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# 有源诱饵的双极化识别\*

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摘 要:针对双极化测量体制毫米波雷达,研究了有源干扰诱饵的极化识别方法。首先介绍了双极化 技术原理,然后详细分析了典型雷达目标和各种极化有源诱饵的双极化回波特性,引入能够有效表征 有源诱饵和雷达目标极化特性差异的同极化比和极化起伏等特征,并提出基于自适应恒虚警阈值的目 标识别方法。最后通过组建双极化试验雷达系统采集并分析了建筑物和垂直极化、水平极化、左旋圆 极化有源诱饵的回波数据,实验结果证明了有源诱饵的双极化识别方法的可行性和有效性。 关键词:毫米波雷达;目标识别;有源诱饵;双极化;极化散射矩阵;同极化;交叉极化 中图分类号;TN95;TN97 文献标志码;A 文章编号:1001-893X(2015)02-0168-07

# **Dual Polarization Identification of Active Decoys**

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**Abstract**: For millimeter wave(MMW) radar system of dual polarization, this paper presents a polarization identification method of active jamming decoys. Firstly, the principle of dual polarization technique is introduced, and the characteristics of dual polarization echo of the representative radar targets and various active decoys are analyzed in detail. Secondly, some effective characteristics of active decoys and radar targets are obtained to express their polarization characteristics differences, such as polarization ratio and polarization undulation. Thirdly, an identification method based on self – adaptive constant false alarm rate (CFAR) threshold is proposed. Finally, a dual polarization test radar system is constructed to gather and analyze the experimentation echo data of buildings, vertical polarization, horizontal polarization and left–handed circular polarization active decoys is feasible and effective.

Key words: millimeter wave radar; target identification; active decoys; dual polarization; polarization scattering matrix; co-polarization; cross-polarization

### 1 引 言

从近来全球范围内爆发的多次局部战争可以看 出,交战双方的电子战对抗愈演愈烈,是直接影响战 争进程的重要因素。有源诱饵干扰是主要的电子对 抗手段之一,它能主动发射电磁干扰诱饵信号,诱饵 信号在幅度、速度和加速度等特征信息上与真实目 标相差无几,有极强的迷惑性和欺骗性,常规的时域 和频域目标识别方法难以取得良好的效果,极大地 影响武器的突防成功率<sup>[1-2]</sup>。

众所周知,雷达极化信息作为继时域、频域和空 域信息以外又一极其重要的特征信息正越来越受到 重视,雷达极化技术也日益成为国内外学术界研究 的热点。目前,极化信息用于雷达抗干扰、反隐身、 目标检测以及识别等方面的研究已取得了大量突出

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的成果。文献[3]提出了全极化雷达的有源诱饵鉴 别方法,但它主要分析的是有源诱饵和简单形体结 构雷达目标的极化特征,并且全极化体制在工程中 也是难以实现的。文献[4]主要根据极化分解的思 路来探讨全极化雷达的目标识别方法,但是极化分 解特性是根据二面角、球等简单散射体提出的,难以 表征现实场景中多散射中心组成的建筑物、舰船和 飞机等典型雷达目标。文献[5]提出了一种融合多 种极化特征的雷达目标识别方法,但该文侧重于融 合识别算法的研究,并未对极化特征做过多的分析。 现有的极化识别技术的研究工作主要是针对理论算 法的研究居多,而对于适应于工程应用需求的极化 识别方法研究较少。

本文基于极化技术工程应用背景,针对双极化体 制毫米波雷达,在详细分析建筑物等典型雷达目标和 有源诱饵双极化特性的基础上,提出基于双极化特征 的自适应目标识别方法,并组建了双极化试验雷达系 统,用建筑物和毫米波信号源分别代表典型雷达目标 和有源干扰诱饵,通过试验采集其回波数据,探讨了 典型目标与有源诱饵的可区分识别性问题。

# 2 双极化技术

电磁波在传播时,电场矢量在水平平面内和垂 直平面内均有分量,被称为电磁波的极化现象。雷 达发射的电磁波照射到目标上时,由于目标的形状、 结构和材料的不同,会对发射电磁波产生不同的极 化扭转效应,这种极化扭转效应在数学上可表示为

$$\begin{cases} E_{H}^{R} = S_{11}E_{H}^{T} + S_{12}E_{V}^{T} \\ E_{V}^{R} = S_{21}E_{H}^{T} + S_{22}E_{V}^{T^{\circ}} \end{cases}$$
(1)

