# Near-Space Slow SAR High-Resolution and Wide-Swath Imaging Concepts

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***Abstract*—In comparison with airborne SAR, Near-Space SAR can provide much larger and long term coverage of the interested ground scene. Moreover, Near-Space SAR owns shorter revisit period and better motor ability than space-borne case. In fact, Near-Space SAR is potential to provide robust survivability, high resolution, wide swath and high revisiting frequency that we have desperately wanted. Current researches of Near-Space SAR focus on fast-speed platform which encounters contradiction between azimuth high resolution and range wide swath. To solve it and achieve sustained imaging, Low-Speed SAR is introduced in this paper. Joint Aperture Technology is then proposed to make full use of the redundant pulse reputation frequency and obtain wide area imaging fast. Performances of the simulations given at the end of the paper verify the effectiveness of the proposed imaging concepts.**

## I. INTRODUCTION

Synthetic aperture radar (SAR) is required to produce continuous high-resolution image over a wide area of surveillance. High-resolution Wide-swath (HRWS) is of great significance in many fields, like public security, disaster warning, etc. Even so, it is impossible to achieve high azimuth resolution and Wide-swath for conventional spaceborne and airborne SARs, simultaneously [1] [2]. Spaceborne SAR has an imaging capability of Wide-swath with a limited azimuth reolution. In contrast, airborne SAR has an imaging capability of high resolution but with a limited swath coverage. There is therefore a clear incentive consideration to increase swath width and azimuth resolution simultaneously [3]. We thus have two gaps: one is the capability in high-resolution and wide-swath (HRWS) remote sensing, and the other is that there is a lack of sensors operating in the altitude between satellites and airplanes. These two gaps can be simultaneously filled by using Near-Space vehicles as the radar platforms [4].

Near space is the region of Earth's atmosphere that lies between 65,000 and 325,000–350,000 feet (20 to 100 km) above sea level [5] [6], as shown in Fig.1(a). Additionally, the velocities of Near-Space vehicles can range from nearly stationary to $1500 m/s$. Because of the unique higher altitude and the velocity of Near-Space platforms, Near-Space SAR is potential to provide robust survivability, high resolution, wide swath and high revisiting frequency that we have desperately wanted.


(a)Space Division (b) Near-Space Low-Speed Platforms

Fig.1.Space Division and Several Typical Near-Space Low-Speed Platforms

Currently, crafts that fly in Near-Space can be sorted into two types **[7]**: ultrahigh speed and low-speed platforms. The former one generally includes the sounding rockets and high speed unmanned aerial vehicles (UAVs). The latter kind includes high altitude balloons and stratosphere blimps, as Fig.1(b) shows. Stratosphere blimp is a typical Near-Space aircraft with flight altitude ranges from 60,000 to 180,000 feet (18 to 55km) above sea level. It qualified with long air-staying time which is potential for high resolution and large ground coverage for wide swath imaging.

Many researches had been developed. Defense Advanced Research Projects Agency (DARPA) funded Integrated Sensor Is Structure (ISIS) project (2004) will provide observation instrument for unmanned High Altitude Airship (HAA) in 2013. National Aeronautics and Space Administration (NASA) Glen Research Center also developed high altitude airship-borne radar for coastal monitoring in 2005. However, current researches of Near-Space SAR focus on High-Speed platforms [8]-[11]. Its inherent defect of contradiction between azimuth high resolution and rang wide swath can not be solved by conventional technologies. So in this paper, we present the design of a Near-Space Low-Speed SAR (NSLS-SAR), and

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its imaging strategy.

Remaining sections are organized as follows. Section II introduces capability of Near-Space in high resolution, wide swath imaging and figures out current researches as well as challenges encountered. Section III shows the characteristic of NSLS-SAR and discusses the new issue of long synthetic time. Joint Aperture Technology (JAT) that solves this new issue is then proposed in Section IV. Details of JAT and following assembling process also described. The performances of simulations verify the effectiveness of the proposed concepts in Section V. Finally, Section VI concludes this whole paper.

