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Effect of earth's rotation on space based radar clutter

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Abstract. The purpose of the present problem is to study the influence of space-based early warning radar (SBEWR) clutter power spectrum with orbit altitude under the condition of earth rotation. To reach this goal, it first analyses the change of Doppler frequency of SBEWR clutter with the change with orbit altitude, then studies the clutter power spectrum change with orbit altitude and earth rotation. Concludes the Doppler frequency increases and the clutter spectrum widens with the increase of orbit altitude. In addition to orbit altitude, the effect is related to earth rotation and orbital inclination. And finally verifies the conclusion by simulations. The conclusions can provide theoretical foundation of selections for SBEWR's orbital parameters.

Key words. Orbit altitude, Space-based early warning radar, Doppler shift, Clutter characteristic spectrum.

1. Introduction

I Radar clutters are useless object signals reflected by radars reach the ground, sea surface and buildings when electromagnetic waves sent out. For most radar, these are useless echoes, but their power is very strong, which brings trouble to the detection of useful signals. Under such circumstances radars are used to detect the useful information of objects from these strong ground clutters. Therefore, the accurate simulation of radar clutters is vital to improve radar performance.

In recent years, due to its advantages space-based radars enjoy [1], such as air-to-ground and air to-air boundless detection, they catch more and more attention of military powers. However, space-based radars also have to face the influence of the earth's rotation [2], which makes space-based radar clutters more complicated, and thus has seriously affected the work performance of space-based radars. The

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change of the yaw angle with the orbital inclination and substellar point latitude is researched in [3]. The formulas of yaw angle and yaw amplitude derived from the earth rotation are derived in papers [4-6]. The space-time clutter model and characteristics is researched in [7-8]. And the effect of earth's rotation and range ambiguity is considered in [9].

In order to understand the clutter characteristics of space-based radars and suppress clutters effectively, this paper studies the effect orbit altitude has on space-based radar clutters under the influence of earth's rotation, deeply analyzes the DOF (degrees of freedom) of clutter and clutter power spectrum with the change of orbit altitude, and then provides a theoretical basis for the selection of space-based radar orbit altitude.

2. Doppler characteristic analysis of space-based radar clutters

For convenience, clutters studied in this paper are static relative to the ground, in other words, relative speed between the clutter and the space-based radar is equal to the working speed of space-based radars. Therefore, without reference to the earth rotation, Doppler frequency of space-based early warning radar ground clutter is:

$f_d = \frac{2V_p}{\lambda} \sin\theta_{EL} \cos\theta_{AZ}$, 1

In the formula, λrepresents the operating wavelength, V_p represents the space-based early warning radar speed, $\theta_{EL}$is the pitch angle of space-based radar, $\theta_{AZ}$is azimuth angle of the space-based radar.

However, the space-based radar is always affected by earth rotation; Doppler frequency of space based radar clutter is consequently changed. Literature [2] gives the Doppler frequency of the space-based radar clutter in consideration of earth rotation.

$f_d = \frac{2V_p}{\lambda} \rho_c \sin\theta_{EL} \cos(\theta_{AZ} + \phi_c)$, 2

In the formula, ϕ_c is the yaw angle, $\rho_c$is the yaw amplitude. Relations between ϕ_c and $\rho_c$with the substellar point latitudeα_1, orbit inclination angle η_i and the orbital altitude H are:

$\phi_c = \tan^{-1}(\frac{\Delta\sqrt{\cos^2\alpha_1 - \cos^2\eta_i}}{1-\Delta\cos\eta_i})$, 3

$\rho_c = \sqrt{1 + \Delta^2\cos^2\alpha_1 - 2\Delta\cos\eta_i}$, 4

In the formula,$\Delta = \frac{V_e}{V_p}(1 + \frac{H}{R_e})$,$R_e$ is the earth radius, V_e is the rotation speed of the earth.

