LETTER
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A novel processing method for side-lobe blanketing jamming suppression

Huanyao Dai[1a)], Yongzhen Li[2], Jianling Cui[1], and Huidong Qiao[1]
[1] *State key laboratory of complex electromagnetic environmental effects on electronics and information system, Unit 63892 of PLA, Luoyang, 471003, China*
[2] *School of Electronic Science and Engineering, National University of Defense Technology, Changsha 410073, China*
a) *leoneast@163.com*

Abstract: Blanketing jamming is widely used in electronic jamming war, whereas the existing electronic countermeasures maybe invalided in the future. By using the spatial polarization characteristic (SPC) modulation effect on jamming signal as antenna scanning, a novel side-lobe blanketing jamming suppression method is proposed. It processed the sample data by using pre-knowledge of jamming direction, SPC, then the orthogonal polarized component and polarization states of receiving signal can be estimated. The polarization filtering is designed to achieve the objective of suppressing jamming. The novel method enables single polarized radar own anti-jamming ability in polarization domain, where the suppression performance can reach to 20 dB. The validity has been proved by simulation experiment.

Keywords: blanketing jamming, suppression, spatial polarization characteristic
Classification: Microwave and millimeter wave devices, circuits, and systems

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1 Introduction

For blanket jamming signal from side-lobe direction, the existed anti-jamming technical measures mainly contains side-lobe cancellation [1], side-lobe blanking [2], frequency agility, etc. With the rapid development of advanced electronic jamming technologies, the existing interference suppression method maybe invalided. In recently years, the polarimetric technology has already been occupied important position in the domain of radar remote sensing [3], target classification and identification, clutter suppression, and anti-jamming [4], and there are many applications. However, the prerequisite of these is that the radar possesses full polarimetric capability. Most existing radar such as air defense radar or warning radar is single polarized which cannot measure polarization; this directly restricts their target-identifying and anti-jamming capabilities in polarization area. Based on SPC, the paper proposed a novel processing method for suppressing blanket jamming from side-lobe direction. The antenna SPC model is built up at first, then the target and jamming signal model is given. Radar observational equations as antenna scan and electronic jamming coming from side-lobe direction is established. It can be abstract as overdetermined linear equations and the polarization estimation of jamming can be solved by Least Square Estimation (LES) method. Later on, the jamming signal is suppressed by polarization filter. The above processing flow and method can be called spatial virtual polarization estimation and filter. Finally, simulation experiment is designed to verify the effectiveness of the proposed method.

2 Polarization estimation and polarization filter method of jamming based on antenna characteristic

The antenna polarization changing in different positions and oriented directions is known as spatial polarization characteristic (SPC) of antenna. Suppose that the peak gain of radar antenna is G, the normalized main polarization pattern is $g_H(\varphi, \theta)$ and the normalized cross polarization pattern is $g_V(\varphi, \theta)$, where θ and φ denote the elevation and azimuth, respectively. In the polarization basis (H, V), the antenna polarization pattern can be written in vector form

$$\boldsymbol{G}(\varphi, \theta) = G \begin{bmatrix} g_H(\varphi, \theta) \\ g_V(\varphi, \theta) \end{bmatrix} = G \cdot \boldsymbol{g}(\varphi, \theta) \tag{1}$$

where, $\boldsymbol{g}(\varphi, \theta) = \begin{bmatrix} g_H(\varphi, \theta) \\ g_V(\varphi, \theta) \end{bmatrix}$ is known as antenna spatial polarization vector and can be seen as a function of scanning angle (φ, θ).

