EFFECT OF LINEAR ARRAY ELEMENTS SPACING ON ANGLE IMAGING PERFORMANCE OF DOWNWARD-LOOKING 3D-SAR

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1. INTRODUCTION

Three-Dimensional Synthetic Aperture Radar (3D-SAR) using linear array antennas (LAA) extends conventional SAR to 3D imaging by replacing the single antenna by a uniform linear array of antenna elements distributed along the cross-track direction (shown in **Fig. 1**). 3D-SAR using LAA obtains the azimuth resolution based on the synthetic aperture principle, the range resolution based on the pulse compression technique and the elevation angle resolution based on beamforming operation, therefore the 3-D high resolution radar images in cylindrical coordinates system are achieved. Furthermore, owing to the solution of angular resolving ability in the elevation angle direction [1], 3D-SAR using LAA has various observation modes including downward-looking and forward-looking except for conventional side-looking, and the advantage of downward-looking SAR system is the full ground range coverage without shadow effects [2]. Because of various advantages of downward-looking 3D-SAR using LAA, the new ARTINO system is being developed at FGAN-FHR [3, 4].

The main idea of 3D-SAR using LAA is to realize a high angle resolution in elevation direction with the linear array antennas distributed along the cross-track direction. Therefore, the parameters of LAA, mostly including the length of LAA and linear array elements spacing, have an important effect on elevation angular resolving performance. It has been clearly analyzed in [3] and [5] that the length of LAA determines the resolution of elevation angle. Analysis on the effect of linear array elements spacing, however, is ambiguous, and it is only mentioned in [4] that the distance between the elements must be equal to or smaller than half carrier wavelength to avoid spatial ambiguities [4]. It is a classical conclusion from array signal processing, but is not fit for angle imaging analysis. There are two reasons: first of all, elevation angle imaging range is not from $-\pi/2$ to $\pi/2$, but from $-\beta/2$ to $\beta/2$, where β denotes the length of angle imaging range decided by the beamwidth of transmit antenna; secondly, the distance between the radar and the target is transmit and receive round-trip range, which is different from one way range in DOA estimation.

This paper analyzes the effect of linear array elements spacing on angle imaging performance, including the configuration of LAA is monostatic mode, which each antenna element is used for transmitting and receiving, proposed in [3, 4] and single-transmit and multiple-receive (STMR) mode, which only one central antenna element transmits signal and the receive antenna elements are spatially separated from the transmit antenna, proposed in [5].

2. RELATION BETWEEN LAA ELEMENTS SPACING AND ELEVATION ANGULAR AMBIGUITY

2.1. Monostatic configuration

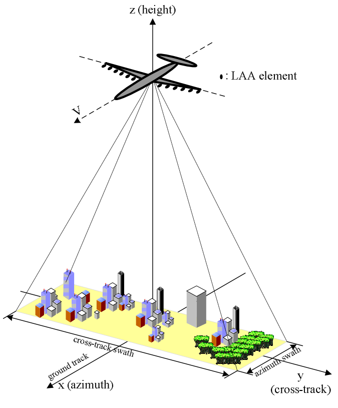

Fig. 1. Geometry of 3D-SAR using LAA

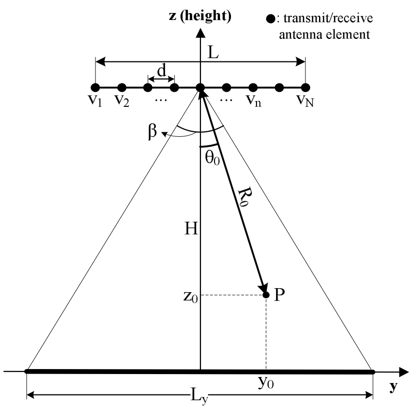

Fig. 2. monostatic configuration

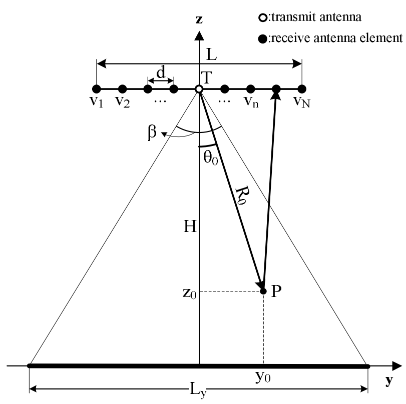

Fig. 3. STMR configuration

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The 3D imaging results of 3D-SAR using LAA with monostatic configuration is given as [3]

