Active Cancellation Algorithm for Radar Cross Section Reduction

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ABSTRACT:

Abstract - Modern components for signal processing make it possible to achieve radar visibility reduction, that requires reduce the radar cross section (RCS) of an aircraft or a system because it seems to be on the enemy's radar detection capabilities. To achieve this goal, this paper proposed an Active cancellation algorithm for radar cross section reduction using MATLAB, C language program, digital radio-frequency memory (DRFM), and phased array technology to generate the desired signal to cancel the reflected radar returns. The algorithm depends on a pre calculation approach in which an omni direction RCS, clutter, and noise databases generated in advance. Signal processing system function analysis parameter of the measured radar signal. Then find the corresponding echo data (amplitude and phase parameters of the coherent echo) in the target RCS database through real-time amendment. Through the establishment of a target scattering field with the abolition of a coherent signal in the direction of the radar system detection, the radar receiver stays in empty pattern synthesis. The result achieved by the proposed method improves visibility reduction by 25% compared to conventional methods.

KEYWORDS: *Active cancellation, coherent, Echo, radar cross section, MATLAB, Phased array antenna, and Stealth.*

I. INTRODUCTION

Radar cross section reduction techniques generally fall into one of four categories [1]; target shaping, materials selection and coating, passive cancellation, and active cancellation. The phased-array antenna techniques, high-speed microelectronic devices, and computer processing have made active cancellation technique more feasible and practical. An active cancellation algorithm for radar cross section reduction can readapt to protect any object, such as aircraft. An active cancellation algorithm for radar cross section reduction uses the coherent signal interference. To avoid target detection, the target must transmit a cancellation signal at the same time with an incoming pulse, providing the required phase and amplitude to cancel the reflected energy from detecting radar. The difficulty in implementing such a system is the need to obtain the parameters of cancellation signal in real time, and to achieve precise adjustment of the phase and amplitude of the cancellation waveform. Active cancellation algorithm for radar cross section was based on adaptive real-time adjustment of electromagnetic (EM) signal within a three-dimensional space. The echo signals are produced by the target, when a radar target is illuminated. According to Electromagnetic inverse scattering theory, if the source of radiation field distribution is known, scatter characteristics and distribution of the scattering can be known. If the radar signals are limited within a small precise angle for the EM wave cancellation, the target can be invisible to radar's receiver system. An important part of the development of Active cancellation system for radar cross section understands a particular goal, which is the comparison between the energy density scattered on the radar receiver with incident energy density in the target. The formal definition of the RCS [2],[3],[4] is in (1):

$$\sqrt{\sigma} = \lim_{R \to \infty} 2\sqrt{\pi R[(E_S \cdot \hat{e}_r)/E_i]} \qquad (1)$$

Where $\sqrt{\sigma}$ is the target RCS complex root, E_i is the electric field strength of the incident signal on the target, R is the distance between the target and the radar, $\hat{e}_r$ is aligned unit vector along electric polarization of the receiver, and $\bar{E}_S$ is the vector of the scattered field. Using active cancellation means, reducing the strength incident field on the target to reduce the reflected power to the radar receiver. A target's RCS can be reduced by reducing the target scattering intensity. According to (1); target's RCS can be measured for many scattering directions and a radar target's scattered field direction can be identified as in (2):

$$E_S = \lim_{R \to \infty} [E_i \sqrt{\sigma . \hat{e}_r} \;/\; 2\sqrt{\pi R}] \qquad (2)$$

II. METHODOLOGY

Active cancellation algorithm for radar cross section reduction consists of two elements:

A. Hardware components:

- Receiving antenna, used to receive a radar signal.
- Transmitting antenna, used to transmit a cancellation signal.
- Reconnaissance receiver used to stores a precision copy a received signal with aide of (DRFM).

B. Software(MATLAB/C functions and databases):

- Signal processing and control function (SPC), used to storing a received signal, database searches, signal analysis, processing, and control of other elements.
- Doppler frequency shift modulation function (DFSM), used to superimposes the Doppler frequency on the output signal.
- Power synthesis and beam forming function (PSBF), used to form the modified beam to transmit.
- Target RCS database, is related to frequency, direction, and polarization, power, for incident signal.
- Noise database, is related to the effective noise temperature, input noise power, etc.
- Clutter database, is related to aircraft speed, airborne, carrier frequency, radar point, altitude radar, distance to target and radar pulse repetition frequency (PRF).