式中, $E_{H}^{R}$ 为电场的反射水平极化分量, $E_{H}^{T}$ 为电场的 发射水平极化分量, $E_{V}^{T}$ 为电场发射的垂直极化分 量, $E_{V}^{R}$ 为电场反射的垂直极化分量, $S_{11}$ 、 $S_{12}$ 、 $S_{21}$ 和 $S_{22}$ 为极化矩阵分量<sup>[6]</sup>。则极化矩阵被规定为

$$\begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix}$$
 (2)

式中, $S_{11}$ 和 $S_{22}$ 是共极化或同极化散射系数,而 $S_{12}$ 和 $S_{21}$ 是交叉极化散射系数。

所谓的双极化测量雷达是一般指仅发射垂直极 化电磁波,同时接收垂直和水平两种极化电磁波的 雷达测量系统。对双极化雷达而言,当发射垂直极 化波,接收到垂直极化波称为同极化现象;但是由于 目标的形状结构等因素会使得部分垂直极化波经反 射转变为水平极化波,称为交叉极化现象。同时由 于目标的形状、结构和材料的不同,也会带来极化波 幅度的起伏,对于复杂的舰船、飞机、建筑物等典型 雷达目标起伏较大,而有源干扰起伏较小。

对于垂直极化发射且双极化同时接收的测量雷达,目标回波的极化散射矩阵为

$$\begin{cases} E_{H}^{R} = S_{12} E_{V}^{T} \\ E_{V}^{R} = S_{22} E_{V}^{T^{\circ}} \end{cases}$$
(3)

式中,*S*<sub>22</sub>表示目标反射雷达回波的共极化能力,与 普通单极化雷达相同;而*S*<sub>12</sub>表示目标的交叉极化能力,与目标的形状、结构、材料、形态等参数相关,是 目标重要的极化特性。

### 3 典型目标和有源诱饵的双极化特性

典型的雷达目标主要包括建筑物、舰船和飞机 等,它们在结构上以二面角和平板为主,当此类目标 被垂直极化电磁波照射时,对电磁波的极化扭转效 应比较弱,所以表现为同极化分量强、交叉极化分量 弱的特点,如图1(a)所示。

对于有源干扰诱饵,它是通过干扰机主动发射电 磁波的干扰手段,它发射的电磁波极化形式主要有垂 直极化、水平极化、斜线 45°极化和圆极化。各种极化 电磁波在水平和垂直标准极化基下可描述为<sup>[6]</sup>:

(1)垂直极化: $E_V = 1, E_H = 0;$ 

(2)水平极化: $E_V = 0, E_H = 1;$ 

(3)斜线 45°极化: $E_V = 1, E_H = 1;$ 

(4) 左旋圆极化: $E_V = \cos wt$ ,  $E_H = \sin wt$ ;

(5)右旋圆极化: $E_V = \cos wt$ , $E_H = -\sin wt_{\circ}$ 

其中,*E<sub>v</sub>*和*E<sub>H</sub>*分别表示垂直分量和水平分量。那么 通过垂直极化发射和双极化同时接收体制的雷达接 收到的上述极化形式的有源诱饵信号存在以下特性:

(1) 左旋圆极化诱饵:由于圆极化电磁波用两种正交单极化天线接收时只是能量下降3 dB,所以同极化分量与交叉极化分量幅度水平也非常接近;

(2)右旋圆极化诱饵:同上;

(3)斜线 45°极化诱饵:同极化分量与交叉极化 分量幅度水平较接近;

(4)垂直极化诱饵:同极化分量远大于交叉极 化分量;

(5)水平极化诱饵:交叉极化分量远大于同极 化分量。

通过上述分析可知,左旋圆极化、右旋圆极化和 斜线 45°极化诱饵有类似的极化特性,如图 1(b)所示;垂直极化诱饵和水平极化诱饵的极化特性如图 1(c)和(d)所示。





