Detection-Discrimination Method for Multiple Repeater False Targets Based on Radar Polarization Echoes

Zhi-wei ZONG, Long-fei SHI, Yong-zhen LI, Xue-song WANG

State Key Laboratory of Complex Electromagnetic Environmental Effects on Electronics & Information System, National University of Defense Technology, Changsha, 410073, China

zzwywzq@sina.com, longfei_shi@sina.com.cn

Abstract. Multiple repeat false targets (RFTs), created by the digital radio frequency memory (DRFM) system of jammer, are widely used in practical to effectively exhaust the limited tracking and discrimination resource of defense radar. In this paper, common characteristic of radar polarization echoes of multiple RFTs is used for target recognition. Based on the echoes from two receiving polarization channels, the instantaneous polarization radio (IPR) is defined and its variance is derived by employing Taylor series expansion. A detection-discrimination method is designed based on probability grids. By using the data from microwave anechoic chamber, the detection threshold of the method is confirmed. Theoretical analysis and simulations indicate that the method is valid and feasible. Furthermore, the estimation performance of IPRs of RFTs due to the influence of signal noise ratio (SNR) is also covered.

Keywords

Multiple repeat false targets, DRFM, jammer, target discrimination, polarization, radar.

1. Introduction

The electronic countermeasures (ECM) have undergone rapid development with the military radar over the past two decades [1]. By making more efficient use of jamming power, the deception jamming is proving to be the more effective and attractive type of ECM for defeating defense radars [2]. With the emergence of the digital radio frequency memory (DRFM) [3], high fidelity multiple repeater false targets (RFTs) created by the storage and regeneration of radio frequency signal (each with individual modulation in amplitude, frequency and temporal characteristic), are used to confuse the victim radar. In order to effectively saturate the target extraction and tracking algorithms, the jammer usually constructs a series of replicas of the transmitted radar signal to form a large number of RFTs, these false targets may appear at different ranges, velocities, or angles relative to the physical targets (PTs). An efficient way must be used to eliminate RFTs for the effectiveness of defense system.

Differences of characteristics between the real and false targets are used to eliminate RFTs, such as the modulated phase characteristic of jamming signal by a phase quantizer of DRFM [4], [5], the motion features of false targets in ballistic missile penetration [6], and so on. All targets are processed by designed recognition algorithm one by one. In some cases, a larger number of targets in target groups would share common characteristics, and these common characteristics can be extracted to classify the target groups. Then, recognition algorithm would be performed as batch processing.

Besides frequency, amplitude and time, polarization is another important characteristic of electromagnetic wave, and the usefulness of polarization information has already been established in most target discrimination applications [7], [8]. More and more defense radars have got polarimetric capabilities. Polarization scatting matrix (PSM) is used to present the relation between the incident and backscattered fields from the target [9]. The method of obtaining the PSM is based on the measurement style of the defense radar [10], and the most widely used method consists of alternate transmission of two orthogonal polarizations while receiving with both. Also there are some other methods, such as, simultaneous transmission of two or more orthogonal polarizations and achieving the PSM during a single measurement.

In practical, PTs are mostly nonstationary targets (aerocrafts, warheads, and so on), and their PSMs are time variant, the amplitude and phase changes with the attitude angle. The polarization style of retransmitted radar signal is decided by the transmitting antenna of the deception jammer, thus, multiple RFTs created by the same jammer share the uniform polarization information. The mentioned difference of polarization characteristic between two types of targets will be used to detect and discriminate RFTs. In this presentation, based on the common polarimetric characteristic of RFTs, a novel detection-discrimination method (DDM) is designed to eliminate RPTs, which directly extracts the polarization characteristic difference of the targets from target echoes of two receiving polarization channels.

