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Research on active cancelation stealth technique

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ABSTRACT

As the science and technology develop rapidly, active cancelation stealth is being taken increasingly seriously as a smart stealth means. The basic principle of active cancelation stealth is introduced, then the research on key technologies of cancelation wave based on active cancelation stealth is analyzed. And the influences of amplitude and phase errors on stealth are discussed. The analysis and discussion indicates that the technology of active cancelation stealth is feasible in theory and difficult in engineering, but also has a bright future in application.

1. Introduction

The modern war has much more need for the stealth and capabilities of the weapons, so the world with various military powers has always tried to find new methods that can make them stealthier. One of which is active cancelation stealth.

The concept of active cancelation stealth was first put forward in the 1960s. The principle is to produce a train of coherent wave to reduce the target's scattering echo through the active mode. Compared to the passive stealth technology, it has the following advantages: (1) without changing the shape of target's, and therefore will not affect its performance; (2) without spraying/laying the absorbing materials, so can greatly shorten the weapon equipment maintenance time; (3) it can work in a plurality of frequency bands, and can be adjusted according to the parameters of the incident radar wave signal. However, the relative difficulty of active cancelation increases with increasing frequency, so the technology appears most suitable for low-frequency RCSR (Radar Cross-Section Reduction), where use of passive stealth technology has very poor results [1].

The work was put on ice fifty years ago because of lower tech level in developing the technology that was available at the time. Now that active cancelation stealth is about to be realized with the rapid development of microelectronics technology, modern radar technology, computer technology, software technology and signal processing technology.

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2. Basic principle

Active cancelation stealth is believed to be a smart and adaptive technique that produces a artificial radiation field which have equal amplitudes and same-frequency, but opposite phase from the target's scattering field.

So the enemy radar receiver always located in the synthetic pattern zero, thereby suppressing the target echo signal received by enemy radar, and ultimately achieve stealthy aim.

According to the definition of RCS [2], we can write it as follows:

$$\sqrt{\sigma} = \frac{\lambda \widehat{e}_{\mathrm{r}} k R \overline{E}_{\mathrm{s}}}{\left|E_{\mathrm{i}}\right| \sqrt{\pi}} e^{-jkR} \tag{2.1}$$

where $\sqrt{\sigma}$ is complex root of the RCS scatterer; λ is wavelength; $k = 2\pi/\lambda$ is wave number; $\widehat{e}_{\mathrm{r}}$ is a unit vector aligned along the electric polarization of the receiver; R is distance between the radar and the scatterer; $\overline{E_{\mathrm{s}}}$ is vector of the scattered field; E_{i} is the electric-field strength of the incident wave impinging on the target.

In theory, the RCS of target in different directions can be measured accurately, and the transient characteristic of radar incident field also can be measured with accuracy through the sensor in platform. And electromagnetic wave has the same characteristics with the acoustic wave, it can be coherence stacked or canceled. So the coherent but opposite phase field can always be generated in the radar direction and scattering field, namely, the active cancelation is established theoretically.

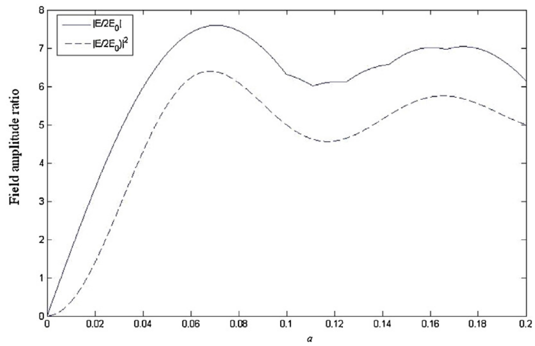

Fig. 1. Field amplitude ratio curve.

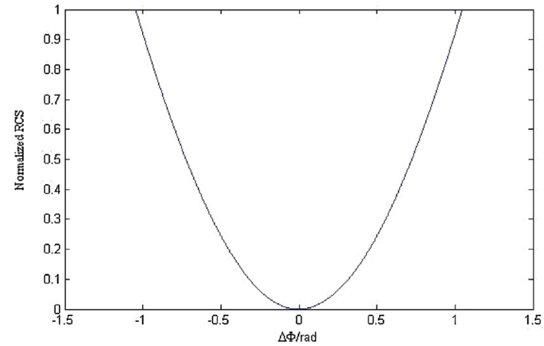

Fig. 2. Curve of normalized RCS versus phase error.

