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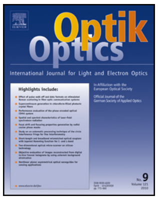

Simulation analysis of an active cancellation stealth system

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ABSTRACT

Active cancellation stealth is a smart signal blanking method, that it has become an important developing direction on modern stealth technology. In order to further explore the active cancellation stealth technology, we are considering the detection and cancellation of receiving/transmitting antenna pattern is different. Put forward active cancellation system simulation structure diagram based on MATLAB/SIMULINK, where the phased array radar system as the modelling object, and established the active cancellation stealth system mathematical model based on digital radio frequency memory (DRFM) and the radar signal processing system of the coherent video simulation model, based on linear frequency modulation and radar coherent pulse signal simulation, verified the rationality and validity of the design, as the active cancellation stealth engineering technology laid the foundation.

1. Introduction

The aim of this paper is to focus on the simulation analysis of an active cancellation stealth system of large and complex radar targets. Active cancellation stealth technology can be widely used in airplane, laser detection and ranging (LADAR) system and other equipment. In these systems, the target must emit cancellation wave in time coincidence with the incoming pulse whose amplitude and phase cancel the reflected energy. The difficulty lies in the need of real-time and accurate to obtain cancellation signal parameters, precise control of the cancellation wave field amplitude and phase [1].

We build up a radar signal processing system of the coherent video simulation model and an active cancellation stealth system model based on digital radio frequency memory (DRFM). The design procedure has the flexibility of designing the algorithm using MATLAB/SIMULINK. Through, the simulation can be in a relatively short period of time with low cost to achieve system design, promote active cancellation stealth system study.

The classical simulation techniques for RCS reduction are based on a target model in terms of facets and wedges. Using this approach, the identification of illuminated and shadowed regions on the geometrical model of the target is very precise by using target simulation and jamming based on DRFM.

2. Coherent video signal simulation model

Target echo signal can be expressed as [2]:

$$s_r(t) = \left[\frac{\lambda^2}{(4\pi)^3 R^4}\right]^{1/2} G(t)\gamma(t)s_t[t-\tau(t)] \tag{1}$$

where λ is radar signal wavelength; R is the distance from the target to the radar; $G(t)$ is the one-way power gain of the antenna in the target direction; $\gamma(t)$ is complex reflection coefficient of the target, represent the scattered electric field amplitude and phase, characterization of the target echo fluctuation characteristics. $s_t(t)$ is calculated by (2):

$$s_t(t) = u(t)\exp[j2\pi(f_0+f_d)t] \tag{2}$$

where $u(t)$ is the complex envelope of the narrow-band transmitted pulse; f_0 is the fundamental carrier frequency; f_d is the Doppler frequency, $f_d = 2v_d/\lambda$ (v_d is the radial velocity of the target relative to the radar, that $v_d > 0$ means the target moves away from the radar).

Where the time-varying delay $\tau(t)$ is

$$\tau(t) = 2\frac{R(t)}{c} \cong \frac{2R_0}{c} + \frac{2v_d t}{c} = \tau_0 + \frac{2v_d t}{c} \tag{3}$$

and R_0 is the initial range position; τ_0 is the initial time delay; c is the light speed.

Note that $G(t)$, $\gamma(t)$ and $\tau(t)$ are slowly changed function of varying with time. Assuming that the goal is a point target, the scanning beam gain in the direction of the target (a function of the elevation

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and azimuth angles) is given by G; f_d can be approximated as a constant because $v_d \ll c$ and time-bandwidth product $B\tau \ll c/2v_d$ (B is signal bandwidth, τ is pulse width); $\gamma(t)$ is only concerned with σ (σ is the radar cross section of the target, namely RCS).

Therefore Eq. (1) can be simplified as:

$$s_r(t) = \left[\frac{\lambda^2}{(4\pi)^3 R^4}\right]^{1/2} G(\theta,\varphi)\sqrt{\sigma}u(t-\tau)\exp(j2\pi f_d t) \tag{4}$$

where θ is azimuth and φ is elevation.

From (4), it can be noted that the point target coherent video signal simulation mainly include: the complex envelope of the radar transmitting signal $u(t)$, antenna pattern function $G(\theta,\varphi)$ and the target parameters (including the target distance, radial velocity, acceleration characteristics, RCS) simulating.