The remaining of the paper is organized as follows. Section 2 introduces the echo models of different types of targets, and then the principle of DDM is analyzed in a theoretical way. Section 3 is devoted to analysis of the estimation variance of the detection statistics. Based on the probabilistic grids, the DDM is designed in details, and the key parameter of DDM is confirmed with the analysis of results of data from a microwave anechoic chamber. In Section 4, computer simulation for some typical scenarios is used to testify the performance of detection-discrimination method. Finally, the paper ends with a conclusion in Section 5.

2. Signal Models and the Principle of DDM

The echo modes of FRTs and PTs will be introduced in this section, and then the principle of DDM will be discussed.

2.1 The Signal Models of RFTs and PTs

Defense radar employs a pair of horizontal (\mathbf{h}_p) and vertical-polarized (\mathbf{h}_q) antennas (in this article, we use Jones vector to represent the polarization of radar antenna, and $\mathbf{h}_p = [1,0]^T$, $\mathbf{h}_q = [0,1]^T$). During the n^{th} pulse repeater interval (PRI), we define the transmitted waveform of radar as

$$\boldsymbol{E}_{n} = \boldsymbol{h}_{n} \boldsymbol{s}(t) \tag{1}$$

s(t) is the modulated pulse radio frequency signal.

Passing through the receiving and transmitting antenna of the jammer, with the modulation of DRFM in amplitude, frequency and temporal domain, the received signals of FRTs in h_p and h_q polarization channels can be expressed as

$$\begin{bmatrix} s_{\rm Jpm} \\ s_{\rm Jqm} \end{bmatrix} = K_{\rm Jm} \begin{bmatrix} \boldsymbol{h}_{\rm p}^{\rm T} \boldsymbol{h}_{\rm Jt}(n) \boldsymbol{h}_{\rm p}^{\rm T} \boldsymbol{h}_{\rm Jr}(n) \\ \boldsymbol{h}_{\rm q}^{\rm T} \boldsymbol{h}_{\rm Jt}(n) \boldsymbol{h}_{\rm p}^{\rm T} \boldsymbol{h}_{\rm Jr}(n) \end{bmatrix} s(t - \tau_{\rm JDm}) e^{2\pi i f_{\rm JDm}}$$
(2)

where K_{Jm} is a coefficient proportional to the range attenuation, the antenna gain, and the amplitude modulated by the jammer, *m* denotes the *m*th repeater false target, f_{JDm} and τ_{JDm} represent the modulated frequency and time delay, respectively. The polarization vector of receiving and transmitting antennas of the jammer are $h_{Jr}(n)$ and $h_{Jt}(n)$.

Then the signals s_{Jpm} and s_{Jqm} pass via a matched filter, we have

$$\begin{bmatrix} V_{\rm Jpm} \\ V_{\rm Jqm} \end{bmatrix} = K_{\rm rJm} \begin{bmatrix} \boldsymbol{h}_{\rm p}^{\rm T} \boldsymbol{h}_{\rm Jt}(n) \boldsymbol{h}_{\rm p}^{\rm T} \boldsymbol{h}_{\rm Jr}(n) \\ \boldsymbol{h}_{\rm q}^{\rm T} \boldsymbol{h}_{\rm Jt}(n) \boldsymbol{h}_{\rm p}^{\rm T} \boldsymbol{h}_{\rm Jr}(n) \end{bmatrix}$$
(3)

where K_{rJm} is proportional to K_{Jm} , the matched filter gain, and the Doppler mismatch. Thus we define the instantaneous polarization radio (IPR) of FRTs as

$$R_{\rm Jm} = \frac{V_{\rm Jqm}}{V_{\rm Jpm}} = \frac{\boldsymbol{h}_{\rm p}^{\rm T} \boldsymbol{h}_{\rm Jt}(n)}{\boldsymbol{h}_{\rm q}^{\rm T} \boldsymbol{h}_{\rm Jt}(n)}, (\boldsymbol{h}_{\rm p}^{\rm T} \boldsymbol{h}_{\rm Jr}(n) \neq 0).$$
(4)

From equation (4), R_{Jm} is referred to as the ratio of the projection of jammer's transmitting antenna polarization vector to two orthogonal polarization vectors of the radar.