$$s_{r,a,e}(t,u,\theta;x_0,y_0,z_0) = C_{r,a}\cdot\left\{\sin\left[\frac{2\pi}{\lambda}Nd(\sin\theta-\sin\theta_0)\right]\Big/\sin\left[\frac{2\pi}{\lambda}d(\sin\theta-\sin\theta_0)\right]\right\} \tag{1}$$

where $C_{r,a}=\mathrm{sinc}\left[B_r\left(t-\frac{2R_0}{C}\right)\right]\cdot\mathrm{sinc}\left[B_a(u-x_0)\right]\cdot\exp\left(-j\frac{4\pi}{\lambda}R_0\right)$, $R_0=\sqrt{y_0^2+(H-z_0)^2}$ and $\sin\theta_0=y_0/R_0$, as shown in **Fig. 2**.

It is shown in expression (1) that it is a periodicity function with respect to sinθ and the period Δ can be calculated to λ/(2d). Grating lobe maxima occur at multiple integer of Δ. In order to avoid the occurrence of grating lobes, one should have

$$d\le\lambda\Big/\left(4\sin\frac{\beta}{2}\right) \tag{2}$$

For $\sin\beta/2\le\beta/2$, when $0\le\beta\le\pi$, inequation (2) can be expressed as

$$d\le D_e/2 \tag{3}$$

where D_e is the length of transmit/receive antenna element in cross-track direction.

2.2. STMR configuration

The 3D imaging results of 3D-SAR using LAA with STMR configuration (shown in **Fig. 3**) is given as [5]

$$s_{r,a,e}(t,u,\theta;x_0,y_0,z_0) = C_{r,a}\cdot\left\{\sin\left[\frac{\pi}{\lambda}Nd(\sin\theta-\sin\theta_0)\right]\Big/\sin\left[\frac{\pi}{\lambda}d(\sin\theta-\sin\theta_0)\right]\right\} \tag{4}$$

In order to avoid the occurrence of grating lobes in STMR configuration, one should have

$$d\le\lambda\Big/\left(2\sin\frac{\beta}{2}\right) \tag{5}$$

$$d\le D_e^T \tag{6}$$

where β is the beamwidth of transmit antenna, and D_e^T is the length of single transmit antenna in cross-track direction.

3. SIMULATION

The elevation angle θ_0 of scatterer P is 10°, and the range of the elevation angle imaging is [-30°, 30°], i.e. β=60°. The number of the antenna elements in the linear array is 101. The space between the antenna elements d is equal to $d_{max}/2$, d_{max}, $2d_{max}$ and $4d_{max}$, respectively, where $d_{\max}=\lambda/(4\sin 10^\circ)=11.5mm$ and $\lambda=8mm$. The imaging results in elevation angle are shown in **Fig.4**.

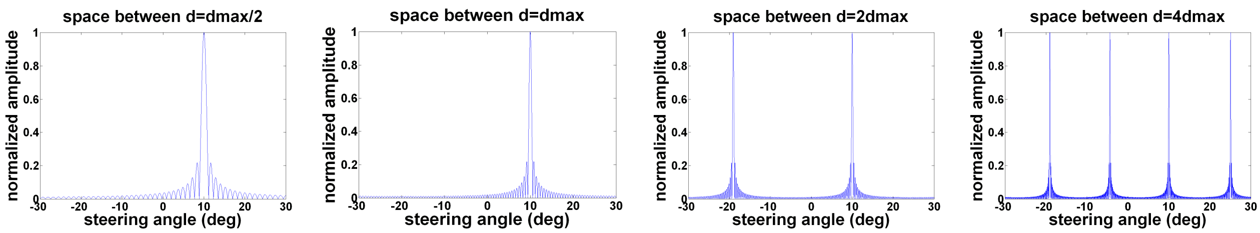

Fig. 4. The imaging results in elevation angle with different linear array elements spacing

The angle resolution is inversely proportional to the space between d when the number of the antenna elements N is invariable. When the space between the antenna elements is larger than d_{max}, elevation angular ambiguity will occur.

4. CONCLUSIONS

The condition satisfied, i.e., the maximal distance between individual antenna elements allowed, to avoid elevation angular ambiguity is discussed in this paper, and the elevation angular ambiguity problem of 3D-SAR using LAA with monostatic configuration is also studied by simulation in the last part of the paper.

5. REFERENCES

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