Bistatic Micro-Doppler Characteristics of Precession Targets

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Abstact: Micro-motion is one of the most important features for radar target recognition. Firstly, the bistatic micro-Doppler models corresponding to the bistatic scattering centers of the precession targets are derived. Then, The dynamic simulation method of the bistatic echo of the precession target is presented using the bistatic scattering coefficients obtained via electromagnetic calculations, and the bistatic scattering coefficients of the blunt-nosed biconical model are calculated using the multilevel fast multipole method. Finally, the theoretic analysis is verified by comparing the time-frequency distribution of the bistatic echo sequences with the theoretical bistatic micro-Doppler. This research is helpful for utilizing the bistatic micro-Doppler for feature extraction and recognition of spatial micro-motion targets.

1. Bistatic scattering Model

According to the geometrical diffraction theory, five bistatic scattering centers of the blunt-nosed biconical model are located at the intersection of the vertex, cone-cylinder edge and bottom edge and the plane that is constructed by the symmetry axis and the bisector of the bistatic angle, and they are labeled as A,B,C,D,E. These bistatic scattering centers changes with the target moving and bistatic geometric configuration. Especially, for the fixed bistatic radar, these bistatic scattering centers will slide on the edge continuously with the target precession.

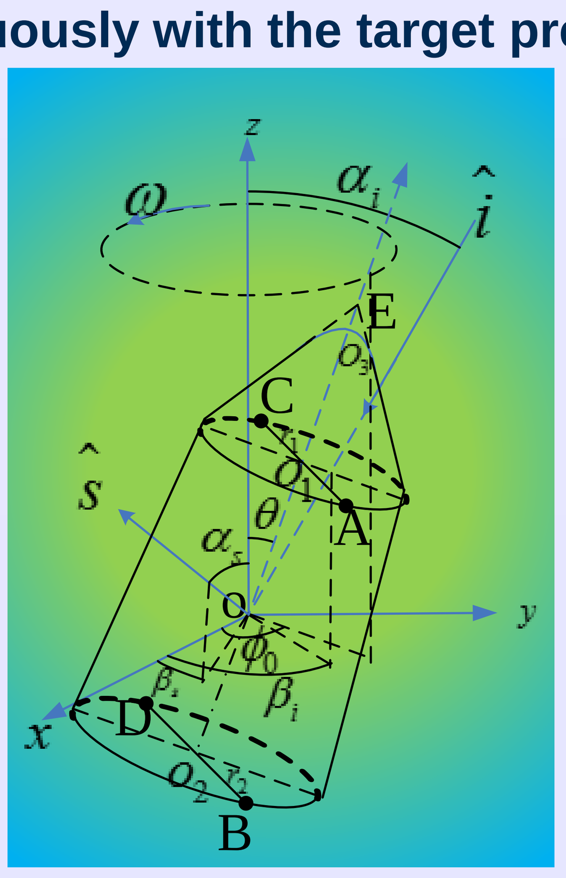


Fig.1 Precession blunt-nosed biconical model

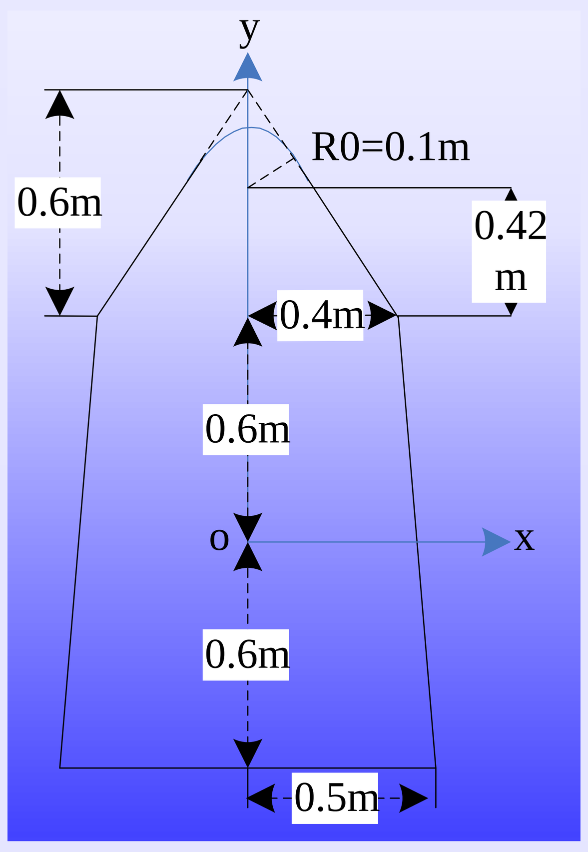


Fig.2 Target size

The angle between the incident vector and the symmetry axis can be expressed as

$$\cos\theta_i = \cos\theta\cos\alpha_i + \sin\theta\sin\alpha_i\cos\left(\omega t + \phi_0\right)$$