The received signals of PTs in h_p and h_q polarization channels can be expressed as

$$\boldsymbol{s}_{\mathrm{Tm}} = \begin{bmatrix} s_{\mathrm{Tpm}} \\ s_{\mathrm{Tqm}} \end{bmatrix} = K_{\mathrm{Tm}} \boldsymbol{S}_{\mathrm{m}}(n) \boldsymbol{h}_{\mathrm{p}} s(t - \tau_{\mathrm{TDm}}) e^{2\pi i f_{\mathrm{TDm}}}$$
(5)

with

$$\boldsymbol{S}_{\mathrm{m}}(n) = \begin{bmatrix} s_{\mathrm{pp}}(n) & s_{\mathrm{pq}}(n) \\ s_{\mathrm{qp}}(n) & s_{\mathrm{qq}}(n) \end{bmatrix}$$

During the n^{th} PRI, PSM of the m^{th} PT is $S_{\text{m}}(n)$, K_{Tm} expresses the signal's amplitude and is determined by the range attenuation and the antenna gain. After pass through a matched filter, we get

$$\begin{bmatrix} V_{\rm Tpm} \\ V_{\rm Tqm} \end{bmatrix} = K_{\rm rTm} \boldsymbol{S}_{\rm m}(n) \boldsymbol{h}_{\rm p}$$
(6)

where $K_{\rm rTm}$ is proportional to $K_{\rm Tm}$, the matched filter gain, and the Doppler mismatch. Then, we can get the IPRs of PTs, $R_{\rm Tm}$.

2.2 The Principle of DDM

As $h_p = [1,0]^T$ and $h_q = [0,1]^T$, from (4), we can see that the IPRs of FRTs are determined by the transmitting antenna polarization vector of the jammer, which does not change during the n^{th} PRI, thus the ratio remains unchanged for different repeater false targets. And from (6), the IPR of PT is the ratio of the two elements in the same row of PSM. Interested physical targets are mostly nonstationary, and the PSMs are time-variant. Amplitude and phase changes with the attitude angle in the n^{th} PRI and the sharp of targets. We rewrite (4) or (6) as

$$R_{\rm m} = \frac{V_{\rm qm}}{V_{\rm pm}} = \frac{x + iy}{u + iv} \tag{7}$$

where $u^2 + v^2 > x^2 + y^2$. In order to take the processing in the real domain, we define the stochastic variables *p* and *q*, corresponding to the real and imaginary part of *R*_m, which can be expressed as

$$R_{\rm m} = p_{\rm m} + iq_{\rm m} = \frac{xu + yv}{u^2 + v^2} + i\frac{yu - xv}{u^2 + v^2}.$$
 (8)

As mentioned above, IPRs of PTs are unequal and will randomly disperse in a two-dimensional coordinate system, (p,q), while IPRs of RFTs will congregate together, as shown in Fig. 1.



Fig. 1. Distribution of IPRs.

3. The Detection-Discrimination Method for Multiple RFTs

In this section, the detection-discrimination method for multiple RFTs will be introduced in details.

3.1 Variances of IPRs

Although the expressions of IPRs are simple and straightforward as listed in (8), it is not easy to derive the estimated variances in the presence of random noise. The measurement of IPR is given by

$$\hat{R}_{\rm m} = \frac{V_{\rm qm} + n_{\rm qm}}{V_{\rm pm} + n_{\rm pm}} = \hat{p}_{\rm m} + i\hat{q}_{\rm m} = (p_{\rm m} + w_{\rm pm}) + i(q_{\rm m} + w_{\rm qm}) . (9)$$

In the equation above, $[n_{pm}, n_{qm}]^T$ is the observation noise vector, whose two elements are assumed to be independent and identically distributed zero-mean complex Gaussian random variable, belonging to $N(0,\sigma^2)$, and σ^2 is variance. Now, we will derive the measurement variances of the above-mentioned real and imaginary part of \hat{R}_m (\hat{p}_m and \hat{q}_m), as this is the basement for designing a reasonable discrimination threshold.

