle deviates from the broadside, the synthetic time and range migration increase, which result in great augment of the echo receiving window. Ury Naftaly from Israel derived that there is a maximum squint angle for the space borne spot SAR with a given PRF. For squint angles greater than the squint limit, the actual receiving window is longer than the Pulse Repetition Interval (PRI) [5]. Thus, the traditional zebra map design method may bring on the result that echoes from the swath edge can not be received completely, and some improvements should be necessary. Other than the side-looking SAR, the effective swath width for squint SAR is no longer the ground range between the proximal and the distal beam along the pointing direction. Analyzing the influence of squint angle on swath width is needed. The swath width is usually given as an index of the system, so the beam width shall be adjusted for different squint angles to meet the requirement of coverage.

In order to accomplish the beam position design for space borne SAR working at a large squint angle, we select the proper spatial geometric model. The zebra map design method is improved in the premise of taking the range migration into account. In addition, the effective swath width for squint SAR is obtained by using the geometric model.

Section 2 improves the zebra map drawing method. The impact of range migration is considered in the limiting conditions of the nadir echo and the protective window for pulse transmission. The effect of squint angle on swath width is also derived, and the requirement of beam width for a given observation swath. Section 3 presents some design results of squint SAR beam position. STK is used to verify the coverage performance, and echo simulation is made to prove that the designed PRI is long enough to completely receive the echo of scene. Our conclusions are presented in Section 4.

2. IMPROVEMENT OF BEAM POSITION DESIGN METHOD

2.1 Improvement of zebra map

Generally the swath width of space borne SAR is about tens of kilometers. Since the radius of the Earth changes barely in the swath, the Earth could be considered as a sphere. Meanwhile, the trajectories of the antenna and the beam footprint are approximated to straight line because of the short coherent time. All the discussions in this paper are based on this model above.

As it is presented in Section 1, large squint angle requires greater reserved time for echo receiving as the range migration increases. Lessening the gap of the zebra map properly can eliminate the migration. Based on the geometric model for space borne SAR, the maximum and the minimum slant ranges of the swath during the synthetic time are obtained. To accomplish valid imaging, following two expressions must be satisfied:

$$\begin{cases} \dfrac{2R_n}{c} > \dfrac{2H}{c} + \dfrac{k}{f_{prf}} + 2\tau + \dfrac{2\left(R_n - R_{\min}\right)}{c} \\ \dfrac{2R_f}{c} + \tau < \dfrac{2H}{c} + \dfrac{k+1}{f_{prf}} - \dfrac{2\left(R_{\max} - R_f\right)}{c} \end{cases} \qquad \begin{cases} \dfrac{2R_n}{c} > \dfrac{k}{f_{prf}} + \tau + \tau_p + \dfrac{2\left(R_n - R_{\min}\right)}{c} \\ \dfrac{2R_f}{c} + \tau < \dfrac{k+1}{f_{prf}} - \tau_p - \dfrac{2\left(R_{\max} - R_f\right)}{c} \end{cases}$$

These formulae are the new circumscribing conditions to draw a zebra map, and the variables are defined in Figure 1.

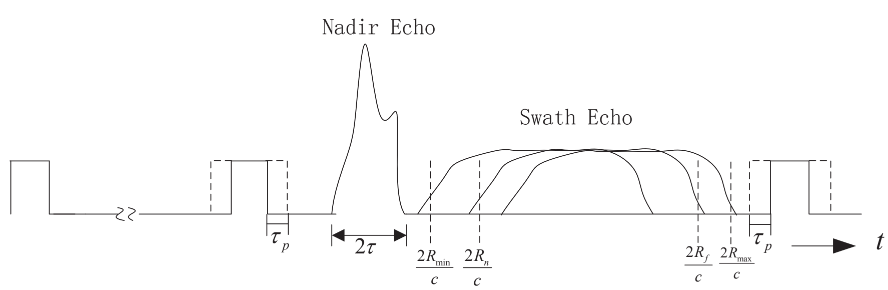

Figure 1: *echo reserved window*

τ_p is the duration of the receiver protection window with the value of half pulse width. R_n and R_f are the proximal and the distal slant range of the range direction (here the range direction is defined as the beam pointing direction instead of the cross-track direction), which correspond to the range look angle bound.

The key issue to improve the zebra map drawing is calculating the maximum and the minimum slant ranges in the coherent time. Considering that each point in the range direction have the same ground squint (ground squint is defined as the projection of the squint angle to the ground), we can acquire the squint angle and α_0 (the looking angle at zero squint to a line parallel to the ground trace) for both the proximal and the distal edges of the beam. Consequently, the two margins of slant range can be solved in slant plane.

2.2. Analysis of effective swath

Since the range direction is no longer vertical to trace, the effective swath should be the projection of the range observation width to the cross-track direction. However, the projection is not the simple relation $W_{eff}=W_{Range}\times cos(\theta_g)$ because the swath is curved, where θ_g is the ground squint. First, we should calculate the proximal and the distal looking angles. Then by applying the geometric model, the corresponding geocentric angles at zero squint is obtained. Hence, the ground range between the two geocentric angles is exactly the effective swath width. Similarly, if the swath width is given as an index, the inverse process is available to calculate the range beam width.

It should be noted that the range observation width has already take the migration effect into account, and the echo is accumulate completely.

3. SIMULATION RESULTS

Elementary simulation is accomplished for a space borne strip-map X-SAR system with 3m resolution and the swath width of 30km. The orbit height is 510km.

By applying the geometric model and the improved beam position design method presented in Section 2, the proper beam position parameters can be calculated. If the squint angle deviates in the slant plane of α_0=35°, the maximum squint angle for receiving the echo completely is 36°, and the squint limit increases to 39° without considering the range migration. The squint limitation and the range beam width for different α_0 are listed in Table 1.

Table 1: *Limitation for squint angle and beam width*

α_0	20	25	30	35	40	45	50
Squint Limitation	32	34	35	36	35	35	34
Range Beam Width	4.31	3.42	2.78	2.27	1.82	1.43	1.08

Note: the range beam width is the result for 30° squint angle, and all the values are in units of degrees.

To verify the validity of the designed beam position design results, we select a set of parameters that shown in Table 2.

Table 2: *SAR system parameters*

α_0	35°
Squint Angle	30°
PRF	2280Hz
Signal Bandwidth	50MHz
Pulse Width	30μs
Wavelength	0.03m
Range Beam Width	2.27°
Azimuth Beam Width	0.29°
Synthetic Time	0.5387s

The STK simulation proves that the swath width of 30km is exactly. And the result of echo simulation for point target at the scenario margin shows that the echoes can be completely received during the PRI with no aliasing.

4. CONCLUSIONS

The effect of range migration for beam position design of highly squint space borne SAR is not negligible. In this paper we improve the design method of zebra map by calculating the range migration, as the beam position selected in the gap of the improved zebra map could be completely accumulated during the imaging time. We also analyze the relation between the swath width and the squint angle; derive the limitation of observation scope for range beam width at large squint angle. Simulations are made to verify the validity of the design results.

5. REFERENCES

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