The method based on generation an anti phase electromagnetic signal to a target's scattered signal. The effectiveness of this method depends on the knowledge of its real-time characteristics, the measurement precision of the radar signal, and the accuracy of the generated cancellation signal, among other factors. Fig. 1 shows the principle process of the algorithm and Fig. 2, shows the flowchart of an active cancellation algorithm for radar cross section reduction. The incident radar phase, amplitude, frequency, polarization, radar space position and waveform characteristics are accurately and quickly measured on the target platform by SPC, and a reconnaissance receiver. The characteristics of target reflection that correspond to the incident radar waveform will be extracted from the target's RCS database controlled by the computer processing system. By generating a signal (waveform) with the appropriate parameters, including phase, intensity, polarization and frequency, the target's echo can be cancelled when the wave returns to the radar receiving antenna. If we can solve the target to separate N scattering centers, then a radar return on a specific frequency is (3):

$$\sigma = \left| \sum_{n=1}^{N} (\sigma_n)^{0.5} . e^{j\varphi_n} \right|^2 \qquad (3)$$

Where σ_n is the Nth scatter RCS and φ_n is the phase due to the physical location of scatterer's.

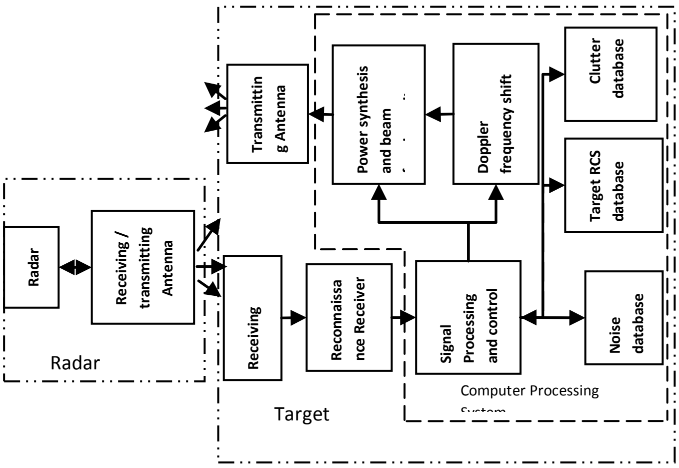


Fig. 1: The principle of an active cancellation algorithm for radar cross section reduction process.