Let the radar transmitter power be P_t, transmitting narrowband pulse signal be $e(t)$, and its pulse width be τ_p. Suppose that there is a target within antenna scan area, the distance is r_T. The corresponding two-way delay is $\tau_0 = \frac{2r_T}{c}$. Assume that the polarization scattering matrix (PSM) of target $\boldsymbol{S}$ in H-V polarization base is stable during antenna scanning period. Thus, the radar received target return signal in the azimuth φ_k can be written

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as

$$\begin{aligned} v_T(\varphi_k,t) &= \sqrt{\frac{P_t G^2 \lambda}{(4\pi)^3 r_{\mathrm{T}}^4}} \cdot e^{-\frac{4\pi r_{\mathrm{T}}}{\lambda}} \cdot \boldsymbol{g}^{\mathrm{T}}(\varphi_k) \cdot \boldsymbol{S} \cdot \boldsymbol{g}(\varphi_k) \cdot e(t-\tau_0) \\ &= K_T \cdot \boldsymbol{g}^{\mathrm{T}}(\varphi_k) \cdot \boldsymbol{E}_a(\varphi_k) \cdot e(t-\tau_0) \end{aligned} \tag{2}$$

where $\boldsymbol{E}_a(\varphi_k) = \begin{bmatrix} E_{a,H}(\varphi_k) \\ E_{a,V}(\varphi_k) \end{bmatrix} = \boldsymbol{S} \cdot \boldsymbol{g}(\varphi_k)$ is polarization vector of target signal after scattering, and $\varphi_k = \varphi_{-K}, \cdots, \varphi_K$, $K_T = \sqrt{\frac{P_t G^2 \lambda}{(4\pi)^3 r_{\mathrm{T}}^4}} \cdot e^{-\frac{4\pi r_{\mathrm{T}}}{\lambda}}$.

Suppose the peak gain of jammer antenna is G_J. Its polarization can approximately seen as a constant during antenna scan period, denoted by $\boldsymbol{J}_{HV} = \begin{bmatrix} J_H \\ J_V \end{bmatrix}$ in radar polarization base (H, V), and $\|\boldsymbol{J}_{HV}\|^2 = 1$. The jammer transmit power is denoted by P_J, and the waveform by $j(t)$. For radar received jamming signal can be modulated by spatial polarization characteristic of antenna. In a fixed azimuth φ_k, the received jamming signal can be expressed as

$$\begin{aligned} V_{r,\mathrm{J}}(\varphi_k,t) &= \sqrt{\frac{P_{\mathrm{J}} G_{\mathrm{J}} G \lambda^2}{(4\pi)^2 r_{\mathrm{J}}^2}} \cdot e^{-j\frac{2\pi r_{\mathrm{J}}}{\lambda}} \cdot \boldsymbol{g}^{\mathrm{T}}(\varphi_k) \cdot \boldsymbol{J}_{HV} \cdot j(\varphi_k,t) \\ &= K_J \cdot [g_H(\varphi_k) J_H + g_V(\varphi_k) J_V] \cdot j(\varphi_k,t) \end{aligned} \tag{3}$$

where r_{J} is the distance between radar and jammer, $K_{\mathrm{J}} = \sqrt{\frac{P_{\mathrm{J}} G_{\mathrm{J}} G \lambda^2}{(4\pi)^2 r_{\mathrm{J}}^2}} \cdot e^{-j\frac{2\pi r_{\mathrm{J}}}{\lambda}}$, and $j(\varphi_k,t)$ is jamming signal in this azimuth.

Suppose that antenna scan a region of space $[\varphi_1,\ \varphi_n]$, then the received signal is the superposition of jamming signal and target signal can be expressed as the following equation set.