同时,由于双极化天线接收到的有源诱饵回波 是由发射机直接发射电磁波,而典型雷达目标回波 则是目标被雷达垂直极化波照射并漫反射返回到天 线被接收到的电磁波,由于典型雷达目标的复杂性 会使漫反射带来大量的随机起伏,所以双极化天线 接收到的有源诱饵的电磁波比典型雷达目标更稳 定,起伏更小。

## 4 双极化识别方法

#### 4.1 极化特征提取

电讯技术

结合上述分析,同极化分量与交叉极化分量之 间的关系以及目标的极化起伏关系是典型雷达目标 和有源诱饵的主要差异,因此可提取以下极化特征 用于典型雷达目标和有源诱饵的识别。双极化回波 的同极化比特征表示雷达所发射的垂直极化波经过 目标反射后的垂直极化波与水平极化波的幅度比 值,此处用多次极化比均值来表示极化比特征,如式 (4)和(5)所示;

$$x = \frac{S_{22}}{S_{12}} = \frac{S_{22}E_V^T}{S_{12}E_V^T} = \frac{E_V^R}{E_H^R},$$
 (4)

$$\bar{x} = \frac{1}{n} \sum_{k=1}^{n} x_{k} \circ \tag{5}$$

极化起伏特征可用同极化比方差、同极化通道 幅度方差、交叉极化通道幅度方差、同极化通道幅度 方差与交叉极化通道幅度方差之比来表示,如式 (6)~(9)所示:

$$s_1^2 = \frac{1}{n} \sum_{k=1}^n (x_k - \bar{x})^2, \qquad (6)$$

$$s_2^2 = \frac{1}{n} \sum_{k=1}^n \left( E_V^R - \overline{E_V^R} \right)^2, \tag{7}$$

$$s_{3}^{2} = \frac{1}{n} \sum_{k=1}^{n} \left( E_{H}^{R} - \overline{E_{H}^{R}} \right)^{2}, \qquad (8)$$

$$R = \frac{s_2^2}{s_3^2} \,. \tag{9}$$

#### 4.2 识别方法

对于典型雷达目标而言,它的极化特征值是服 从以均值为中心的高斯分布的,那么其概率密度函 数为

$$P(X) = \frac{1}{(2\pi)^{1/2}\sigma} \exp\left[-\frac{(x-\mu)^2}{2\sigma^2}\right]_{\circ} \quad (10)$$

式中, $\mu$ 和 $\sigma$ 分别表示极化特征值的均值和方差。 那么令 $X_1 = (X - \mu) / \sigma$ ,则极化特征值的概率密度函 数可描述为

$$P(X_1) = \frac{1}{(2\pi)^{1/2}} \exp\left[-\frac{X_1^2}{2}\right]_{\circ}$$
(11)

本文采用恒虚警 (Constant False Alarm Rate, CFAR)的自适应阈值方法来进行目标识别的判决。 根据 Neyman-Pearson 准则可得虚警率 $P_{f}$ :

$$P_{f} = \int_{-\infty}^{-L_{1}} P(X_{1}) dX_{1} + \int_{L_{1}}^{+\infty} P(X_{1}) dX_{1} = 2\int_{-\infty}^{-L_{1}} \frac{1}{(2\pi)^{\frac{1}{2}}} \exp\left[-\frac{X_{1}^{2}}{2}\right] dX_{1} \circ$$
(12)

对于给定的 $P_{f}$ ,可由式(12)查表求得 $L_{1}$ ,进而可 求得门限阈值为

$$T = \pm L_1 \sigma + \mu_{\circ} \tag{13}$$

那么,典型雷达目标和有源诱饵的识别如公式 (14)所示:

 $\hat{X} \in (-L_1 \sigma + \mu, L_1 \sigma + \mu)$ (representative radar targets, (14)(active decoys, else

