

The PRF Selection for Space-borne SAR

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ABSTRACT For the design of the space-borne Synthetic Aperture Radar(SAR), the Pulse Repetition Frequency(PRF) selection is one of the key problems. It is constrained by a number of factors. Two of the factors are the transmit and the nadir interference restrictions. These restrictions are related to the actual satellite height, the pulse duration, the slant range and so on. In this paper, we will give three-dimension relationship for PRF, incident angle and earth radius and its projection on PRF plane, incident angle plane and earth radius plane. We will discuss the influence of the earth radius the antenna pattern and the processing gain on the PRF selection and give the locus of PRF to earth radius and incident angle to earth radius.

KEY WORDS SAR, Digital Earth

1. Introduction

The SAR is an active microwave imaging sensor. As an active sensor, the SAR provides its own illumination and is not dependent on the light from the sun. And as a result, the SAR can image the surface of the Earth day and night. It provides the ability to observe properties about the Earth's surface that previously were not detectable. The SAR used to be thought as an all-weather imaging system, in fact, environmental factors often have effects on the interpretation of the data. Even though, the SAR has found significant applications, such as elevation mapping, ice flow mapping, earthquake, and forest mapping and applications on hydrology and glaciology, etc. And many new SAR systems are under designing and developing^[2].

Although, the concept of SAR can be traced back to near fifty years and the SAR is a mature technique from a system architecture point of view, there is room for improvements especially in the space-borne case from a technology point of view.

Up to now, many states and international organizations had their own space-borne SAR^[1]. China had successfully developed her own air-borne SAR systems and real-time SAR image processor for many years and is developing her own space-borne SAR system right now^{[3][4]}. In this period, we encounter many technology problems. In this paper, we present our study on the choice of PRF for space-borne SAR.

2. Nadir and Transmit Interference

2.1 Traditional Result for Nadir and Transmit Interference

The geometry of the space-borne SAR is shown in Fig.1. The antenna of the radar is fixed on the spacecraft. The radar beam illuminates the Earth's surface perpendicular to the orbit of the SAR

platform. The radar transmits the linear frequency modulated(LFM) signal. The SAR has a single antenna for both transmit and receive.

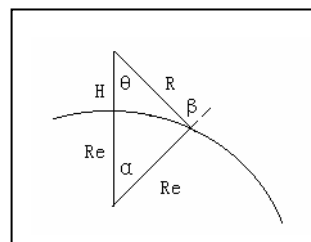


Fig. 1 Geometry of Space-borne SAR

PRF selection is constrained by many factors, such as Azimuth Ambiguity to Signal Ratio(AASR), Range Ambiguity to Signal Ratio(RASR), Doppler bandwidth, and nadir and transmit interference etc. In this paper, we'll only address to the nadir and transmit interference.

The transmit interference restriction on the PRF can be written as follows:

$$n/PRF + Tw_0 + Tw_{rp} < 2R_1/c \quad (1a)$$

Or

$$n/PRF - Tw_{rp} > 2R_2/c \quad (1b)$$

Where

n indicates the echo of the transmitted pulse returned after the nth transmitted pulses

Tw₀: the pulse duration

Tw_{rp}: the receiver protect window

R₁: the near slant range

R₂: the far slant range

c: light speed

The nadir interference restriction on the PRF can be written as follows:

$$2H/c + j/PRF > 2R_2/c \quad (2a)$$

Or

$$2H/c + 2Tw_0 + j/PRF < 2R_1/c \quad (2b)$$

Where

H is the actual height of the satellite from the nadir earth surface

j indicates echo is the jth transmit pulses after the nadir return

Therefore, it is clear that the restrictions are closely related to the H. Suppose the orbit of the satellite is a circle and the earth is an ellipse, the change of the radius will cause the change of H and as a result the restrictions on PRF selection. Although authors had given the locus for PRF to incident angle for both equator and pole, they didn't consider the restriction on PRF selection for different earth radius^[5]. For comparison, we rewrite the traditional result as follows:

Fig.2. is the nadir and transmit interference for equator and Fig.3. for pole. We take a space-borne SAR parameter and listed as follows:

- the width of the pulse: $Tw_0 = 33 \mu s$
- the return protect window: $Twrp = Tw_0$
- The radius of the earth(pole): $R_{ep} = 6356.779km$

- the radius of the earth(equator): $R_{ee} = 6378.164km$
- the swath: $W = 40km$
- the nominal height of the satellite: $H_{nom} = 621.703km$
- the antenna length: $D = 9m$
- wavelength: $\lambda = 23.5cm$
- incident angle: $\theta = 35^\circ$

2.2 The Influence of the Earth Radius

The three-dimensional relationship for PRF, incident angle and earth radius is shown as Fig4. And projection on earth radius plane as Fig5.