2.1. Complex envelope of the radar transmitting signal u(t) simulation

Conventional radar transmitting signal bandwidth is smaller than the emission carrier frequency, and most of the energy is concentrated in the carrier frequency, so it is a narrow band signal. Common signal form includes: coherent pulse train signal, linear frequency modulation (LFM) signal and phase coded signal. The three complex envelope function of the modulation signal $u(t)$ as shown below [3]:

$$u(t) = A\sum_{i=0}^{N-1} rect\left[\frac{t-iT_r}{\tau}\right] \tag{5}$$

$$u(t) = A\sum_{i=0}^{N-1} rect\left[\frac{t-iT_r}{\tau}\right]\exp\left[j\pi\frac{B}{\tau}t^2\right] \tag{6}$$

$$u(t) = \frac{A}{\sqrt{P}}\sum_{i=0}^{N-1} rect\left[\frac{t-iT_r}{\tau}\right]\cdot \exp\left[j\sum_{i=0}^{P-1} c_i rect\left[\frac{t-iT_r}{\tau}\right]\right] \tag{7}$$

where $rect(t/\tau) = \begin{cases} 1, & |t/\tau| \le 1/2 \\ 0, & |t/\tau| > 1/2 \end{cases}$ is rectangular window function; A is signal amplitude; T_r is pulse repetition cycle; N is burst pulse number; c_i is phase-coded sequences in the i sub code value, the value is only desirable 0 or π for Binary code; P is phase-coded length.

2.2. Phased array antenna pattern function simulation

According to the characteristic of phased array antenna, based on the literature [4] of the antenna pattern function model were simplified, described in detail as follows:

$$F(\theta) = \begin{cases} ASa\left[\dfrac{\alpha\theta}{\theta_1/2}\right]K_0, & |\theta| \le \alpha_1 \\ BSa\left[\dfrac{\alpha(\theta \pm \alpha_{1,5})}{\theta_2/2}\right]K_0, & |\theta| > \alpha_1 \end{cases} \tag{8}$$

where $K_0 = \sqrt{\cos\theta_0}$ is the control of phased array antenna beam gain with the scanning angle variation factor (θ_0 is beam scanning angle); θ_1 is unbiased beam main lobe beam-width of 3 dB; θ_2 is unbiased beam first side-lobe 3 dB width; A is unbiased beam main lobe gain value; B is unbiased beam first side-lobe gain value; $a = 2.783$; $a_1 = \pi\theta_1/a$ is unbiased beam first zero(radian); $a_{1.5} = \pi\left(\theta_1+\theta_2\right)/a$ is unbiased beam first side-lobe peak point of view (radian). The three-dimensional pattern can be simplified into azimuth and elevation pattern multiplication result, namely:

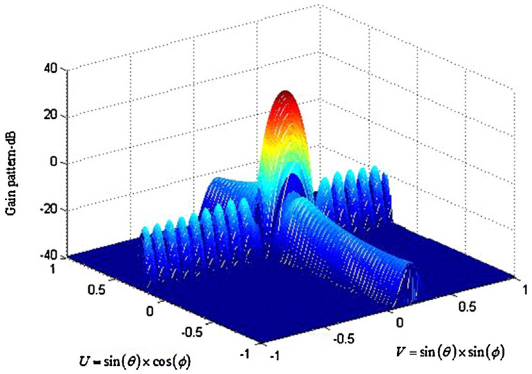

Fig. 1. 3D antenna pattern.

$$F(\theta,\varphi) = F_\theta(\theta)F_\varphi(\varphi) \tag{9}$$

where $F_\theta(\theta)$ is azimuth pattern and $F_\varphi(\varphi)$ is elevation pattern.

Assumption of the radar antenna vertical main lobe beamwidth is 2°, the main lobe gain is 40 dB; the first sidelobe width is 1°, the gain is 9 dB. The 3D antenna pattern as shown in Fig. 1.

2.3. Target parameters simulation

Set the initial time is 0, the distance is R_0, the radial velocity is v_0, the radial acceleration is $a(t)$, so the target radial velocity in time t is:

$$v_d(t) = v_0 + a(t)t \tag{10}$$

The target distance is:

$$R(t) = R_0 + \frac{a(t)t^2}{2} \tag{11}$$

The target RCS is simulated by χ^2 distribution model, determined the random number which in compliance with χ^2 distribution by using the rejection method, the steps as followed:

(1) Calculation of the constants: $a = \sqrt{2k-1}$, $b = 2k - \ln 4 + 1/a$;
(2) Generate uniformly distributed, independent random number r_1 and r_2 in [0 1] interval;
(3) $y = k[r_1/(1-r_1)]^k$;
(4) If $y > b - \ln(r_1^2 r_2)$, refused to r_1 and r_2 then returns to the step (2);
(5) If $y \le b - \ln({r_1}^2 r_2)$, then random variable $x = y/(k/\sigma_{av}) = \sigma_{av}[r_1/(1-r_1)]^k$, that is the random variable in compliance with χ^2 distribution.

Marcum model and Swerling model I–IV can be simulated by changing the k value [5].

3. Receiver noise simulation

In general, receiver noise is the white Gaussian noise, and the narrowband filter output envelope obeys the Rayleigh distribution. Therefore, we need to produce two mutually orthogonal, independent of random numbers which fit the standardized normally