Note that all these IPRs are non-linear functions related to[x, y, u, v]; hence the distributions of IPRs are usually not Gaussian. However, in order to simplify the computation, we still assume that these IPRs are Gaussian and the variances are determined by a first-order Taylor series expansion. Then let σ_{pm} and σ_{qm} denote the standard deviation of w_{pm} and w_{qm} .

with

1

$$\sigma_{\rm pm}^2 = \mathbf{A}_{\rm pm} \cdot \mathbf{P} \cdot \mathbf{A}_{\rm pm}^{\rm T} \tag{10}$$

$$\boldsymbol{P} = \operatorname{Var}([x, y, u, v]^{\mathrm{T}}) = \sigma_{\mathrm{u}}^{2} \begin{bmatrix} \gamma^{2} & 0 & \rho\gamma & 0\\ 0 & \gamma^{2} & 0 & \rho\gamma\\ \rho\gamma & 0 & 1 & 0\\ 0 & \rho\gamma & 0 & 1 \end{bmatrix},$$
$$\boldsymbol{A}_{\mathrm{pm}} = \begin{bmatrix} \frac{\partial p_{\mathrm{m}}}{\partial u}, \frac{\partial p_{\mathrm{m}}}{\partial v}, \frac{\partial p_{\mathrm{m}}}{\partial x}, \frac{\partial p_{\mathrm{m}}}{\partial y} \end{bmatrix},$$

$$\frac{\partial p_{\rm m}}{\partial u} = \frac{xv^2 - u^2x - 2uyv}{(u^2 + v^2)^2}; \frac{\partial p_{\rm m}}{\partial x} = \frac{u}{u^2 + v^2},$$
$$\frac{\partial p_{\rm m}}{\partial v} = \frac{yu^2 - v^2y - 2uxv}{(u^2 + v^2)^2}; \frac{\partial p_{\rm m}}{\partial y} = \frac{v}{u^2 + v^2}$$

where ρ is a correlation coefficient and $\gamma = \sigma_x / \sigma_u$ is the ratio of the standard deviation in two polarization channels, σ_u is the standard deviation of *u*. In practice, σ_u can be achieved through the estimation of the noise of every polarization channels. Also we can get σ_{pm} in the same way. That is $w_{pm} \sim N(0, \sigma_{pm}^{-2}), w_{qm} \sim N(0, \sigma_{qm}^{-2}).$

3.2 The Detection-Discrimination Method

Detection-discrimination of the IPRs in a two-dimensional coordinate system is a typical clustering problem. As we have got the distribution of w_p and w_q , in this article, a different way is taken to detect and discriminate the RFTs. Here, based on the distribution of IPRs, we make use of probabilistic grids [11], [12] to represent the clustering characteristic of the IPRs. First, the two-dimensional space of p and q, will be divided into many grids with the same size, and then, the probabilistic of \hat{p}_m or \hat{q}_m located in certain grid will be calculated; finally, according to the straightforward display of the clustering characteristic of the IPRs. For the data with different SNR, probability grids have obvious advantages that SNR of the data will be fully taken into account.