Formula (3) and formula (4) show, when substellar point latitude and orbit inclination angle of the space radar are definite, considering the influence of the earth rotation, Doppler frequency of the space-based radar clutter will be influenced by the orbital altitude. When the orbital altitude increases from H_1 to H_2, Doppler frequency difference of the space-based radar clutter is:

$\Delta f_d = f_{d2} - f_{d1} = \frac{2V_{p2}}{\lambda}\rho_{c2}\sin\theta_{EL}(\cos(\theta_{AZ} + \phi_{c2})) - \frac{2V_{p1}}{\lambda}\rho_{c1}\sin\theta_{EL}(\cos(\theta_{AZ} + \phi_{c1}))$, 5

According to formula (3) and formula (4), it is found that the change value of Δ caused by the orbit change is extremely small. According to the tangent function, when $x \to 0$, the nature of $\tan x \approx x$, and when altitude change is much smaller than the earth radius $V_{p1} \approx V_{p2}$, simplify the above equation:

$$\triangle f_d = -2V_e h\sqrt{cos^2\alpha_1 - cos^2\eta_i}\rho\sin\theta_{EL}\ \sin\theta_{AZ}\ /\lambda R_e(1-\triangle\cos\eta_i\ ) \tag{1}$$

3. Characteristics analysis of space-based radar clutters

The literature [6] gives the covariance matrix formula of the space-based early warning radar ground clutter, namely:

$$R_c = [r\,(\Delta n, \Delta k)]_{NK\times NK}, \tag{2}$$

Here, [ ] represents matrix. $r\,(\Delta n, \Delta k)$ represents the covariance of ground clutter which array differential isΔn and time difference isΔk.

In the formula $n_1, n_2=1, 2, \cdots, N$, $k_1, k_2=1, 2, \cdots, K$.

$$\omega_s(\theta_{AZ}, \psi_l) = \frac{2\pi d}{\lambda}\cos\theta_{AZ}\cos\psi_l, \omega_t(\theta_{AZ}, \psi_l) = \frac{4\pi V_p}{\lambda f_r}\cos\theta_{AZ}\cos\psi_l, \tag{3}$$

In the formula, $\omega_s(\theta_{AZ}, \psi_1)$ is angular frequency of air zone $\omega_t(\theta_{AZ}, \psi_1)$ is angular frequency of time domain, $N$is the sampling number of air zone, $K$is the sampling number of time domain, $f_r$is the pulse repetition frequency, ψ is the grazing angle, d is the submatrix space, $g_n\,(\psi_l)$ is reception directional pattern of the NO.n row submatrix, $F\,(\theta_{AZ}, \psi_1)$is the transmitting directional pattern, R_l is the radar slant range corresponding to the NO.l range ring, $L$is the totality of maximum unambiguous range.

According to the calculation formula of angular frequency of time domain and clutter Doppler frequency, when the grazing angle ψ and pitch angle θ_{EL} satisfy $\psi + \theta_{EL} = \frac{\pi}{2}$,it can be found that the relations of them is $w_t\,(\theta_{AZ}, \psi_l) = 2\pi f_d/f_r$. Considering the earth rotation, variation difference of angular frequency caused by the change of orbit altitude is $\triangle w_t\,(\theta_{AZ}, \psi_l) = 2\pi\triangle f_d/f_r$. Put equation (6) into it:

$\Delta\omega_t(\theta_{AZ}, \psi_l) = \frac{2\pi\triangle f_d}{f_r} = -\frac{4\pi V_e}{\lambda f_r}\frac{h}{R_e}\frac{\sqrt{\cos^2\alpha_1 - \cos^2\eta_i}}{1-\Delta\cos\eta_i}\rho\sin\theta_{EL}\sin\theta_{AZ}$. 10

When the grazing angle, azimuth, orbital inclination and substellar point latitude are certain, the formula (10) shows that the airspace angular frequency difference is proportional to the orbital altitude difference and speed of the earth rotation, is inversely proportional to the radius of the earth and radar working wavelength, and has nothing to do with the speed of the space-based early warning radar. With the change of airspace angular frequency, degrees of freedom of clutter and spectrum breadth of clutter change consequently, so that the performance of detecting moving targets is consequently lowered.