#### 5 试验分析

为了验证上述有源诱饵的极化识别方法,组建 了双极化试验雷达系统。前面已分析对于舰船、飞 机和建筑物等典型雷达目标而言,它们有相似的极 化特性,所以此处为采集试验数据的方便,选择用建 筑物为例代表典型雷达目标。试验中有源诱饵通过 毫米波信号源波形发生器和喇叭天线(包括垂直极 化、水平极化和左旋圆极化喇叭天线)模拟,可以模 拟垂直极化、水平极化和左旋圆极化诱饵。虽然信 号源波形发生器产生的连续波信号和真实的有源诱 饵存在一定差异.但是由于本文研究的是目标经检 测后的识别问题,那么选择一定距离单元内的连续 波信号是能够代表检测到的有源诱饵波形的极化特 性的,所以本文以此为例采集数据进行分析。

#### 双极化试验雷达原理 5.1

双极化试验雷达系统如图2所示,包括毫米波 双极化天线、雷达、功分器、数据采集设备和显控设 备等。该雷达系统可以实现垂直极化发射,并同时 接收垂直和水平两种极化电磁波。



双极化试验雷达原理框图 图 2 Fig. 2 Principle diagram of dual polarization test radar

#### 5.2 各类目标的一维距离像

图 3 分别列出了接收到的以上 4 种目标双极化 回波数据经过脉冲压缩后所得到的一维距离像,其 中横坐标表示距离单元序号,纵坐标表示雷达回波 的幅度值,可明显观察到不同目标两个通道目标位 置处幅度值的差异。



Fig. 3 Dual polarization echo of buildings and active decoys

# 5.3 极化特征分析

对以上4种目标分别选取同极化比、同极化比 起伏、同极化通道起伏、交叉极化通道起伏、起伏比 等5个特征进行了分析,每类目标的每个特征值均 选取多次回波各得到10个特征值,如表1所示。从 表1可以看出4类目标的极化特征差异明显。

	表1	建筑物和有源诱饵的极化特征分析
Table 1	Analysis of po	larization characteristics of buildings and active decoys