Rectangle grids are taken to divide up the two-dimensional space; the length Δl and the width Δw are determined by σ_{pm} and σ_{qm} , which are proportional to the RCS of PTs or the altitude modulation of RFTs. Thus we regard the minimum values of σ_{pm} and σ_{qm} as Δl and Δw , that is $\Delta l = \min{\{\sigma_{pm}\}}, \ \Delta w = \min{\{\sigma_{qm}\}}$. The whole two-dimensional space contains $K_1 \times K_w$ grids, and $K_1 = 2/\Delta l, \ K_w = 2/\Delta w$. When a value of (\hat{p}_m, \hat{q}_m) is got, the accumulative probability of the value located in every grid is

$$P\{j\Delta l, k\Delta w | (\hat{p}_{m}, \hat{q}_{m})\} = \{P_{p}(j\Delta l | \hat{p}_{m}) + P_{q}(k\Delta w | \hat{q}_{m})\} / C, (11)$$

(j = 1,2,..., K₁; k = 1,2,..., K_w)

with

$$C = \sum_{j=1}^{K_1} \sum_{k=1}^{K_w} P\{j\Delta l, k\Delta w | (\hat{p}_m, \hat{q}_m)\}$$

where $P_{\rm p}(j\Delta l|\hat{p}_{\rm m})$ means the accumulative probability of $\hat{p}_{\rm m}$ fall into the $j^{\rm th}$ interval, $P\{j\Delta l, k\Delta w|(\hat{p}_{\rm m}, \hat{q}_{\rm m})\}$ means the probability of $(\hat{p}_{\rm m}, \hat{q}_{\rm m})$ locate in the (j, k) grid. The joint distribution of $\hat{p}_{\rm m}$ and $\hat{q}_{\rm m}$ is given by [13], for simplicity, we assume $\hat{p}_{\rm m}$ and $\hat{q}_{\rm m}$ are independent here. According to the probability distribute function (PDF), $\hat{p}_{\rm m}$ or $\hat{q}_{\rm m}$ falls into three-sigma region of confidence, that is,

$$P(p_{\rm m} - 3\sigma_{\rm pm} \le \hat{p}_{\rm m} \le p_{\rm m} + 3\sigma_{\rm qm}) \ge 99.7\%.$$
 (12)

Then after some manipulation we get,

$$P(\hat{p}_{\rm m} - 3\sigma_{\rm pm} \le p_{\rm m} \le \hat{p}_{\rm m} + 3\sigma_{\rm qm}) \cong 99.7\%.$$
 (13)

It means when $\hat{p}_{\rm m}$ or $\hat{q}_{\rm m}$ is got, the true value, $p_{\rm m}$ or $q_{\rm m}$ falls into interval of $[\hat{p}_{\rm m} - 3\sigma_{pm}, \hat{p}_{\rm m} + 3\sigma_{pm}]$ with the confidence probability of approximately 99.7%. Thus, while trying to get the accumulative probability of every grid that $\hat{p}_{\rm m}$ or $\hat{q}_{\rm m}$ may fall into, only the grids within the three-sigma region will be taken into account, others will be zero.

A probability density matrix M is defined for the detection-discrimination method, and its element $M_{jk}(j = 1, 2...K_{l}; k = 1, 2...K_{w})$ corresponds to the summation of the accumulative probability that the measurement values locate in the (j,k) grid. During every PRI, we can use the value of M_{jk} to detect the existence of FRTs, that is

$$\begin{cases} \max{\{M_{jk}\}} \ge D, RFTs \text{ existence}; \\ \max{\{M_{jk}\}} < D, RFTs \text{ non - existence}; \end{cases}$$
(14)

D is the detection threshold. From (14), if RFTs are existence, and the maximum value of *M* locates in (j_{peak}, k_{peak}) grid, based on the variance of IPRs, the RFTs can be discriminated following some rules. Let (p_{cen}, q_{cen}) denote the centre point of the (j_{peak}, k_{peak}) grid and the discrimination rule can be simply designed as

$$T_{\rm m} = \begin{cases} RFT, \ \left| \hat{p}_{\rm m} - p_{\rm cen} \right| < \eta \sigma_{\rm pm} \text{ and } \left| \hat{q}_{\rm m} - q_{\rm cen} \right| < \eta \sigma_{\rm qm}; \\ PT, \ else; \end{cases}$$
(15)