From Fig.4., we can have a general idea about the relation between PRF, incident angle and the earth radius. And with this simulation program, we can have the PRF to incident angle relation for different earth radius, i.e. nadir and transmit interference for different earth radius. This simulation result is the guide for SAR on-orbit PRF selection. We project the 3-D figure on earth radius plane and have Fig.5. It illustrates the nadir and transmit interference for different earth radius. As a demonstration, we only evenly take four different earth radius to show the trend.

We find the change of the earth radius significantly influence the restriction on the PRF selection.

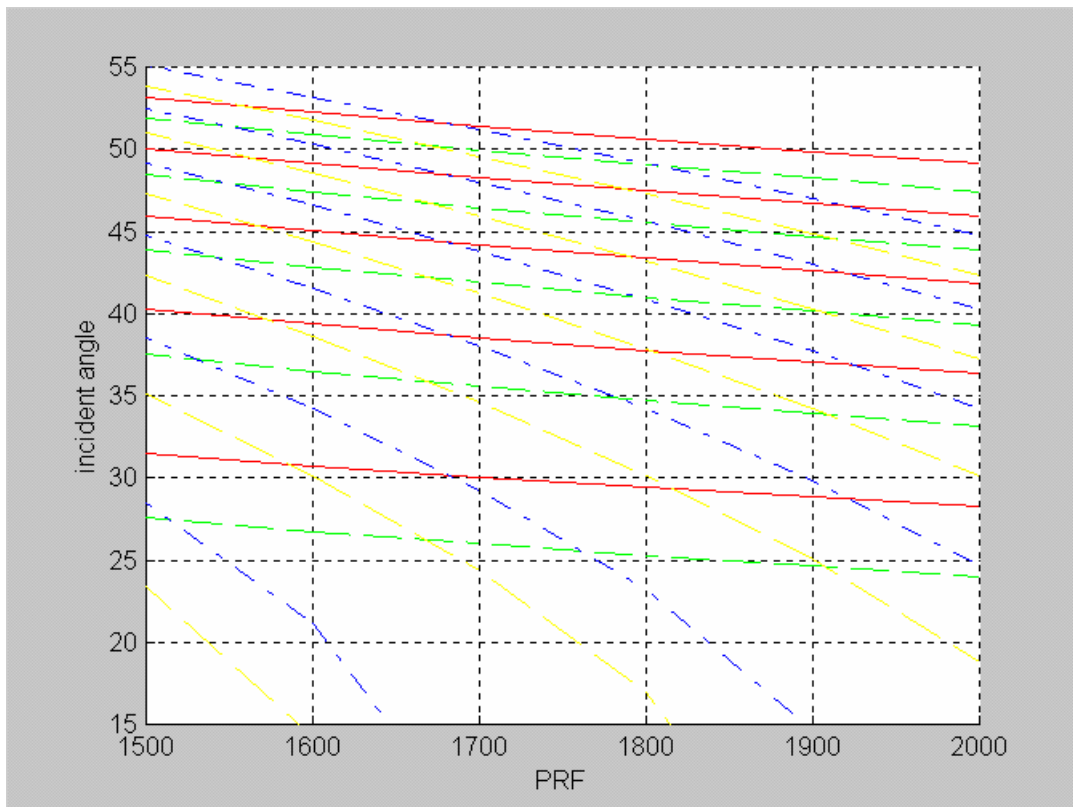


Fig. 2 Nadir and Transmit interference for equator

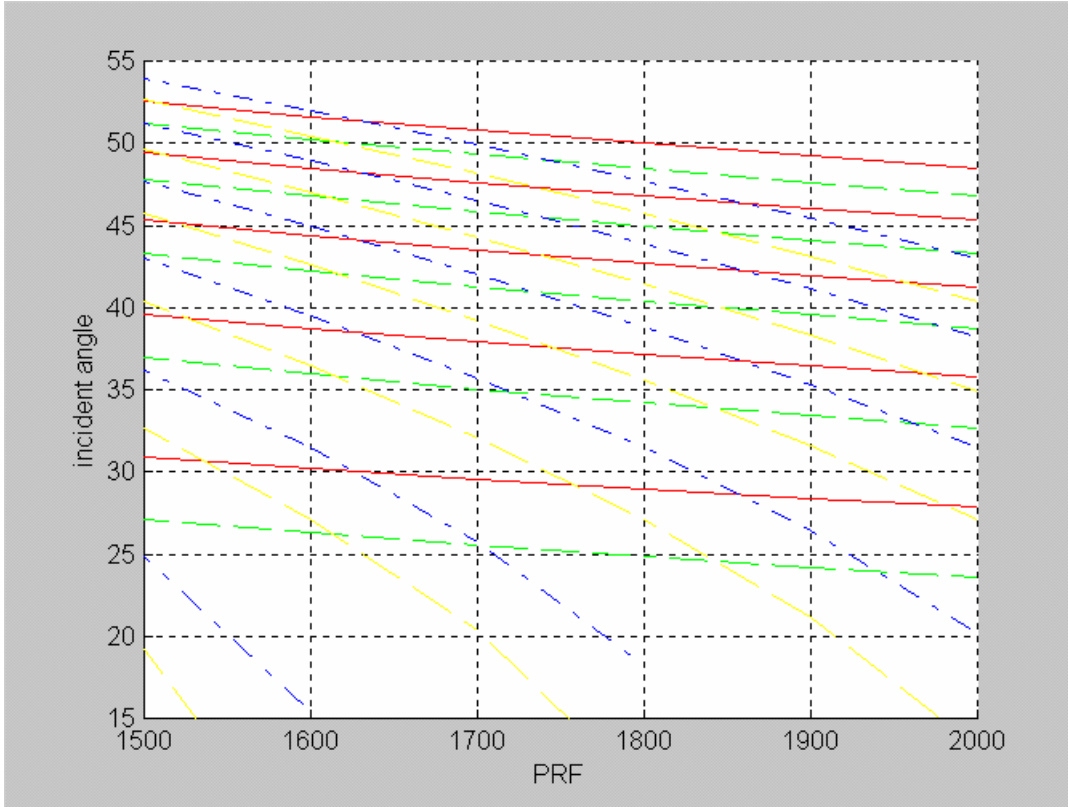


Fig. 3 Nadir and Transmit interference for pole

During this work, we also find that the duration for nadir not necessary to be taken as 2 times of the transmit pulse duration, as shown in (2b), considering the pattern of the antenna in elevation direction. It is designed with a very low side lobe at the angle of nadir direction. Therefore the energy level of the nadir return is several tens decibel lower than the energy level of the echo from the image zone. It is only the interference at a level about the signal can cause noticeable effects on the image. Therefore, considering this effect, the nadir interference may be less severe and its duration should be shorter. The inequality should be

$$2H/c + a * Tw_0 + j/PRF < 2R_1/c \quad (3b)$$

Where a should be reasonable less than 2. The coefficient a should be calculated according to the elevation pattern of the antenna. Furthermore, the SAR echo is processed by a matched filter. The matched filter is matched with the echoes from the image zone, but is not matched with the nadir return. It can result a significant reduction of the processing gain of the nadir return. The ratio of processing gain between a mismatched filter and a matched filter for LFM pulse signals is^[6]

$$(SNR)_r = \frac{(SNR)_{mis}}{(SNR)_{match}} = \frac{1}{|k_2 - k_1| T^2} \quad (4)$$

where the k_2 , k_1 are the linear frequency modulation rate of matched signal and mismatched signal respectively and T is the time duration of the pulse. This corresponding to the range processing of SAR data^[5].