$$\begin{cases} V_{r1}(t) = K_J \boldsymbol{g}^{\mathrm{T}}(\varphi_0+\varphi_1) \cdot \boldsymbol{J}_{HV} \cdot j((\varphi_0+\varphi_1),t) \\ \qquad + K_T \cdot \boldsymbol{g}^{\mathrm{T}}(\varphi_1) \cdot \boldsymbol{E}_a(\varphi_1) \cdot e(t-\tau_0) + n(t) \\ V_{r2}(t) = K_J \boldsymbol{g}^{\mathrm{T}}(\varphi_0+\varphi_2) \cdot \boldsymbol{J}_{HV} \cdot j((\varphi_0+\varphi_2),t) \\ \qquad + K_T \cdot \boldsymbol{g}^{\mathrm{T}}(\varphi_2) \cdot \boldsymbol{E}_a(\varphi_2) \cdot e(t-\tau_0) + n(t) \\ \qquad \vdots \\ V_{rn}(t) = K_J \boldsymbol{g}^{\mathrm{T}}(\varphi_0+\varphi_n) \cdot \boldsymbol{J}_{HV} \cdot j((\varphi_0+\varphi_n),t) \\ \qquad + K_T \cdot \boldsymbol{g}^{\mathrm{T}}(\varphi_n) \cdot \boldsymbol{E}_a(\varphi_n) \cdot e(t-\tau_0) + n(t) \end{cases} \tag{4}$$

In the real world, the jamming signal from superpower jammer is very strong, so the target signal is submerged by jamming, the radar will not detect target. If we ignore the effect of target signal and receiver noises effect on the received signal, then the above equations can be simplified as

$$\begin{cases} V_{r1}(t) = K_J \boldsymbol{g}^{\mathrm{T}}(\varphi_0+\varphi_1) \cdot \boldsymbol{J}_{HV} \cdot j((\varphi_0+\varphi_1),t) \\ V_{r2}(t) = K_J \boldsymbol{g}^{\mathrm{T}}(\varphi_0+\varphi_2) \cdot \boldsymbol{J}_{HV} \cdot j((\varphi_0+\varphi_2),t) \\ \qquad \vdots \\ V_{rn}(t) = K_J \boldsymbol{g}^{\mathrm{T}}(\varphi_0+\varphi_n) \cdot \boldsymbol{J}_{HV} \cdot j((\varphi_0+\varphi_n),t) \end{cases} \tag{5}$$

As we known, the jamming signal is a random variable obeying Gaussian distribution of zero mean and δ_{J}^2 variance in different azimuths, and its variable quantity is $\Delta j(\theta_k, \tau_{\mathrm{J}})$, so we have $\Delta \boldsymbol{j}(\varphi, \tau_{\mathrm{J}}) \sim N(0, \delta_{\mathrm{J}}^2)$. In this way,

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the received voltage under each azimuth within the same range cell can be written in the form of linear equations as

$$\boldsymbol{V}_J(\varphi, \tau_{\mathrm{J}}) = K_J \cdot \boldsymbol{G}(\varphi) \cdot \boldsymbol{J} \cdot j(\tau_J) + \boldsymbol{\Delta j}(\varphi, \tau_J) \tag{6}$$

where $\boldsymbol{V}_J(\varphi, \tau_{\mathrm{J}}) = \begin{bmatrix} V_J(\varphi_0+\varphi_1, \tau_J) \\ V_J(\varphi_0+\varphi_2, \tau_J) \\ \cdots \\ V_J(\varphi_0+\varphi_n, \tau_J) \end{bmatrix}$, $\boldsymbol{G}(\varphi) = \begin{bmatrix} g_H(\varphi_0+\varphi_1) & g_V(\varphi_0+\varphi_1) \\ g_H(\varphi_0+\varphi_2) & g_V(\varphi_0+\varphi_2) \\ \cdots & \\ g_H(\varphi_0+\varphi_n) & g_V(\varphi_0+\varphi_n) \end{bmatrix}$,

$\boldsymbol{\Delta j}(\theta, \tau_{\mathrm{J}}) = \begin{bmatrix} \Delta j(\varphi_0+\varphi_1, \tau_{\mathrm{J}}) \\ \cdots \\ \Delta j(\varphi_0+\varphi_2, \tau_{\mathrm{J}}) \\ \cdots \\ \Delta j(\varphi_0+\varphi_n, \tau_{\mathrm{J}}) \end{bmatrix}$, and $\Delta j(\varphi, \tau_{\mathrm{J}}) \sim N(0, \delta_{\mathrm{J}}^2 \cdot \boldsymbol{I})$, $\boldsymbol{I}$ is identity matrix.