## II. CURRENT NEAR-SPACE SAR AND PROBLEMS

Based on the SAR resolution theory, a high azimuth resolution requires a short antenna to illuminate a long synthetic aperture, viz. it will results in a wide Doppler bandwidth. To satisfy the Nyquist sampling criterion, this azimuth bandwidth must be sampled at a high pulse repeated frequency (PRF). However, a high PRF means a smaller swath width. The relation between the maximum imaging swath on ground $W_s$ and the required PRF can be expressed as

$$`W_s \le \frac{c}{2 \cdot PRF \cdot \sin\theta_0} \tag{1}$$

where $c$ and $\theta_0$ denote the speed of light and the incidence angle, respectively. That is to say a low PRF is favorable to unambiguously image a wide swath on the ground.

And based on the Pulse compression theorem, the azimuth resolution is

$$\rho_a = \frac{v}{B_a} \ge \frac{v}{PRF} \tag{2}$$

where $v$ is the speed of the platform, and $B_a$ denotes the doppler bandwidth.

Substituting equation (2) into equation (1), we can get the following restriction

$$\frac{W_s}{\rho_a} \le \frac{c}{2 \cdot v \cdot \sin\theta_0} \tag{3}$$

Generally speaking, $c/v$ is nearly constant at 20 000 for spaceborne SARs and typically in range of 300 000-750 000 for airborne SARs. In contrast, Near-Space platforms can fly at a speed ranging from nearly stationary to $1500m/s$, then the corresponding $c/v$ will be greater than 100 000. Thus, compared with spaceborne and airborne SARs, Near-Space SAR can provide a more flexible choice between azimuth resolution and swath width for satisfy the High-Resolution and Wide-Swath imaging.

Also, equation (2) can also be reformed into the basic minimum antenna area ( $A_{antenna}$ ) constrain

$$A_{antenna} \ge \frac{4v\lambda R_c \cdot \tan(\theta_0)}{c} \tag{4}$$

where $\lambda$ is the radar wavelength and $R_c$ is the slant range from the radar to the midswath.

In reported materials, researches of Near-Space SAR focus on High-Speed platform [8]-[11]. From equation (4) we can get that, with regard to the High-Speed platforms, the minimum antenna area of $A_{antenna}$ will be relatively large. However, in order to achieve the HRWS imaging, the antenna area should be small. So as to alleviate the requirements imposed on the minimum antenna area for the High-Speed platform, several multichannel- or multi-aperture-based techniques, such as displaced phase center antenna (DPCA) technique [15], digital beamforming (DBF) technique [8]-[11], viz., have been proposed.

Nevertheless, multichannel- or multi-aperture on receiver greatly increase the complexity of the whole system both in hardware and software.

To address these problems for High-Speed platforms, we present the design of NSLS-SAR, and its imaging strategy in the following sections.

## III. CHARACTERISTICS OF NSLS-SAR IMAGING

NSLS-SAR is carried by high altitude balloons and stratosphere blimps. Those vehicles take advantages of aerostatic buoyancy to balance its own gravity. With the help of aerostatic buoyancy, persistent coverage and long air-staying time is obtained while energy is saved. The saved energy then reinforces maneuverability, the ability to continued imaging and the ability to large ground coverage.

On the other hand, the maneuverability of NSLS-SAR is special with low movement speed which closely linked to the long air-staying time.

In fact, air current in Near-Space is much more fluent than the one in troposphere. But because of the long synthetic aperture time and low speed characteristics for NSLS-SAR, the movement of the low speed platform in Near-Space is very complicated. Therefore, the characteristics of NSLS-SAR can be summarized by two aspects, the long air-staying time and large ground coverage.

### *A. Long air-staying time*

NSLS-SAR balances its gravity with aerostatic buoyanc. So, long air-staying time is possible in this method of energy efficiency. Due to the adopt of low speed vehicles, synthetic time shows pretty long. But low speed is attached to the long synthetic time in this case. Hence, the long air-staying time characteristics could be further sorted into two related aspects, long synthetic aperture time with low speed and rapid changing reflectivity.

Assume the scenario that adopts a vehicle speed of 30m/s, shortest squint length of 72Km, beam width of 3 ° and wavelength of 3cm, the synthetic time would be enlarged to 120s. Long synthetic time is what we desperately wanted which is also potential for fine resolution.