Image Protect 2005         Protect Protect 2005         Protect 2005 <th< th=""><th colspan="2"></th><th>同场化业/JP</th><th>同极化业担任</th><th>同场化通道封住</th><th><u>あ</u>叉通道担任</th><th></th></th<>			同场化业/JP	同极化业担任	同场化通道封住	<u>あ</u> 叉通道担任	
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	目标		円板化LL/ dB	回饭化比起休	門饭化通道起伏	文义通道起伏	
2         15.495         0.409 / 1         3.338 0         22.1/4 3         -10.501 0           4         13.592 1         0.520 8         6.124 6         32.041 9         -14.372 9           5         13.377 0         0.311 4         2.060 2         19.296 1         -17.383 3           6         13.403 0         0.326 0         2.122 6         18.352 7         -18.736 8           7         13.556 3         0.302 9         2.777 0         18.230 5         -16.344 4           8         13.819 0         0.384 4         3.376 2         21.984 2         -16.273 7           9         13.711 6         0.388 4         3.020 9         21.860 1         -17.100 2           10         13.527 2         0.347 2         3.642 6         20.228 8         -14.891 3           2         1.226 0         1.014 9         50.438 7         79.588 5         -3.961 7           3         1.312 2         1.356 2         96.656 4         83.150 6         1.307 3           4         0.792 4         1.412 3         67.026 3         76.821 0         -1.184 7           5         0.999 9         1.628 5         76.305 8         101.351 1         -2.465 4           4         0	建筑物	1	13.354 6	0.4634	1.504 9	26.402.8	-24.882 /
3         15,413 +         0.389 +         2.0012         22,109 3         -14,372 9           22         5         13,377 0         0.311 4         2.608 0         19.296 1         -17,383 3           6         13,403 0         0.326 0         2.122 6         18.352 7         -18,736 8           7         13,536 3         0.302 9         2.777 0         18.230 5         -16.344 4           9         13,711 6         0.388 4         3.020 9         21.860 1         -17,190 2           10         13.527 2         0.347 2         3.642 6         20.228 8         -14.891 3           1         0.695 6         1.360 9         80.102 4         93.043 5         -1.300 8           2         1.226 0         1.014 9         50.438 7         79.588 5         -3.961 7           3         1.312 2         1.355 2         76.305 8         101.351 1         -2.465 4           4         0.792 4         1.412 3         67.026 3         76.821 0         -1.184 7           5         0.999 9         1.628 5         76.305 8         101.351 1         -2.465 4           10         2.114 4         0.781 0         64.647 5         91.910         -0.038 2           10		2	13.490 2	0.4097	5.558 0 2.601 2	23.2/4 3	-10.301 0
1         13.322 1         0.320 8         0.124 0         32.011 9         -14.312 9           2         13.403 0         0.326 0         2.122 6         18.352 7         -18.736 8           7         13.536 3         0.302 9         2.777 0         18.230 5         -16.344 4           8         13.819 0         0.384 4         3.376 2         21.984 2         -16.737 7           9         13.711 6         0.388 4         3.020 9         21.860 1         -17.190 2           10         13.527 2         0.347 2         3.642 6         20.228 8         -14.891 3           1         0.695 6         1.360 9         80.102 4         93.043 5         -1.300 8           2         1.226 0         1.014 9         50.438 7         79.588 5         -3.961 7           3         1.312 2         1.355 2         96.656 4         83.150 6         1.300 8           2         1.226 0         1.614 3         67.026 3         76.821 0         -1.184 7           10         5.0999 9         1.628 5         76.305 8         101.351 1         -2.465 4           11         5.072 8         1.928 89.795 0         90.191 0         -0.038 2         -0.729 3           10		3	13.413 4	0.5894	2.001 2	23.109.3	-18.972 4