Let $\boldsymbol{x}(\tau_{\mathrm{J}}) = \begin{bmatrix} x_H(\tau_{\mathrm{J}}) \\ x_V(\tau_{\mathrm{J}}) \end{bmatrix} = K_{\mathrm{J}} \cdot j(\tau_{\mathrm{J}}) \cdot \boldsymbol{J}$. Then the above equation can be simplified into

$$\boldsymbol{V}_{\mathrm{J}}(\varphi, \tau_{\mathrm{J}}) = \boldsymbol{G}(\varphi) \cdot \boldsymbol{x}(\tau_{\mathrm{J}}) + \boldsymbol{\Delta j}(\varphi, \tau_{\mathrm{J}}) \tag{7}$$

Let the radar antenna beam scanned a region of space, with a total of n azimuth discrete samplings φ_1, φ_2, $\cdots$, φ_n. Denote the received voltage at each azimuth φ_k by $V(\varphi_k, t)$. This voltage is composed of m range resolution cells. Then the n voltages within the same range cell can form a vector $\boldsymbol{V}(\varphi, \tau_m)$.

From above, we can see the radar observation equation is overdetermined equations. These can be solved by least square estimation method. Polarization estimation is to decompose the signal at each range resolution cell by using the given antenna's spatial polarization characteristic and least square method. The two-way orthogonal polarized signals $\boldsymbol{x}(\tau_m)$ are obtained by using the following equation:

$$\boldsymbol{x}(\tau_m) = arg \min_{v(\tau_J)} \|\boldsymbol{V}(\varphi, \tau_m) - \boldsymbol{G}(\varphi) \cdot \boldsymbol{x}(\tau_m)\|^2 \tag{8}$$

Expanding the above equation, we have

$$\boldsymbol{x}(\tau_m) = [\boldsymbol{G}^H(\varphi)\boldsymbol{G}(\varphi)]^{-1} \cdot \boldsymbol{G}^H(\varphi) \cdot \boldsymbol{V}(\varphi, \tau_m) \tag{9}$$

where $\boldsymbol{x}(\tau_m) = \begin{bmatrix} x_H(\tau_m) \\ x_V(\tau_m) \end{bmatrix}$, $\tau_m = \tau_1, \cdots, \tau_M$. Through energy normalization of jamming signal, the polarization is estimated as $\hat{\boldsymbol{J}} = \dfrac{\hat{\boldsymbol{x}}_{LS}(\tau_J)}{\|\hat{\boldsymbol{x}}_{LS}(\tau_J)\|}$.

Having obtained the polarization states $\hat{\boldsymbol{J}}$ of jamming, based on the rule of interference suppression, we calculate the polarization filter vector $\boldsymbol{h}_r$ by

$$\begin{cases} \arg \quad \boldsymbol{h}_r, \ \mathrm{s \cdot t} \cdot \boldsymbol{h}_r^T \hat{\boldsymbol{J}} = 0 \\ \qquad \|\boldsymbol{h}_r\|^2 = 1 \end{cases} \tag{10}$$

Where "s • t" denote "subject to", the orthogonal polarization signals $\boldsymbol{v}(\tau_m)$ are then filtered out by polarization filter vector $\boldsymbol{h}_r$, and the jamming signals

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will be suppressed. The outputted signal in each range cells is as follows.

$$o(\tau_m) = \boldsymbol{h}_r^T \cdot \boldsymbol{v}(\tau_m) \tag{11}$$

In jamming range cells τ_{J}, the mean value of polarization filtered result is

$$E\{o(\tau_{\mathrm{J}})\} = \boldsymbol{h}_r^T \boldsymbol{x}(\tau_{\mathrm{J}}) \tag{12}$$