where $T_{\rm m}$ is the $m^{\rm th}$ target. η is a design parameter, mostly tuned by engineering experience, a recommended selection of value interval can be set as $\eta \in [1,3]$. Let $h_{\rm Jt} = [h_{\rm JtH}, h_{\rm JtV}]^{\rm T}$, with the priori information of radar antenna, the IPRs of RFTs can be expressed as

$$R_{\rm Jm} = \frac{h_{\rm JtV}}{h_{\rm JtH}} = p_{\rm Jm} + iq_{\rm Jm} = (j_{\rm peak}\Delta l - 1) + i(k_{\rm peak}\Delta w - 1).$$
(16)

From equation (16), we can see that the estimation accuracy is influenced by the size of probability grid, and h_{Jt} can be estimated as $[1, p_{cen}+iq_{cen}]^T$.

3.3 Analysis of Data from a Microwave Anechoic Chamber

Up to this point, the DDM has been introduced. In this section, based on data from a microwave anechoic chamber, the value of the detection threshold D will be discussed.

PSMs of a scale model of missile are obtained through microwave anechoic chamber, with the frequency varying from 8.75 GHz to 10.01 GHz and the angle from 0° to 50° . The frequency interval is 20 MHz, the angle interval is 0.2° . The values of *p* and *q* stochastically locate in the interval [-1, 1], as shown in Fig. 2, and in order to display the details of p and q, we set p = 0 or q = 0 when |p| > 1 or |q| > 1.



Fig. 2. Values of p and q at different frequency and angle.

The probability distribution of p and q are displayed in Fig. 3, PSMs of other two types of target models (cone with and without cut), obtained from the microwave anechoic chamber, are also taken into account.



Fig. 3. Probability distribution of *p* and *q*.

From Fig. 3, we can see that, with quite large probability, (p,q) of targets are centered around (0,0). It means, for all there three types of targets, their cross-polarization component s_{qp} are mostly far less than co-polarization components s_{pp} , values of $|R_{Tm}|$ will be in the vicinity of zero. When the transmitting antenna of jammer is referred to, in order to confirm the effectiveness for different styles of radar receiving antenna, there must be approximately amplitude modulation gain for orthogonal polarization channels. That means values of $|R_{Jm}|$ will be in the vicinity of one.

As mentioned above, large numerical difference exists between $|R_{\text{Tm}}|$ and $|R_{\text{Jm}}|$. And the time variant characteristic of (p,q) as shown in Fig. 2, together with the numerical difference constitutes the theoretical foundation of the DDM.

As the congregation of p and q belonging to PTs will increase the false alarm probability of RFTs, detection threshold D must be determined by the probability of a number of targets falling in the same grid. That can be expressed as

$$D = \mu N P_{\max}(\Delta l, \Delta w), N \ll K_1 \times K_w.$$
(17)

Let N denote the number of targets, and D mean the cumulative probability of μN targets located in a single grid. $P_{\max}(\Delta l, \Delta w)$ is the accumulative probability of a certain grid include a value of (\hat{p}_m, \hat{q}_m) , that is

$$P_{\max}(\Delta l, \Delta w) = P_{p}(\Delta l) + P_{q}(\Delta w)$$
(18)

with

$$P_{\rm p}(\Delta l) = P_{\rm p}(\hat{p}_{\rm m} - 0.5\Delta l < \hat{p}_{\rm m} < \hat{p}_{\rm m} + 0.5\Delta l),$$

$$P_{\rm q}(\Delta w) = P_{\rm q}(\hat{q}_{\rm m} - 0.5\Delta w < \hat{q}_{\rm m} < \hat{q}_{\rm m} + 0.5\Delta w).$$

The choice of μ may influence the detection probability of RFTs and the false alarm probability. We define the ratio of target number and grid number as κ .

$$\kappa = \frac{N}{K_1 \times K_w} \,. \tag{19}$$

The data from the microwave anechoic chamber are randomly taken as the PSMs of targets. Distribution of μ in view of κ is shown in Fig. 4, with κ being 1, 0.1, 0.01, 0.001 and 0.0001 over 1000 trials.