4. Simulation

Figure 1 shows the simulation results of Doppler shift of space-based radar while the cone angle cosine change, where the orbital inclination is 75^o, the substellar point latitude is 30^o, the altitude of the orbit is 600 km, 1400 km, 2200 km, 3000 km and 3800 km respectively. The simulation results shows, when the orbital inclination and the substellar point latitude are certain, cone angle cosine of space-based radar clutter – the curvature of Doppler track is more serious with the increase of altitude. Figure 2 (a), (b) and (c) show the variation of clutter characteristics spectrum of space-based early-warning radar with the change of angle cosine respectively. Simulation conditions: orbital inclination is 75^o, substellar point latitude is 30^o, the radar wavelength is 0.25m, element spacing is half-wavelength, pulse repetition frequency is 120kHz. Row array element, column array element, and pulse number are all 8. Figure 3 (a), (b), (c) simulate the power spectrum of clutter in the above three cases. Figure 4 (a), (b), (c) simulate the clutter power contour map in the above three cases. Figure 2 shows that freedom degree of clutter spectrum of space-based radar increases with the increase of orbital altitude. Figure 3 and Figure 4 show that the clutter spectral breadth increases with the increase of orbital altitude, in other words, the space-based radar will be seriously affected by ground clutter, target-detecting capacity decreases with the increase of orbital altitude. Above

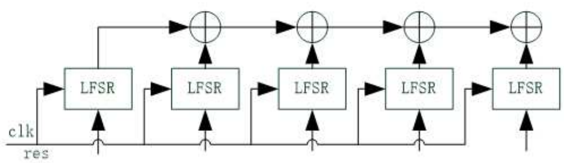


Fig. 1. Normalized doppler shift of the clutter

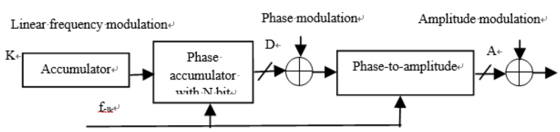
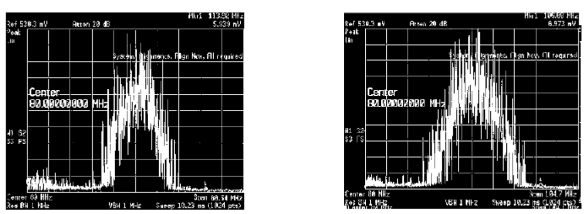


Fig. 2. The clutter characteristics spectrum of the space-based early-warning radar



(a) $\Delta w_{0.5} = 40.27$ MHz (b) $\Delta w_{0.5} = 52.35$ MHz

Fig. 3. Clutter spectrum of the space-based early-warning radar

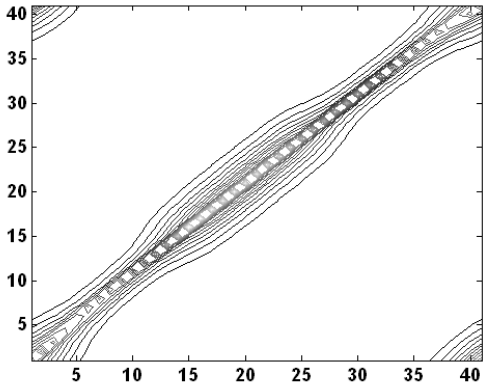


Fig. 4. Clutter power contour map of space-based early-warning radar

simulations show:

(1) Considering the earth rotation, when the orbital inclination and the substellar point latitude are certain, cone angle cosine of space based radar clutter – the curvature of Doppler track is more serious with the increase of orbit altitude.

(2) The freedom degree and spectral bandwidth of space-based radar clutter increase with the increase of orbital altitude then influence space-based radar operating performance.

5. Conclusion

Under the influence of the earth rotation, Doppler shift occurs to clutters, thus reducding the performance of space-based early-warning radar. In order to better study clutter characteristics of space-based early-warning radar, this paper studies the effect of the orbit altitude change on clutters of early-warning radars under the influence of the earth rotation, makes a detailed analysis of relationship between the orbit altitude, clutter Doppler frequency and clutter characteristics, derive the formula of the clutter Doppler frequency and time angular frequency with the change of orbit altitude, therefore draws a conclusion that Doppler shift is more serious with the increase of orbit altitude, and finally verifies the conclusion through simulations. Simulation results also indicate that the radar will be affected seriously by ground clutters and its performance will be decreased with the increase of orbit altitude. The conclusion provides theoretical grounds for selecting orbital altitude and orbital inclination for space-based early-warning radar.

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