While the mean value of polarization filtered result in target range cell τ_T is

$$E\{o(\tau_{\mathrm{T}})\} = \boldsymbol{h}_r^T \boldsymbol{x}(\tau_{\mathrm{T}}) + \boldsymbol{h}_r^T \cdot \left\{[\boldsymbol{G}^{\mathrm{H}}(\varphi)\boldsymbol{G}(\varphi)]^{-1} \cdot \boldsymbol{G}^{\mathrm{H}}(\varphi) \cdot \boldsymbol{s}(\varphi, \tau_{\mathrm{T}})\right\} \tag{13}$$

where $\boldsymbol{s}(\varphi, \tau_{\mathrm{T}})$ denotes the original desired target signal.

This processing procedure above is called spatial virtual polarization estimation and polarization filtering. The algorithm flow is given in Fig. 1.

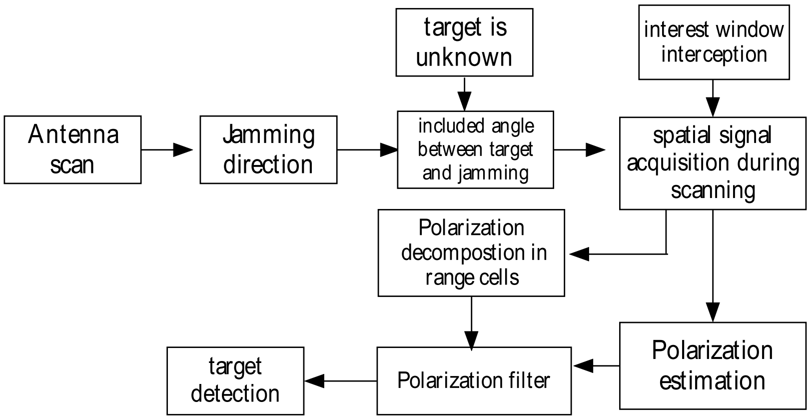

Fig. 1. Algorithm flow of spatial virtual polarization estimation and filter

3 Simulation experiment

In the experiment, radar adopted reflector antenna which mechanical scanning in azimuth direction. Radar works in S band. The azimuth scan window width is set at $-4°\sim4°$ with a total of 101 spatial sampling points. The antenna polarization pattern is shown in Fig. 2 (a), the jamming coming from side-lobe direction and hypothetic target direction is signed on it. The jammer adopts left-hand circularly polarized antenna, transmitting narrow-band white noise jamming, the bandwidth of jamming is about 9 MHz. The interference-to-noise ratio (INR) is about 25 dB. The target signal is within $800\text{th}\sim1000^{\text{th}}$ range cells, pulse width is $10\,\mu$s, and the PSM of target is $\boldsymbol{S} = 10\begin{bmatrix} 1 & 0.1j+0.2 \\ 0.1j+0.2 & j \end{bmatrix}$. The input signal-to-interference ratio is $SIR_{in} = -23.6085$ dB, the target range information is completely submerged by blanketing jamming signal which makes radar fail to detect the target information.

The polarization estimation of range cells is shown in Fig. 2 (b). The output signal after polarization filtered is shown in Fig. 3 (a). Because the