But, platform's random motion would seriously attach to azimuth time-Doppler feature under this speed. In a word, extra long synthetic time with low speed platform could result into an unexpected motion disturbance which makes it hard to focus well. This is very harmful for NSLS-SAR imaging. Based on the numerical analysis, the allowance movement error of NSLS-SAR platform is generally less than one centimeter. In this case, low speed sets new complex challenge for motion composition [16].

Beside the motion composition, another emergency challenge for NSLS-SAR is the rapid changing reflectivity. In model of high speed platform, change of reflectivity could be neglected. But in the model of low speed platform, the change of reflectivity could parallel to the low speed. Thus, reflectivity change should be taken into consideration. This is another key challenge for NSLS-SAR.

In summarize, long air-staying time is potential for high resolution while brings two special issues, motion composition and rapid changing reflectivity.

### *B. Large ground coverage*

Low-Speed platforms operate at speed of 0~30m/s which is dozens of times smaller than High-Speed SAR. Because of this special speed, from equation (4) we can get that NSLS-SAR could adopt energy efficient platform and solve restrictions above while keeps conventional radar structure. For example, assuming the speed of the platform is 30m/s, the azimuth resolution is 0.5m, then the Doppler bandwidth is 60Hz, so the PRF should be larger than 60Hz. And also we assume the large rang width is 200km, then we can get the PRF should be smaller than 750Hz. We can see that the two restrictions are not contradictory. So NSLS-SAR can avoid the problems for High-Speed platforms. Meanwhile, because of the Low-speed, it can also achieve the sustained imaging as following explanation.

Low-Speed SAR uses airship or balloon as its platform while High-Speed SAR uses vehicles. Vehicles are born with defect of short air-staying time while airship and balloon are perfect of suspension in the air. Moreover, sunlight is plenty in Near-Space which enables energy replenishing. Wind direction is stable for sustained imaging. In this way, Low-Speed SAR could operate months and even years in certain area. So NSLS-SAR can achieve the sustained imaging.

However, new issue slow-speed results in long synthetic time, which is greatly adverse to fast imaging and real-time monitoring.

## IV. JONIT APERTURE TECHNOLOGY

In order to deal with the long synthetic time caused by the Low-Speed, we will make full use of the redundant PRF and propose the JAT.

The main idea of JAT is mapping one aperture to various ground area to accomplish large azimuth area surveillance. In JAT, certain large area is divided into several parts with overlapping area between neighbors, and the azimuth width of the overlapping area is one synthetic aperture length, which will be used to assemble the multi-images. Radar periodical changes its Line-of-sight (LOS) angle to illuminate each part of the area. Under this circumstance, muti-imaging areas share the same aperture during synthetic time and large imaging areas is generated fast. After imaging process, register adjacent part and assemble the whole image. We will discuss in more detail of the JAT in the following part.

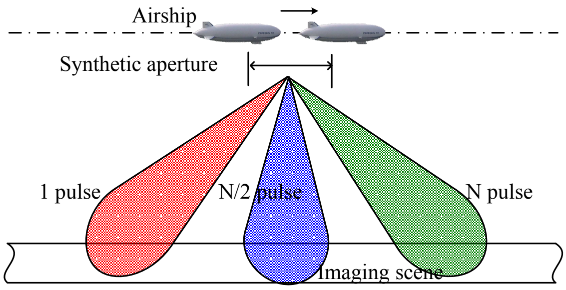


Fig.2.The geometry configuration of JAT.

### *A. Target area divide*

As shown in Fig.2, radar periodical changes its LOS angle to cover large area. The cycle time equals to a pulse repetition interval (PRI). For each LOS angle, beam form illuminates a unique area. The number of the LOS (viz. N) should be satisfy the following restriction

$$N \le round\left(\frac{PRF}{B_a}\right) \tag{5}$$

where $round(\cdot)$ represents rounding operation. Then the required time of the whole area imaging will cut down to 1/N of the traditional stripmap mode. The processing structure of NSLS-SAR is shown in Fig.3.