According to [3], any radar echo that satisfies the conditions described below can be canceled out completely.

$$\begin{cases} \Delta f = 0; \\ \Delta a = 0; \\ \Delta \phi = (2k+1)\pi, \quad k \text{ is an integer.} \end{cases} \tag{2.2}$$

where Δa is the amplitude error, Δf is the frequency error and $\Delta \phi$ is the phase error.

But it turned out, there are some errors of cancelation signal caused by the some of the extraneous and uncontrolled factors. These would produce the negative influence on active cancelation stealth effect.

2.1. Effect of frequency error

The complex target can be resolved into a collection of N discrete scatterers or scattering centers, then the formula (2.1) can be written in another form [4]:

$$\sigma = \left| \sum_{n=1}^{N} \sqrt{\sigma_n} e^{j\phi_n} \right|^2 \tag{2.3}$$

where σ_n is the RCS of the nth scatters; ϕ_n is the relative phase of the scatter's contribution due to its physical location in space.

There are many reasons influencing the effect of the active cancelation, of which the most influential was the frequency error. Because of the frequency difference will destroy the coherence and cause the beat phenomenon, and thus can not obtain ideal cancelation effect. But when the difference is very small, and the signal is pulse mode, there will be some new characteristic. In order to simplify the model, the initial values of phase difference about the two carriers can be set as the odd times of π. And the pulse train signal will be represented by sampling function $\sum_n \delta_n (t - nT_t)$. So the synthesis of the field amplitude can be expressed as follows:

$$\left| E \right| = 2E_0 \sum_n \left| \sin(na\pi) \right| \tag{2.4}$$

where T_t is pulse repetition period; $a = \Delta f / \Omega_t$, $\Omega_t = 2\pi / T_t$.

$$\left| E \right|^2 = 4{E_0}^2 \sum_m \sum_n \left| \sin(ma\pi) \sin(na\pi) \right| \tag{2.5}$$

Obviously, the coefficient of formula (2.4) and (2.5) is of value 0 at the same time if and only if a is an integer. At this time, the cancelation effect is best. Cancelation effect have to do with the pulse cumulant while a is not integer. When the number of pulse accumulation is large, such as 100, and the cancelation effect has almost completely lost. The curve of field amplitude ratio against a is illustrated in Fig. 1 (corresponding pulse accumulation number is 10). It can be seen from Fig. 1, only when the a value diverge from integer is very small, there will be some canceling effects. Therefore, active cancelation stealth is very hard on the frequency error tolerance.

In general, the active cancelation system can be divided into transmitting and response according to the different methods of generating the canceling wave. In order to ensure that working frequency is accurate and consistent, the transmitting system is suggested to construct the canceling wave. Due to the wide application of digital radio frequency memory (DRFM), it has become possible [5–7].

2.2. Effect of phase error

Only consider the effects of phase error, the following equation can be derived from the formula (2.3),

$$\overline{\sigma} = 4 \sin^2 \left(\frac{\Delta \phi}{2} \right) \tag{2.6}$$

where $\overline{\sigma} = \sigma / \sigma_0$, is the normalized RCS; σ_0 is the original target RCS; $\Delta \phi = \phi_1 - \phi_0 - (2k+1)\pi$, ϕ_0 is the phase of target, ϕ_1 is the phase of canceling wave.

The plot of normalized RCS versus phase error is a parabolic curve, as shown in Fig. 2. We can see from the chart that the phase error cannot exceed 60°, otherwise, the coherent wave not only can not canceling the target echo, but to strengthen the scattering characteristics of the target. And the curve is steep, it is indicating that the active cancelation stealth is very sensitive to phase error. So it must be minimized in practice.

2.3. Effect of amplitude error

If only considering the effects of amplitude error, the following equation can be derived from the formula (2.2) and (2.3),

$$\overline{\sigma} = (1 - \sqrt{1 + a})^2 \tag{2.7}$$

where $a = \Delta \sigma / \sigma_0$, $\Delta \sigma$ is amplitude error.

Fig. 3 is the relation curve between the normalized RCS and the amplitude error. As shown in the diagram, the curve is gentle, this suggests that the active cancelation stealth is less sensitive to amplitude error. From the above formula (2.7) it can be seen that the scattering characteristics of target have not changed when $a = -1$ or $a = 3$, this means have had little stealth effect. When a in the range of $(-1,3)$, the RCS of target is reduced that means the target has achieved certain active cancelation stealth effect. The amplitude of the target RCS not decreased but increased when $a > 3$, which shows that the target echo is strengthened. Thus beyond the active cancelation stealth on magnitude error tolerance.

There are phase error and amplitude error at the same time that the curve of normalized RCS can be changed, as shown in Fig. 4. It