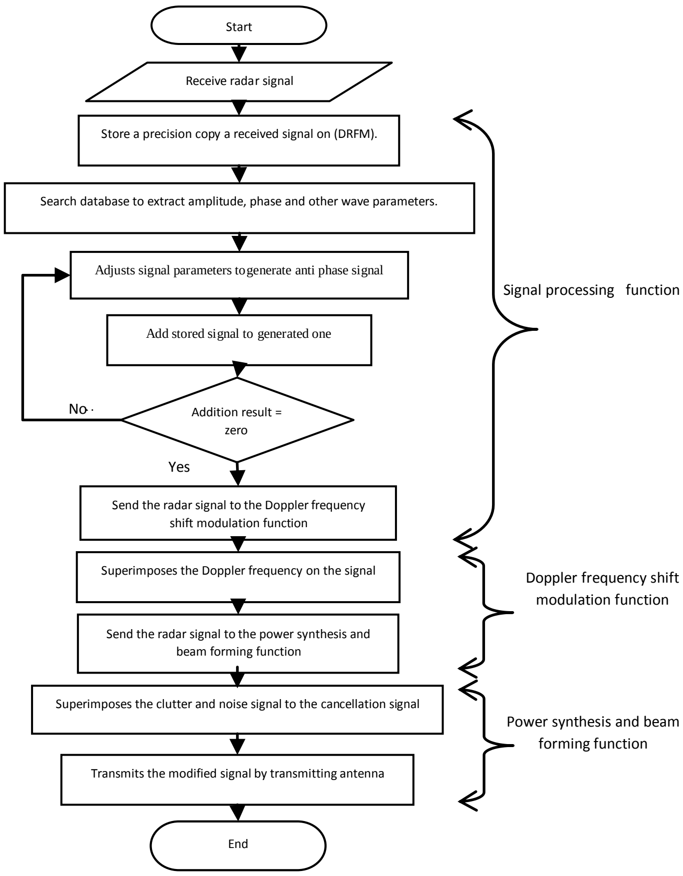


Fig. 2: An active cancellation algorithm for radar cross section reduction flowchart.

A target with a huge number of scattering centers, several controlling scattering centers will exist for a specific incident signal angle and operating radar frequency. Reduction of the radar returns from these centers can reduce the target's RCS. If the original RCS of the target is denoted as σ_0, an active cancellation system for RCS reduction can produced an equivalent RCS scattering center denoted by σ_1. The phases are φ_0 and φ_1, respectively of scattering centers. The superposition σ0 and σ1 is given by (4):

$$\sigma = \left| (\sigma_0)^{0.5} e^{j\varphi_0} + (\sigma_1)^{0.5} e^{j\varphi_1} \right| \qquad (4)$$

By analyzing (4), (5) will get as following:

$$\sigma = \sigma_0 \left| 1 + \sigma_1 / \sigma_0 + 2(\sigma_1 / \sigma)^{0.5} [\cos(\varphi_1 - \varphi_0)] \right| \qquad (5)$$

Controlling σ_1 and φ_1 can optimize those parameters to get (6):

$$\begin{cases} \sigma_1 = \sigma_0 \\ \varphi_1 - \varphi_0 = (2k+1) \quad (\textit{where} \quad k \text{ is } \textit{Integer}) \end{cases} \qquad (6)$$

When σ = 0, this indicates that stealth in the direction of the enemy's radar has been achieved.

Compiling the target's RCS database is an important step in designing an active cancellation algorithm for RCS reduction. The RCS entry is a function, rather than just varied number with different frequency, direction, and polarization for incident signal. It is necessary to establish an RCS database due to different frequencies, polarizations, and directions, according to real-time measurements for frequency, direction, power, and polarization of incident signal. This database must support real-time modification for the parameter of the transmitter to produce an effective cancellation signal for transmission.The reconnaissance receiver is used for reception and reconnaissance signals from enemy's radar transmitters. A received radar signal is applied to SPC function which stores a precision copy a received signal with aide of (DRFM) and alternately, it analyzed for amplitude and phase adjustment to generate anti phase signal with same amplitude. By comparing the stored signal with the wave signal generated by SPC function, the result from this comparison is checked to obtain a minimum output value (zero balance), when this happen, the SPC function will send the radar signal to the DFSM function, with coherent superposition of clutter and noise. The transmitting antenna and PSBF function are used to form and transmit the active cancellation signal.

The system's memory is used for storing the databases, including the noise database, target echo database, and the clutter database. The algorithm work with the assumption that an echo signal consists of three parts: noise, clutter, and target echo so a radar echo can be as follows (7):

$$X(t) = S(t) + N(t) + C(t) \qquad (7)$$

Where S(t) is target's echo signal, N(t) is the noise signal, and C(t) is the clutter signal.

Due to a great deal of calculation and processing power that required to determine the radar's cancellation signal; it is difficult to achieve calculations in real-time without pipeline delays. For this, an offline calculation is used to build a target RCS database. Approximation prediction method is the based method for obtaining a complex target RCS [5],[6],[7].The database for noise and clutter usually uses a distribution of Gaussian for White noise, which can be produced by the Monte Carlo method [8][9]. Clutter data is related to aircraft speed, airborne, carrier frequency, radar point, altitude radar, distance to target and radar pulse repetition frequency (PRF). When clutter data are calculated, reduction of large amount of data is done because the speed, radar frequency, and aircraft altitude are fixed, and only PRF and radar point are changed [10].Signal processing and control function is the core of an active cancellation algorithm for radar cross section reduction, which used for storing a received signal, database searches, signal analysis, processing, and controlling the other elements. The Doppler shift in the radar wave is produced due to superimpose of the Doppler frequency by the Doppler frequency shift modulation function. The power synthesis and beam forming function, used to form the modified beam to transmitted via the transmitting antenna under control of signal processing and control function.