The angle between the scattering vector and the symmetry axis can be expressed as

$$\cos\theta_s = \cos\theta\cos\alpha_s + \sin\theta\sin\alpha_s\cos\left(\omega t + \phi_0 - \beta_s\right)$$

The bistatic angle satisfies

$$\cos(\psi) = \sin\alpha_i\sin\alpha_s\cos\left(\beta_i - \beta_s\right) + \cos\alpha_i\cos\alpha_s$$

According to the spatial geometry, the azimuth angle of the LOS of the receiver in the local ordinates, can be approximated by the following expression

$$\cos\varphi_s \approx \frac{\cos\psi - \cos\theta_i\cos\theta_s}{\sin\theta_i\sin\theta_s}$$

The bistatic scattering coefficients are decided by the angles

$$(\theta_i,\ \theta_s,\ \varphi_s)$$

2. Bistatic micro-Doppler Model

According to the bistatic range and differential, the bistatic micro-Doppler of the scattering center A, B,C D and E can be expressed as follows, respectively.

$$\begin{cases} f_{A,C}(t) = -2\dfrac{f_0}{c}\omega\cos\dfrac{\psi}{2}\sin\theta\sin\alpha\sin\left(\omega t+\phi_0-\phi_1\right)\left(-|OO_1| \pm r_1\Delta(t)\Big/\sqrt{1-\Delta^2(t)}\right) \\ f_{B,D}(t) = \dfrac{2f_0}{c}\omega\cos\dfrac{\psi}{2}\sin\alpha\sin\theta\cos\left(\omega t+\phi_0-\phi_1\right)\left(-|OO_2| \mp r_2\Delta(t)\Big/\sqrt{1-\Delta^2(t)}\right) \\ f_E(t) = -2|OO_3|\dfrac{f_0}{c}\omega\cos\dfrac{\psi}{2}\sin\alpha\sin\theta\sin\left(\omega t+\phi_0-\phi_1\right) \end{cases}$$

3. Dynamic simulation and analysis

A conductive blunt-nosed biconical model is constructed using FEKO software to verify the previously described analysis using the parameters shown in Fig.2. And the electromagnetic calculation parameters are listed in Table 1.

Table.1 Electromagnetic calculation parameters

Parameter	Unit	Value
Frequency	GHz	8
Incident elevation	deg	0~180
Scattering elevation	deg	0~180
Scattering azimuth	deg	0~180
Angle interval	deg	0.2