G 13, 37, 0 0 0, 311 4 2, 003 0 19, 290 1 19, 290 1 17, 353 6 8     7 13, 536 3 0, 302 9 2, 777 0 18, 230 5 -16, 344 4     8 13, 819 0 0, 384 4 3, 376 2 21, 984 2 -16, 273 7     9 13, 711 6 0, 388 4 3, 020 9 21, 860 1 -17, 190 2     10 13, 527 2 0, 347 2 3, 642 6 20, 228 8 -14, 891 3     1 0, 6695 6 1, 360 9 80, 102 4 93, 043 5 -1, 300 8     2 1, 226 0 1, 014 9 50, 438 7 79, 588 5 -3, 961 7     3 1, 312 2 1, 356 2 96, 656 4 83, 150 6 1, 307 3     4 0, 792 4 1, 412 3 67, 026 3 76, 821 0 -1, 184 7     [     [     ]		4	13.392 1	0.320.8	0.124 0	32.041 9 10.206 1	-14.372.9
初         0         13.40.0         0.300.9         2.122.0         18.30.7         -16.344           8         13.819.0         0.384.4         3.376.2         21.984.2         -16.273.7           9         13.711.6         0.388.4         3.020.9         21.860.1         -17.190.2           10         13.527.2         0.347.2         3.642.6         20.228.8         -14.891.3           1         0.695.6         1.360.9         80.102.4         93.043.5         -1.300.8           2         1.226.0         1.014.9         50.438.7         79.588.5         -3.961.7           3         1.312.2         1.356.2         96.656.4         83.150.6         1.307.3           5         0.999.9         1.628.5         76.305.8         101.351.1         -2.465.4           6         1.603.7         1.441.7         53.980.2         107.315.0         -5.968.5           6         1.635.3         40.728         1.92.8         89.795.0         90.191.0         -0.038.2           10         2.114.4         0.781.0         64.647.5         91.962.6         -3.061.2           1         35.574.1         5.402.5         41.983.5         254.564.9         -15.654.4		5	13.377 0	0.3114	2.008.0	19.290 1	-17.385 5
$ \begin{array}{c} 1 & 13.53.5 & 3.03.84 & 3.376 & 2.19.84 & 2.16.273 & 16.273 & 7 \\ 9 & 13.711 & 0.384 & 3.020 & 21.860 & 1 & -17.190 & 2 \\ 10 & 13.527 & 0.347 & 2 & 3.642 & 20.228 & -14.891 & 3 \\ 1 & 0.695 & 1.360 & 9 & 80.102 & 4 & 93.043 & 5 & -1.300 & 8 \\ 2 & 1.226 & 0 & 1.014 & 9 & 50.438 & 7 & 79.588 & -3.961 & 7 \\ 3 & 1.312 & 2 & 1.356 & 2 & 96.656 & 83.150 & 6 & 1.307 & 3 \\ 4 & 0.792 & 1 & 1.412 & 3 & 67.026 & 76.821 & 0 & -1.184 & 7 \\ \hline & 5 & 0.999 & 1.628 & 76.305 & 101.351 & -2.465 & 4 \\ \hline & 6 & 1.603 & 7 & 1.441 & 7 & 53.980 & 2 & 107.315 & -5.968 & 5 \\ \hline & 7 & 1.861 & 4 & 1.868 & 79.049 & 5 & 85.973 & 3 & -0.729 & 3 \\ \hline & 8 & 0.877 & 1.203 & 69.686 & 4 & 87.185 & -1.945 & 9 \\ 9 & 1.672 & 1.192 & 8 & 89.795 & 90.191 & -0.038 & 2 \\ 10 & 2.114 & 0.781 & 64.647 & 5 & 91.962 & -3.061 & 2 \\ \hline & 1 & 35.574 & 5.402 & 5 & 41.983 & 254.564 & 9 & -15.654 & 4 \\ 2 & 36.365 & 3 & 6.588 & 42.552 & 4 & 338.515 & 1 & -18.013 & 1 \\ 3 & 35.405 & 9 & 4.0467 & 30.3571 & 227.642 & 1 & -17.499 & 8 \\ \hline & 4 & 35.081 & 4.643 & 27.390 & 229.954 & -18.840 & 1 \\ \hline & 4 & 35.081 & 4.643 & 27.390 & 4 & 299.546 & -18.480 & 9 \\ \hline & 7 & 38.061 & 9 & 5.227 & 9 & 37.077 & 4 & 286.587 & -17.763 & 0 \\ \hline & 8 & 37.495 & 4.141 & 5 & 36.190 & 4 & 205.171 & 3 & -15.070 & 5 \\ 9 & 37.550 & 7 & 4.972 & 43.118 & 