Since under certain conditions, we may take the azimuth processing of SAR data as a Doppler chirp signal and applying the above result to it. Therefore the Doppler rate f_{dri} of the echoes from image zone corresponds to the k_2 and the Doppler rate f_{drn} of the echoes from the nadir zone corresponds to the k_1 . The synthetic aperture time T_a corresponds to the T . Form^[8] we have

$$f_{dr} = \frac{2V^2}{\lambda R} \quad (5)$$

Where f_{dr} is the Doppler rate

V is the velocity of the SAR platform

λ is the wavelength

R is the distant between the target and the SAR platform

It is easy to deduct from^[8] that

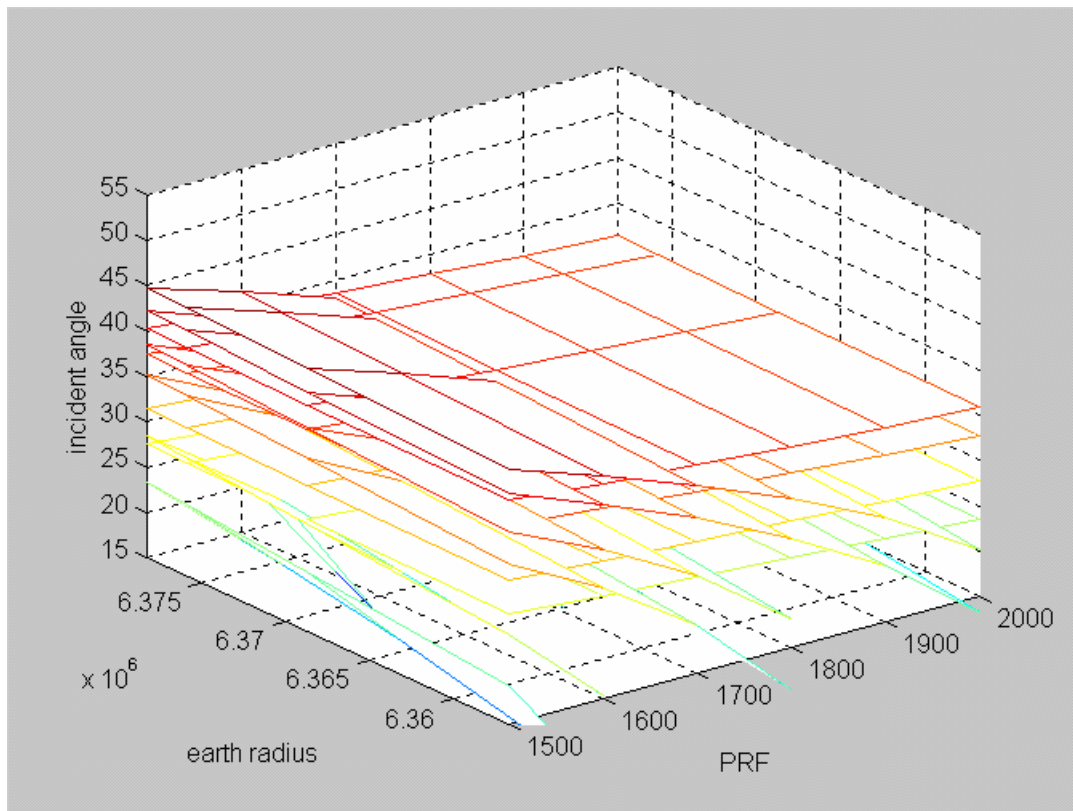


Fig. 4. Three Dimension Relationship for PRF, Incident Angle and Earth Radius

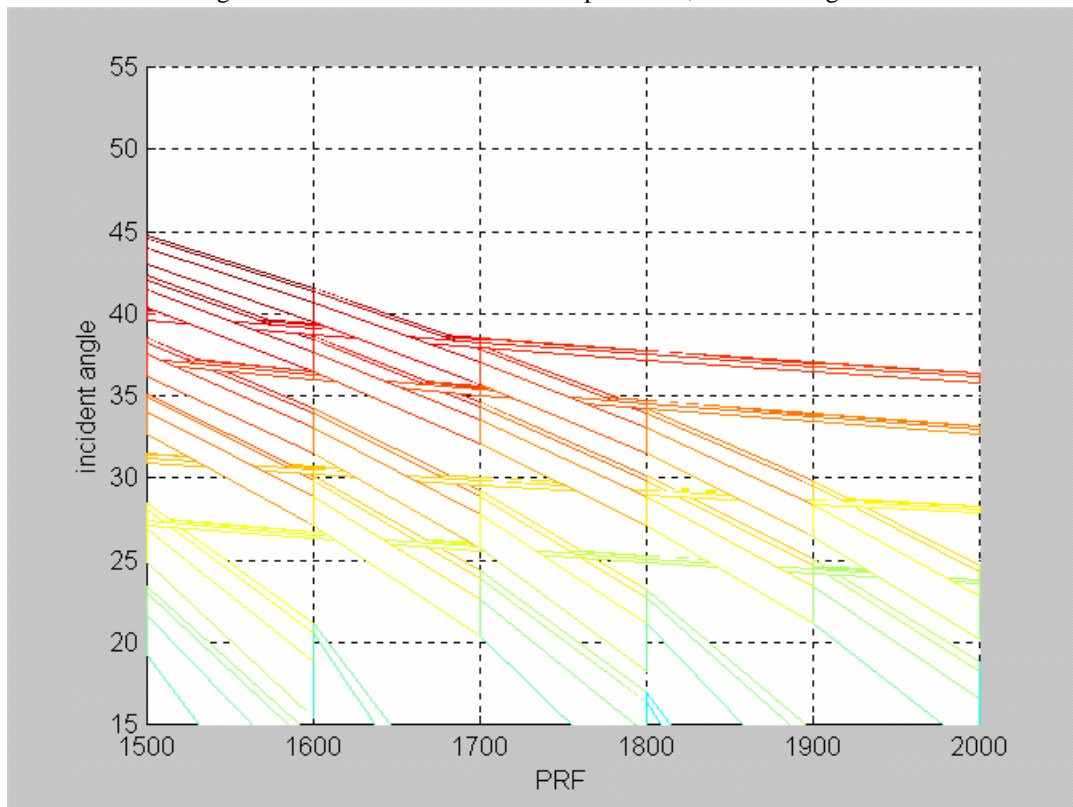


Fig. 5 Nadir and Transmit Interference for Different Earth Radius

$$T_a = \frac{\lambda R}{DV} \quad (6)$$

Where D is the length of the antenna

Considering the orbit of the SAR platform is a circle, from [9] we have

$$V = \sqrt{\mu/R_a} \quad (7)$$

Where μ is the gravitational constant times earth mass

R_a is the distant between the SAR platform and the center of the earth

From [1] and reference to Fig.1, we have

$$\beta = \arcsin\left[\left(\frac{H + R_e}{R_e}\right) \sin \theta\right] \quad (8)$$

$$\alpha = \beta - \theta \quad (9)$$

$$R = \sqrt{(H + R_e)^2 + R_e^2 - 2(H + R_e)R_e \cos \alpha} \quad (10)$$