The dynamic simulation flow chart is described as follows

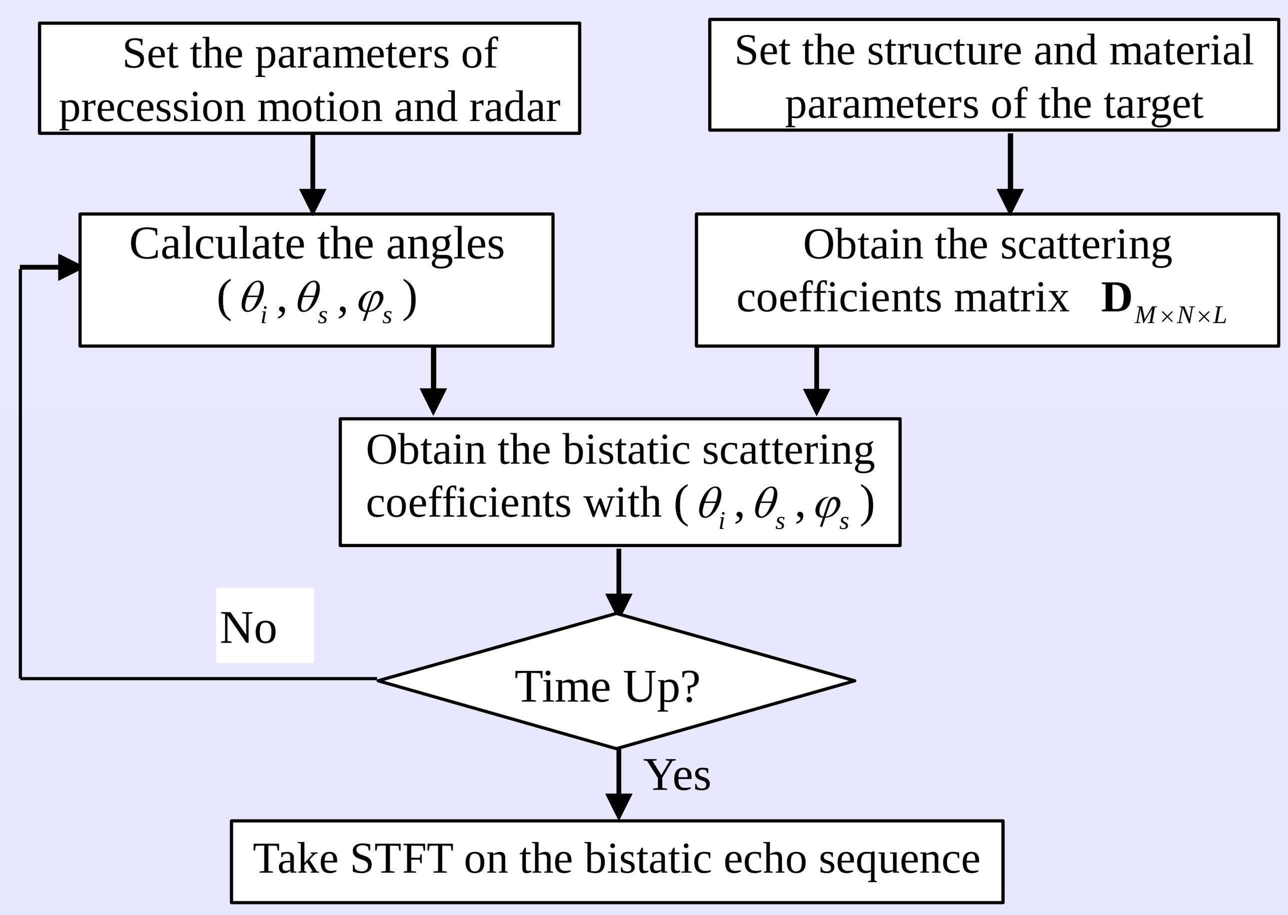
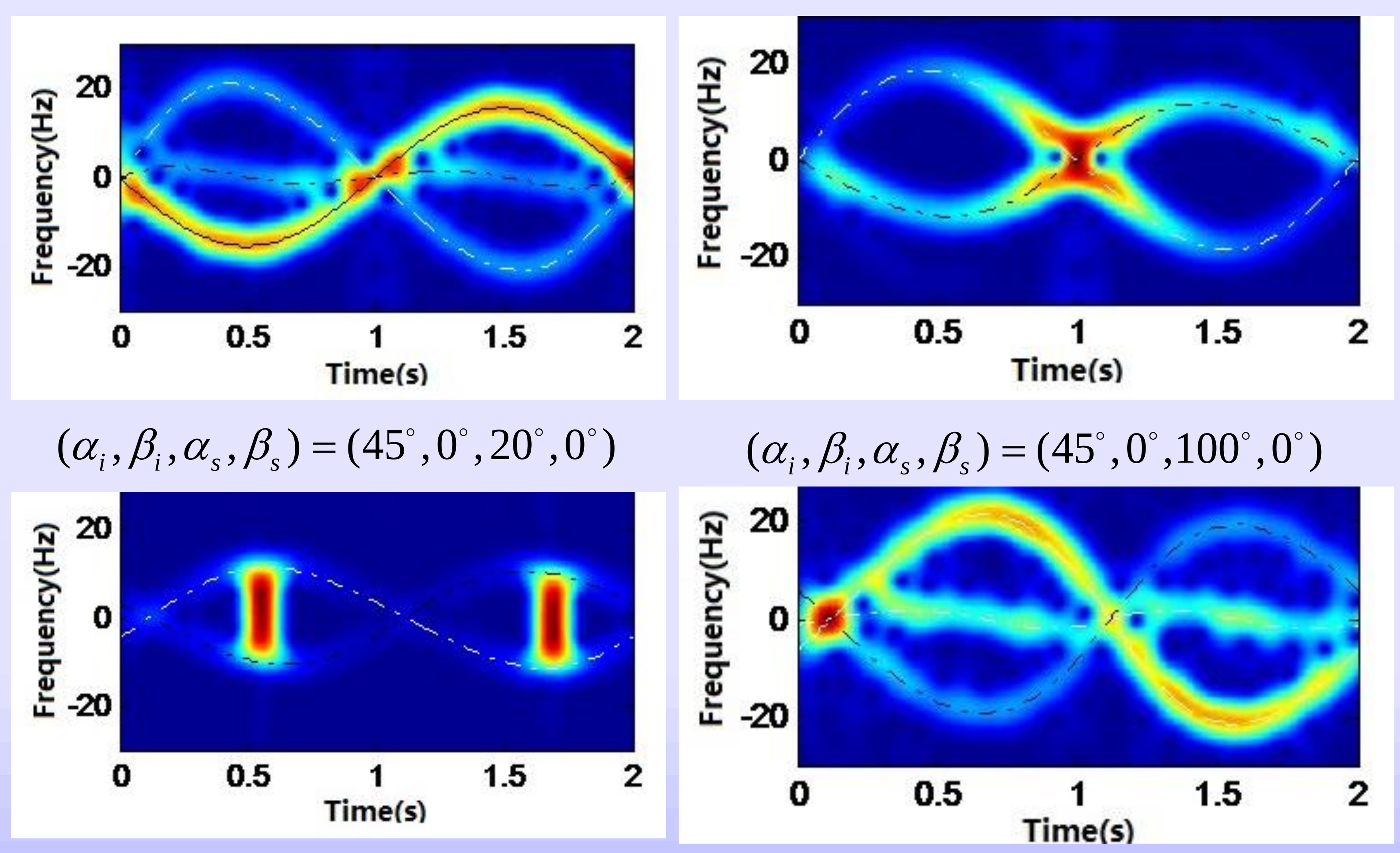


Fig.3 Flow chart of the dynamic simulation

The simulation parameters: precession angle 10deg and precession frequency 0.5Hz.



$(\alpha_i,\beta_i,\alpha_s,\beta_s) = (45^\circ,0^\circ,20^\circ,0^\circ)$ $(\alpha_i,\beta_i,\alpha_s,\beta_s) = (45^\circ,0^\circ,100^\circ,0^\circ)$

$(\alpha_i,\beta_i,\alpha_s,\beta_s) = (135^\circ,0^\circ,40^\circ,45^\circ)$ $(\alpha_i,\beta_i,\alpha_s,\beta_s) = (135^\circ,0^\circ,140^\circ,45^\circ)$

Fig.4 Time-frequency distribution of precession blunt-nosed biconical model

4.Conclusion

Although the bistatic micro-Doppler model can be simplified as the monostatic case, the complexity of bistatic geometry configurations leads to large differences in observed target characteristics, which bring new challenges in utilizing the bistatic micro-Doppler for feature extraction and recognition. Only part of the scattering centers can be observed with one observation aspect from the dynamic simulation, whereas the entirety of all scattering centers can be observed by multi-aspect observation. Future studies will consider a method for simultaneous extraction of the target size and precession angle via multiple receivers.