III. TEST AND RESULTS:

An active cancellation algorithm for radar cross section reduction was tested with the following conditions for evaluation purpose:

1. A coherent pulse train with 1 MHz modulation rate for radar transmit signal.
2. The signal has PRF of 1 kHz and a pulse width of 4 μs.
3. Uniform speed for the target movement with 100 km initial distance away from the radar transmitter, 300 m/s initial radial velocity, 0 deg of both azimuth and elevation angles and 2 m^2 target's RCS according to the Swelling model II.
4. The reference pattern function for reconnaissance is described by (8):

$$F(\theta) = \begin{cases} ASa & [a\theta / (\theta_1/2)]\, k_0 & |\theta| \le a_1 \\ BSa & [a(\theta \pm a_2)/(\theta_2/2)]\, k_0 & |\theta| > a_1 \end{cases} \qquad (8)$$

Where $\kappa_0 = (\cos\theta 0)^{0.5}$ is the control factor for phased-array antenna modified beam gain with variation of scanning angle, θ_0 is the beam of scanning angle, θ_1 is the unbiased-beam main-lobe beam width of 3 dB, θ_2 is the unbiased-beam first side-lobe 3-dB beam width, AS is the unbiased-beam main-lobe gain value, BS is the unbiased-beam first side-lobe gain value, a = 2.783, ($a_1 = \pi\theta_1/a$) is first zero unbiased-beam (in rads), and ($a_2 = \pi(\theta_1 + \theta_2/a$) is the unbiased-beam first side-lobe peak point of view (in rads).The 3D Electromagnetic pattern can be simplified into an elevation and azimuth multiplication pattern result as shown in (9).

$$F(\theta, \varphi) = F_\theta(\theta) F_\varphi(\varphi) \qquad (9)$$

Where $F_\varphi(\varphi)$ is the elevation pattern and $F_\theta(\theta)$ is the azimuth pattern. Assuming that the radar antenna vertical main-lobe beam-width is 2 degree, the main-lobe gain is 40 dB, the gain is 9 dB, and the first side-lobe-width is 1 degree, the 3D antenna pattern shown in Fig. 3 will be generated.

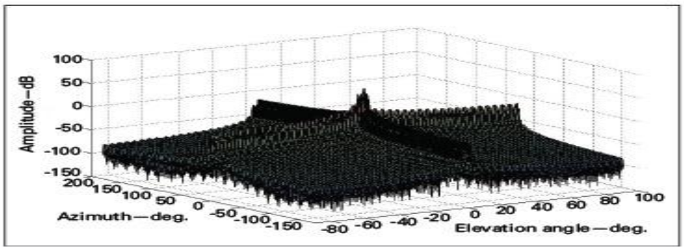


Fig. 3: Three dimensional (3D) antenna's pattern.

The algorithm can used for (ECM) Electronic countermeasures function using rectangular array antenna M x N pattern function described below as (10):

$$g(\theta, \varphi) = G(\theta, \varphi) \left| E(\theta, \varphi) \right| \left| e(\theta, \varphi) \right| \qquad (10)$$

Where g(θ, φ) is the pattern of the antenna, G(θ, φ) is the factor of the directivity, E(θ, φ) is the array factor for the beam shape determines, e(θ, φ) is the factor of the array element with (e(θ, φ) ≈ 1), φ is the elevation angle on spherical coordinates array, θ is the azimuth angle on spherical coordinates array, ($\varphi \in [0, \pi/2]$), and($\theta \in [0, 2\pi]$). Adjacent-array element spacing of $d = \lambda/2$ can be described in the x and y directions, E(θ, φ) as (11):

$$E(\theta,\varphi) = \sum_{m=1}^{M} \sum_{n=1}^{N} I_{mn} \exp[\,jkd\ (m\tau_x\ n\tau_y)] \qquad (11)$$

Where $k = 2\pi/\lambda$ is the wave number and I_{mn} is the weighting coefficient.

$$\begin{cases} \tau_x = \sin\theta\cos\varphi - \sin\theta_0\cos\varphi_0 \\ \tau_Y = \sin\theta\cos\varphi - \sin\theta_0\cos\varphi_0 \end{cases} \qquad (12)$$

Where (θ_0, φ_0) is a beam pointing vector. If M = 51, N = 21, θ_0 = 30 deg., φ_0 = 20 deg, the (51 x 21) will result array antenna pattern shown in Fig. 4.