Fig. 4. Distribution of μ against ratios of target number and grid number.

We can see that when $\kappa < 0.01$, 99% of μ is smaller than 0.2, which would be used to detect the existence of RFTs.

4. Numerical Result

In this simulation, a LFM signal, with pulse width 50 µs and bandwidth 5 MHz, is employed, and its carrier frequency is 10 GHz. [x, y, u, v] are assumed to be independent, thus $\rho = 0$. As listing all PSMs of targets is impossible, the PSMs of all three types of targets mentioned above are stochastically used as PSMs of PTs to verify the effectiveness of the DDM.



Fig. 5. Sketch of measured values of (p.q).

The transmitting antenna polarization vectors of jammer is [1,0.6*i*], and by retransmitting the radar signal, the jammer creates twenty RFTs. Ten PTs and other ten false targets formed by clutter are also comprised in the simulation scenario, and $\eta = 3$.

There are total forty signal echoes to be processed during a single PRI, and we assume SNR to be zero. After signal pulse compression processing, all measured values of (p,q) are shown in Fig. 5. In the figure, "others" is used to denote false targets formed by the clutter.

From equation (11), we can get the probability of a target falling in a given grid. Fig. 6 shows the accumulation probability in every grid. In this simulation, the total number of grids can be obtained, 17161, thus, $\kappa = 0.0003$, and then we can set the value of μ to be 0.2. Based on (17), the detection threshold *D* is 6.1268. According to (14), the existence of RFTs can be easily confirmed and the estimated measured value of (p,q) of RFTs falls in $(j_{\text{peak}}, k_{\text{peak}})$ grid.



Fig. 6. Accumulation probability in every grid.

In Fig. 7, the result of the MMD is displayed and all multiple RFTs created by the jammer are fully separated with others. That means only half of target groups need follow-up processing.



Fig. 7. Sketch of the separated targets.

Next, we will investigate the estimation performance of R_{Jm} under the influence of SNR.

SNR(dB)	-5	0	5	10	15
mean	-0.0015	-0.0030	-0.0005	0.0003	0.0001
standard deviation	0.0279	0.0122	0.0066	0.0045	0.0024

Tab. 1. Estimation accuracy of p against different SNR.

According to the polarization vector [1,0.6i], from (4) the theoretical value of (p,q) belonging to RFTs will be (0,0.6), with SNR being different values, over 50 trials, mean and standard deviation of the measured values of p is listed in Tab. 1. We can see that, the estimation accuracy of (p,q) is quite high.

RFTs can be realized by delaying and retransmitting the radar pulses with the angle measurements the same as the jammer itself. Then targets with similar angle information could be processing together, and the mutual impact between PTs will be enormously reduced.

5. Conclusion

The existence of multiple RFTs will effectively confuse the signal or data processing system of defense radar, it will be a great challenge to detect and recognize highthreat target, but novel target recognition method can also be designed based on the common characteristic of multiple RFTs. In this paper, using the data from two receiving polarization channels, the detection-discrimination method is presented. Based on the probability grids, data with different SNR are aggregated together to detect the existence of RFTs. Theoretical analysis and simulations indicate that the method is valid and feasible. Furthermore, this method is easy for practical implementation because of its simplicity and lower hardware requirement.

With the development of DRFM technology, multiple RFTs will be widely used as a most effective radar countermeasure scheme in practical. The topic of future research will be designing discrimination method based on the modulation characteristic of DRFM systems for multiple RFTs, which is the inherent common characteristic of the retransmitted radar signals.

Acknowledgements

This work was supported by the National Natural Science Foundation of China (61072119).