For image zone, the distant follows the formulation (10) and for nadir zone, the distant is just the satellite height itself.

And we rewrite (4) as

$$(SNR)_r = \frac{1}{|f_{dri} - f_{dm}| T_a^2} \quad (11)$$

With this formulation and parameter in 2.1, here we omit the procedure of calculation and present the result only and we have

Table 1

f_{dri} (Hz/s)	f_{dm} (Hz/s)	Ta(s)	V (m/s)	(SNR)
616	770	2.72	754	0.0009
		4	6	

This means the gain for matched signal is about 1000 times the one for mismatched signal. Therefore, the nadir interference may not be so severe as we thought before.

3. Conclusion

Although the SAR is a mature system, there are still many problems to be addressed. In this paper we presented one of the problems. We give the simulation result for earth radius effect on the nadir

and transmit interference, i.e., the PRF selection and the earth radius do have significant effect. We give the 3-D figure to shown the concept and the trend.

Our result is preliminary. Still we have many interesting problems to study for the space-borne SAR. We simply list some of the problems and we'll solve those problems later.

- The nadir return duration, i.e., the optimum value for a in inequality (3b).
- The effect of the satellite orbit, such as ellipticity.
- The space-borne SAR geometry model. We usually take space-borne SAR as right side-looking, in fact it is working in squint model^[7].

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