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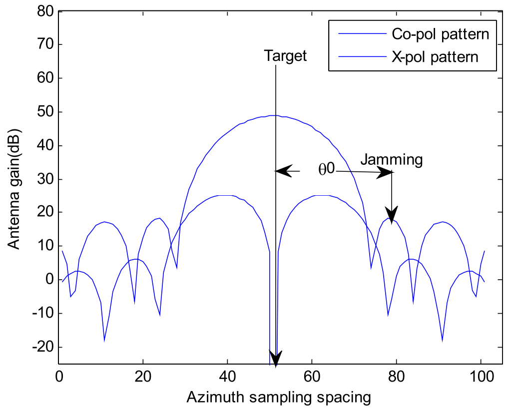
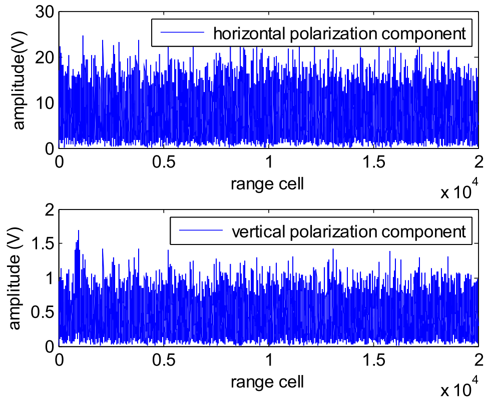


(a) Antenna polarization pattern



(b) Polarization estimation of range cells

Fig. 2. Antenna pattern and polarization estimation results

jamming signal is effectively suppressed in each range cell by spatial virtual polarization filters, the target signal is predominant, with the output signal-to-interference ratio $SIR_o = 10.6394\,\text{dB}$. The Electronic Counter-Countermeasure (ECCM) improvement factor EIF is about 33.9037 dB. Via numerical calculation and simulation, we may find the ECCM improvement factor is better than 20 dB, and the influence of receiver noise on the ECCM is so small that can be neglected. Figure 3 (b) gives the performance relationship between the input and output signal-to-interference ratio, which shows the field of application of the proposed method. 0

4 Conclusion

Based on the SPC of radar antenna, a novel processing method of barrage blanketing jamming which coming from side-lobe direction is proposed. Firstly, from the antenna scan modulated received signal, the jamming direction can be easily estimated. Then, we setup a scan region window to obtain spatial signal, and building up radar observation equations. By least square estimation, the polarization of jamming signal in each range cells can be obtained. In order to suppress jamming signals, the estimated signal is then polarization filtered, the output signal is used for target detection. Even in high Jamming Signal Ratio (JSR) condition, the proposed method is still

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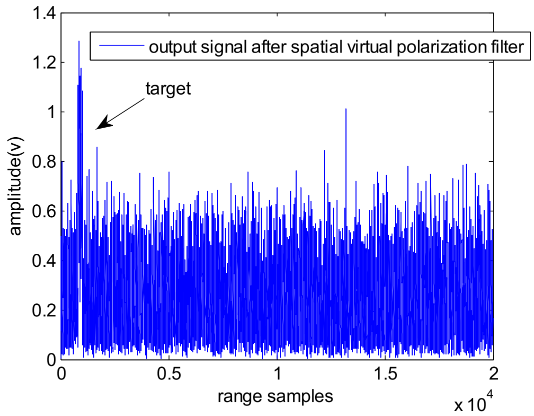
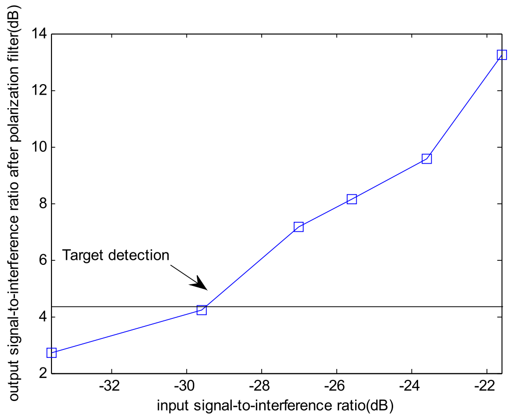


(a) Spatial virtual polarization filtering output



(b) Performance relationship between the input and output signal-to-interference ratio

Fig. 3. Spatial virtual polarization filter output and its performance

works well, and the ECCM improvement factor can be better than 20 dB. From a practical implementation point of view, the proposed method provide a novel processing idea which is more suitable for engineering realization since it need only one polarization channel, saved the equipment quantity, and reduced the requirement of hardware system.

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