References

- MORRIS, G. V., KASTLE, T. A. Trends in electronic countercountermeasures. In *National Telesystems Conference Proceedings* (NTC'91). Atlanta (USA), 1991, p. 265-269.
- [2] RANKEL, S. Defeating theater missile defense radars with active decoys. *Science and Global Security*, 1997, vol. 6, no. 3, p. 333 to 355.
- [3] ROOME, S. Digital radio frequency memory. *IEE Electronics and Communications Engineering Journal*, 1990, vol. 2, no. 4, p. 147 to 153.
- [4] BANDIERA, F., FARINA, A., ORLANDO, D., RICCI, G. Detection algorithms to discriminate between radar targets and ECM signals. *IEEE Transaction on Signal Processing*, 2010, vol. 58, no. 12, p. 5984–5992.
- [5] GRECO, M., GINI, F., FARINA, A. Radar detection and classification of jamming signals belonging to a cone class. *IEEE Transaction on Signal Process*, 2008, vol. 56, no. 5, p. 1984–1993.
- [6] RAO, B., ZHAO, Y.-L., XIAO, S.-P., WANG, X.-S. Discrimination of exo-atmospheric active decoys using acceleration information. *IET Radar, Sonar and Navigation*, 2010, vol. 4, no. 4, p. 626 to 638.
- [7] TANG, B., LI, H.-M., SHENG, X.-Q. Jamming recognition method based on the full polarization scattering matrix of chaff clouds. *IET Microwaves, Antennas and Propagation*, 2012, vol. 6, no. 13, p. 1451-1460.
- [8] SHI, L.-F., WANG, X.-S., XIAO, S.-P. Polarization discrimination between repeater false-target and radar target. *Science of China Series F: Information Science*, 2009, vol. 52, no. 1, p. 149-158.
- [9] GIULI, D., FOSSI, M. Radar target scattering matrix measurement through orthogonal signals. *Radar and Signal Processing, IEE Proceeding-F*, 1993, vol. 140, no. 4, p. 233–242.

- [10] SANTALLA, V., YAHIA, M., ANTAR, M. A comparison between different polarimetric measurement schemes. *IEEE Transaction on Geoscience and Remote Sensing*, 2002, vol. 40, no. 5, p. 1007-1017.
- [11] ZHAO, Z.-C., WANG, X.-S., XIAO, S.-P. Grid-based probability density matrix for multi-sensor data fusion. *IEEE Prime Asia*, 2009, p. 205-208.
- [12] ELFES, A. Using occupancy grids for mobile robot perception and navigation. *IEEE Computer*, 1989, no. 6, p. 46-57.
- [13] GROVES, G. W., BLAIR, W. D., CHOW, W. C. Probability distribution of complex monopulse ratio with arbitrary correlation between channels. *IEEE Transactions on Aerospace and Electronic Systems*, 1997, vol. 33, no. 4, p. 1345-1350.

About Authors ...

Zhi-wei ZONG was born in Shandong, China, 1986. He received his B.S. from the National University of Defense Technology, Changsha, China, in 2010. His research interests include target recognition and the radar signal processing.

Long-fei SHI was born in Anhui, China, in 1978. He received the B.S. and Ph.D. degrees from the National University of Defense Technology, Changsha, China, in 2002 and 2007, respectively. His current research interests inlude the polarization signal processing, technology of radar attack and defense.

Yong-zhen LI was born in Inner Mongolia, China, in 1977. He received the B.S. and Ph.D. degrees from the National University of Defense Technology, Changsha, China, in 1999 and 2004, respectively. He was an associate research fellow. His current research interests include the polarization signal processing.

Xue-song WANG was born in Baotou, China, 1972. He received his B.E. and Ph.D. degrees from the National University of Defense Technology, China, in 1994 and 1999, respectively. He is currently working as a professor at NUDT. His current research interests include radar signal processing, radar polarimetry, and computational electromagnetic. Dr. Wang is a senior member of the Chinese Institute of Electronics (CIE).