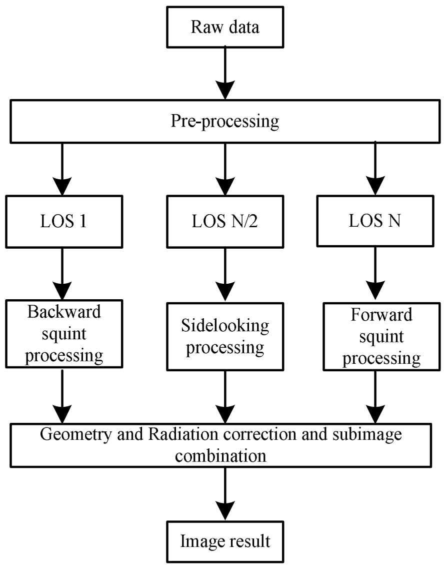


Fig. 3. The processing structure of NSLS-SAR.

### *B. Multi-images Assembling*

After the processes above, image from different LOS angle are independent obtained. In order to get whole image of wide swath area, the multi-images assembling technology based on image registration (MIAT-IR) will be introduced in this paper. This MIAT-IR includes two main steps:

Firstly, image registration technology will be used in order to assemble the adjacent regions. Each two registration areas of the different adjacent LOS angle sub-images have the same size but different resolution. So it is suitable for using correlation coefficient registration method. The registration location is determined at the largest correlation location.

Secondly, remove the overlapping area that shares only part of whole aperture and assemble different parts together. Then the whole image of the large area has been got.

## V. PERFORMANCE OF AN EXAMPLE SYSTEM

According the statement above, we present three groups of contrast experiment to show the long air-staying issues and LOS angle division issues of NS-LSSAR.

Firstly, we present a group of experiment specify in a point target with and without reflectivity change. Fig.4 presents a point target with shortest squint length of 40Km and LOS angle of 30°. This target is focused without reflectivity change. On the contrary, a same point with reflectivity change is shown in Fig.5.

It's obvious that the rapid changing reflectivity aggravate resolution of target. In fact, if the reflectivity of target area changes too fast, it would be impossible to focus. For example, a walking man could disappear in the playground in two minutes. So, one could not image an inexistent object.

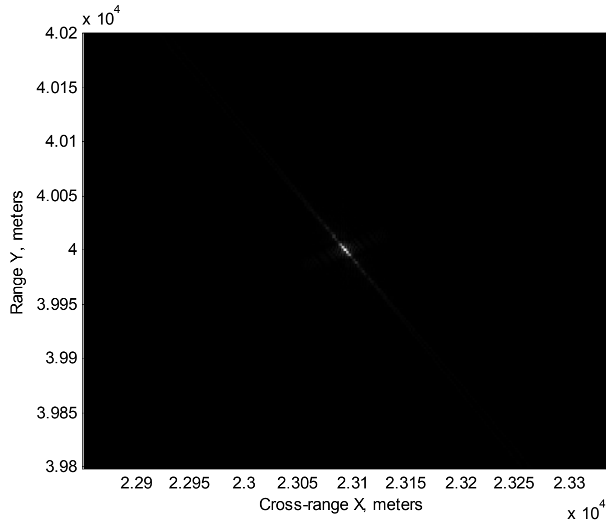


Fig.4. Point target with stable reflectivity

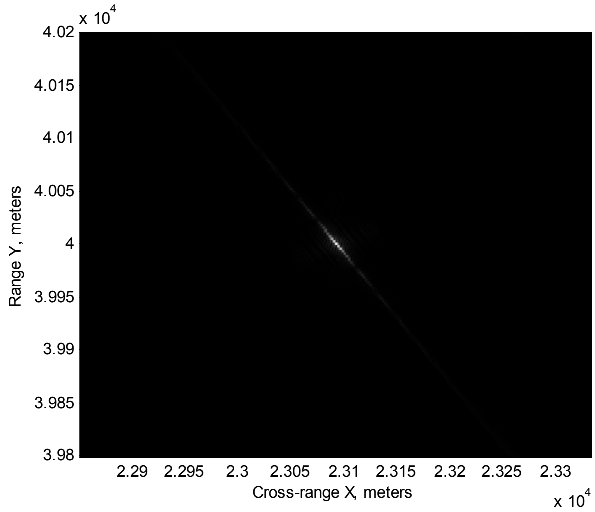


Fig.5. Point target with unstable reflectivity

Secondly, we present two point targets with the same parameters. Fig.6 simulates the cross section of two static point targets. They are both well focused.