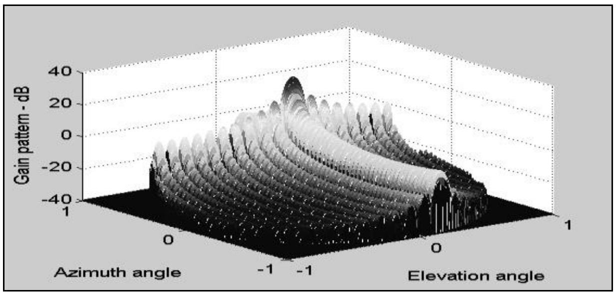


Fig. 4: Pattern from multiple-element array antenna.

Fig. 5, shows the result obtained from the algorithm, (a) shows the a coherent pulse train spectrum, (b) shows superimposed of coherent pulse train on the noise and clutter waveform, with completely target signal submerged under noise and clutter, (c) shows a signal spectrum contains added noise and clutter with the target signal, and (d) shows the contrast before (top) the cancellation signal and (bottom) after the cancellation signal has been added to radar return.

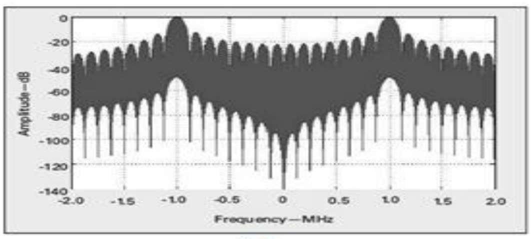
The cancellation signal can be described as (13):

$$S = 20\log[\,1 + \left|\Delta\vec{E} / \vec{E}_S\right|\,] \qquad (13)$$

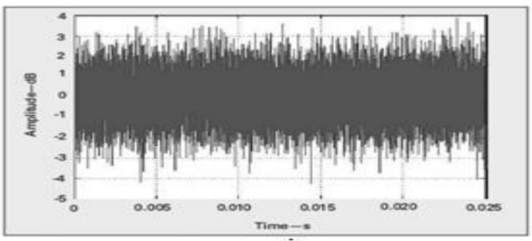
Where $\Delta\bar{E}$ is the cancellation residual field and $\bar{E}_S$ is the target's scattering field. Complete stealth is realized when S = 0, From Fig. 5 (d), it can be seen that corresponding cancellation signal, S to $\Delta\bar{E}$ max (6 x 10−2dB) is 0.51 dB, so the reduction of radar detection maximum range is 25% of original value.

IV. CONCLUSION:

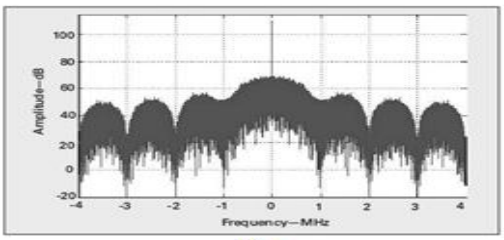
From the results, an active cancellation algorithm for radar cross section reduction reduces the target detectability. This approach can be used with different number of others radio echo scenarios.



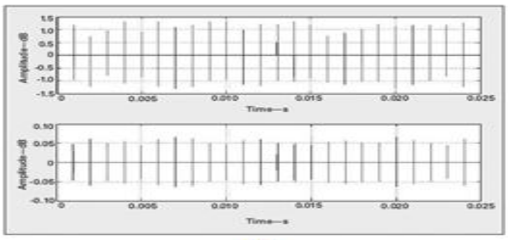
(a)



(b)



(c)



(d)

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