4 & 336.493 & 3 & -17.846 & 3 \\ 10 & 34.174 & 5.867 & 0 & 24.865 & 428.713 & 2 & -24.731 & 4 \\ \hline & 1 & -33.060 & 1 & 6.841 & 3 & 348.711 & 8 & 42.816 & 7 & 18.217 & 1 \\ 2 & -31.644 & 8 & 4.413 & 7 & 212.128 & 3 & 46.943 & 6 & 13.100 & 5 \\ 3 & -32.951 & 9 & 6.420 & 0 & 415.384 & 537.887 & 0 & 20.792 & 2 \\ \hline & \pi & 4 & -29.530 & 9 & 5.626 & 6 & 243.904 & 3 & 37.648 & 6 & 16.229 & 4 \\ \hline & \pi & 4 & -39.530 & 9 & 5.626 & 6 & 243.904 & 3 & 37.648 & 6 & 16.229 & 4 \\ \hline & \pi & -33.2951 & 9 & 6.420 & 0 & 415.384 & 537.887 & 0 & 20.792 & 2 \\ \hline & \pi & 4 & -29.530 & 9 & 5.626 & 6 & 243.904 & 3 & 37.648 & 6 & 16.229 & 4 \\ \hline & \pi & 4 & -39.530 & 9 & 5.626 & 6 & 243.904 & 3 & 37.648 & 6 & 16.229 & 4 \\ \hline & \pi & 4 & -39.531 & 9 & 6.420 & 0 & 415.384 & 537.887 & 0 & 20.79$		7	13.403.0	0.3200	2.1220 2.7770	18.3327	-16 344 4
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$		8	13.819.0	0.384.4	3 376 2	21 984 2	-16 273 7
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$		9	13.711.6	0.388.4	3.020.9	21. 860 1	-17, 190 2
1       0.695 6       1.360 9       80.102 4       93.043 5       -1.300 8         2       1.226 0       1.014 9       50.438 7       79.588 5       -3.961 7         3       1.312 2       1.356 2       96.656 4       83.150 6       1.307 3         4       0.792 4       1.412 3       67.026 3       76.821 0       -1.184 7         5       0.999 9       1.628 5       76.305 8       101.351 1       -2.465 4         6       1.603 7       1.441 7       53.980 2       107.315 0       -5.968 5         7       1.861 4       1.868 5       79.049 5       85.973 3       -0.729 3         8       0.877 5       1.203 3       69.686 4       87.185 6       -1.945 9         9       1.672 8       1.192 8       89.795 0       90.191 0       -0.038 2         10       2.114 4       0.781 0       64.647 5       91.962 6       -3.061 2         1       35.574 1       5.402 5       41.983 5       254.564 9       -15.654 4         2       36.365 3       6.558 3       42.552 4       338.515 1       -18.013 1         3       35.405 9       4.046 7       30.357 1       227.642 1       -17.499 8         4		10	13.527.2	0.347.2	3.642.6	20 228 8	-14 891 3
10.695 61.300 980.102 493.043 5-1.300 821.226 01.014 950.438 779.588 5-3.961 731.312 21.356 296.656 483.150 61.307 3 $4$ 0.792 41.412 367.026 376.821 0-1.184 7 $100$ 50.999 91.628 576.305 8101.351 1-2.465 4 $4$ 0.792 41.417 53.980 2107.315 0-5.968 5 $7$ 1.861 41.868 579.049 585.973 3-0.729 3 $8$ 0.877 51.203 369.686 487.185 6-1.945 9 $9$ 1.672 81.192 889.795 090.191 0-0.038 2 $10$ 2.114 40.781 064.647 591.962 6-3.061 2 $1$ 35.574 15.402 541.983 5254.564 9-15.654 4 $2$ 36.365 36.558 342.552 4338.515 1-18.013 1 $3$ 35.405 94.046 730.357 1227.642 1-17.499 8 $\frac{11}{10}$ 35.081 04.643 827.390 4229.954 6-18.480 9 $\frac{11}{10}$ 36.815 14.003 346.314 3186.324 2-12.091 1 $\frac{11}{10}$ 78.061 95.227 937.077 4286.587 7-17.763 0 $\frac{11}{10}$ 38.061 95.227 937.077 4286.587 7-17.763 0 $\frac{11}{10}$ 34.174 65.867 024.865 5428.713 2-24.731 4 $\frac{11}{10}$ -33.060 16.841 3348.711 842.816 718.217		10				201220 0	
