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Simulation and verification of active cancellation system

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ABSTRACT

In this paper, the expressions of active cancellation signal of the LFM and NLFM are introduced and a simulation model of active cancellation system based on Simulink is investigated. The generation of target echo signal and cancellation signal based on Simulink has been proposed in details. Active cancellation is combined with RCS calculation and detection probability calculation to further measure the effectiveness of the system. The simulation is carried out on a stealth unmanned reconnaissance aircraft RQ-170 and result shows that after active cancellation, the peak of spectrum analyzer has reduced in all azimuths; the omnidirectional RCS has also decreased; the detection probability of all azimuths has dropped under 50% which can be considered as undetectable target.

1. Introduction

Stealth technology is an integrated technology to make it difficult for detection system to find the targets through changing the detectable signal characteristics of weapons, platforms or other targets. Stealth technology can be divided into active stealth technology and passive stealth technology. Passive stealth technology include shaping method, absorbing material method and passive cancellation method. Active stealth technology mainly include electronic spoofing and active interference, smart materials, active cancellation.

Active stealth technology is artificially changing the radar target scattering distribution characteristics through active means to reduce the radar receiving power of the target echo, thus making the target achieve stealth purpose. Active stealth technology can adapt to the diversity of protected targets and protect target in any shape in principle [1].

Active cancellation is a smart mode of active stealth technology. It combines target scattering field and the artificial introduced radiation field in the radar direction to realize coherent cancellation, thereby reducing the radar cross section (RCS) in the radar direction [2,6]. Active cancellation does not involve changes in the platform profile and structure, so it is particularly suitable for the installation of existing platforms [1].

At present, there are few studies on active cancellation. Liang pointed out that if active cancellation satisfies the following two conditions: (1) The RCS of equivalent scattering center is equal to the RCS of original scattering center. (2) The phase difference is$(2k+1)\pi$; the best cancellation parameter can be achieved [3]. Qu carried out an active cancellation analysis of some typical signals, such as coherent pulse signal, phase encoded signal as well as linear frequency modulation signal [4]. Wang developed a radar echo cancellation algorithm on LFM signal and gave the simulation results [5]. The current study does not propose a complete method for process of active cancellation system and measurement of the effectiveness of the system. There are also no complete Simulink block diagram of active cancellation system. We can deal with a variety of radar signals if we have a generic Simulink model.

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This paper aims to design an active cancellation system, calculate the equivalent RCS after active cancellation and measure the effectiveness of the active cancellation using detection probability. This paper is divided into five parts. The first part mainly describe linear frequency modulation (LFM) signal and four kinds of non-linear frequency modulation (NLFM) signal and derive the expression of their cancellation signal; the second part is the theoretical basis of the simulation; the third part is the process of establishing the simulation model using Simulink; the forth part is an active cancellation example carried on RQ-170 using the simulation model in this paper; the fifth part is to analyze the result of the simulation and draw a conclusion.

2. LFM and NLFM signal

The time domain complex signal of the pulse waveform can be written as:

$$s(t) = s_e(t)e^{j\varphi(t)} \tag{1}$$

where $s_e(t)$ denotes signal complex envelope; $\varphi(t)$ denotes the phase modulation function. The relationship between frequency function and phase function is shown as:

$$\varphi(t) = 2\pi \int_{-\infty}^{t} f(\lambda)d\lambda \tag{2}$$

Therefore the phase modulation function $\varphi(t)$ can be got through frequency function $f(t)$.

The jamming signal $e(t_1)$ is given by:

$$e(t_1) = s(t_1) \times s^*(t_1 - \Delta\tau) \times a_{RCS} \times \exp(j\varphi_{RCS}) \tag{3}$$

where $\Delta\tau$ is the jammer processing delay, a_{RCS} and φ_{RCS} respectively denote the amplitude and phase characteristic of target. $s^*(t)$ is the complex conjugate of $s(t)$. Let $s(t_1) = s(t - \tau_1)$,τ_1 is the time interval between radar signal received time and cancellation signal transmitted time, so the cancellation signal $S_J(t)$ can be expressed as follows [7,8]:

$$\begin{aligned} S_J(t) &= s(t - \Delta\tau) \times e(t_1) \\ &= s(t - \Delta\tau)s(t - \tau_1) \times s^*(t - \tau_1 - \Delta\tau) \times a_{RCS} \times \exp(j(\varphi_{RCS} + \pi)) \end{aligned} \tag{4}$$

For LFM signal, the signal complex envelope is rectangular envelope and shown as:

$$s_e(t) = \frac{1}{\sqrt{T}} rect(\frac{t}{T}), |t| < \frac{T}{2} \tag{5}$$

The phase modulation function $\varphi(t)$ is written as:

$$\varphi(t) = \frac{\pi B}{T}t^2 = \pi\mu t^2, |t| < \frac{T}{2} \tag{6}$$

where B is the bandwidth, T is the pulse duration, $\mu = B/T$ represents slope of frequency modulation.

According to Eq. (4), the cancellation signal for LFM signal can be obtained and simplified as follows [9]:

$$S_J(t) = s(t)a_{RCS} \exp[j(\varphi_{RCS} + \pi)] \exp(-j\pi\mu\tau_1\Delta\tau) \tag{7}$$

Next we discuss cancellation signals of four different kinds of NLFM waveform as follows:

(1) Taylor window function modulation NLFM waveform

The frequency function $f(t)$ can be written as [10]:

$$f(t) = \frac{Bt}{T} - \frac{B}{2} + \sum_{n=1}^{\infty} A(n)B \sin\frac{2\pi nt}{T} \tag{8}$$

where $A(n)$ is the coefficient of the infinite series. Therefore the phase function $\varphi(t)$ can be acquired by Eq. (2) and given as:

$$\varphi(t) = \frac{\pi Bt^2}{T} + 2BT\sum_{n=1}^{N}\frac{A(n)}{n}\sin^2(\frac{\pi nt}{T}) \tag{9}$$

The quality of the waveform is not affected when Fourier series term is finite. Choose $N = 10$ in Eq. (9).