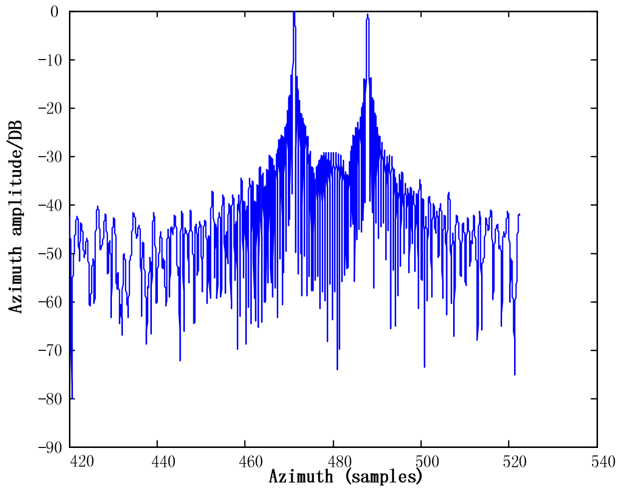


Fig.6. Two static point target

Thirdly, we present three points target with different LOS angle of 0° and 50°. Fig.7 and Fig.8 shows points target simulation for this imaging.

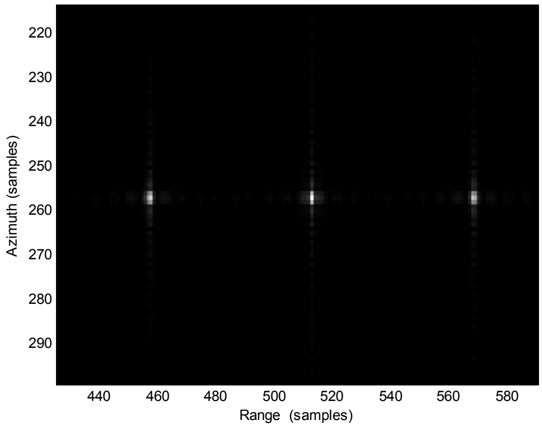


Fig.7. The first direction with LOS angle 0°

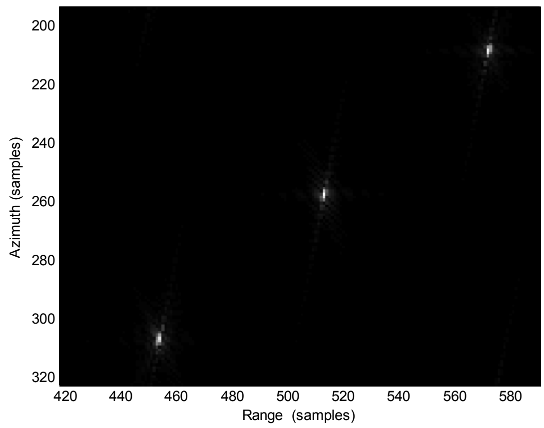


Fig.8. The first direction with LOS angle 50°

It shows that, the same points target with different LOS angle has different geometry and radiation distortion. If we combine each sub-image directly, the large image would be seriously distorted. In this case, geometry and radiation correction should firstly be presented before further process. And sub-image could then be combined together through the above MIAT-IR technology.

## VI. CONCLUSION

NS-LSSAR owns unique advantages compared with airborne and space-borne SAR. This paper has explained what characteristics NS-LSSAR owns and how it could be exploited for high resolution wide swath imaging applications.

Long air-staying time and large ground coverage are investigated. While Low-speed brings out the long synthetic time problem, then in order to deal with the slow imaging speed, the redundant PRF has been made full use of and the JAT is proposed to shorten the time needed for the large area imaging. This scheme shows simple construction, cost economy and high efficiency. Comprehensive simulation examples are provided to analysis these issues.

Further more, potential applications on NS-LSSAR such as low-speed target detection should be researched in the future.

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