21. 226 01. 014 950. 438 779. 588 5-3. 961 7 $3$ 1. 312 21. 356 296. 656 483. 150 61. 307 3 $4$ 0. 792 41. 412 367. 026 376. 821 0-1. 184 7 $5$ 0. 999 91. 628 576. 305 8101. 351 1-2. 465 4 $6$ 1. 603 71. 441 753. 980 2107. 315 0-5. 968 5 $7$ 1. 861 41. 868 579. 049 585. 973 3-0. 729 3 $8$ 0. 877 51. 203 369. 686 487. 185 6-1. 945 9 $9$ 1. 672 81. 192 889. 795 090. 191 0-0. 038 2 $10$ 2. 114 40. 781 064. 647 591. 962 6-3. 061 2 $1$ 35. 574 15. 402 541. 983 5254. 564 9-15. 654 4 $2$ 36. 365 36. 558 342. 552 4338. 515 1-18. 013 1 $3$ 35. 405 94. 046 730. 357 1227. 642 1-17. 499 8 $\frac{34}{4}$ 35. 081 04. 643 827. 390 4229. 954 6-18. 480 9 $\frac{4}{18}$ 36. 815 14. 003 346. 314 3186. 324 2-12. 091 1 $\ell_{L}$ 636. 562 75. 402 028. 768 1297. 271 7-20. 284 8 $41$ 738. 061 95. 227 937. 077 4286. 587 7-17. 763 0 $8$ 37. 495 24. 141 536. 190 4205. 171 3-15. 070 5 $9$ 37. 550 74. 972 243. 118 4336. 493 3-17. 846 3		1	0.6956	1.360 9	80.1024	93.043 5	-1.300 8
$E_{\rm E}$ 31.3121.356296.656488.1501.307 $I_{\rm E}$ 40.7921.412367.02676.8210-1.184 $I_{\rm E}$ 50.9991.62876.3058101.3511-2.465 $I_{\rm E}$ 61.60371.441753.9802107.3150-5.9685 $I_{\rm E}$ 71.86141.868579.049585.973-0.729391.67281.192889.79590.91910-0.0382102.1140.78164.64791.962-3.0612135.57415.40241.9835254.564-15.654236.36536.558342.5524338.5151-18.013335.40594.046730.3571227.6421-17.4998#435.081<04.643827.3904229.9546-18.4809336.81514.003346.3143186.3242-12.0911 $V_{\rm E}$ 636.56275.40228.7681297.271-20.2848435.06195.227937.077286.587-17.7630937.5504.97243.118348.71142.81618.21711-33.0601		2	1.226 0	1.014 9	50.4387	79.588 5	-3.961 /
III40.7921.412567.02670.8210-1.1847 $III50.9991.628576.3058101.3511-2.4654III61.60371.441753.9802107.3150-5.9685III1.86141.868579.049585.9733-0.729380.87751.203369.686487.1856-1.945991.67281.192889.795090.1910-0.0382102.11440.781064.647591.9626-3.0612135.57415.402541.9835254.5649-15.6544236.36536.558342.5524338.5151-18.0131335.40594.046730.3571227.6421-17.4998##435.08104.643827.3904229.9546-18.480910536.81514.003346.3143186.3242-12.091111636.56275.402028.7681297.2717-20.2848637.49524.141536.1904205.1713-15.0705937.55074.972243.1184336.4933-17.84631034.17465.867024.8655428.7132-24.73141-33.06016.8413348.711842.816718.21712-31.64484.4137212.128346.943613.10053-32.95196.4200415.384537.887020.7992III-33.06016.84167377.121438$	左	3	1.312.2	1.356 2	96.6564	83.150.6	1.30/3
          	旋圆	4	0. 792 4	1.412.3	67.026.3	/6.821.0	-1.184 /
代表 0 1.005 7 1.441 7 35.380 2 107.315 0 -5.368 5 3     (7 1.861 4 1.868 5 79.049 5 85.973 3 -0.729 3     8 0.877 5 1.203 3 69.686 4 87.185 6 -1.945 9     9 1.672 8 1.192 8 89.795 0 90.191 0 -0.038 2     10 2.114 4 0.781 0 64.647 5 91.962 6 -3.061 2     1 35.574 1 5.402 5 41.983 5 254.564 9 -15.654 4     2 36.365 3 6.558 3 42.552 4 338.515 1 -18.013 1     3 35.405 9 4.046 7 30.357 1 227.642 1 -17.499 8     垂 4 35.081 0 4.643 8 27.390 4 229.954 6 -18.480 9     重 5 36.815 1 4.003 3 46.314 3 186.324 2 -12.091 1     化 6 36.562 7 5.402 0 28.768 1 297.271 7 -20.284 8     7 38.061 9 5.227 9 37.077 4 286.587 7 -17.763 0     8 37.495 2 4.141 5 36.190 4 205.171 3 -15.070 5     9 37.550 7 4.972 2 43.118 4 336.493 3 -17.846 3     10 34.174 6 5.867 0 24.865 5 428.713 2 -24.731 4     1 -33.060 1 6.841 3 348.711 8 42.816 7 18.217 1     2 -31.644 8 4.413 7 212.128 3 46.943 6 13.100 5     3 -32.951 9 6.420 0 415.384 5 37.887 0 20.799 2     水 4 -29.530 9 5.626 6 243.904 3 37.648 6 16.229 4     桜 5 -35.321 6 6.816 7 377.121 4 38.614 8 19.794 6     化 K     K     7 33.065 1 3.934 5 29.783 9 36.612 9 15.953 7     9 -32.223 2 6.966 7 317.339 3 38.292 4 18.368 2     10 -30.794 9 4.992 1 289.023 6 44.707 6 16.211 0	极	5	0.999 9	1.628 5	76.305 8	101.351 1	-2.465 4
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30.677 31.203 30.000 40.710 00.110 0-0.038 291.672 81.192 889.795 090.191 0-0.038 2102.114 40.781 064.647 591.962 6-3.061 2135.574 15.402 541.983 5254.564 9-15.654 4236.365 36.558 342.552 4338.515 1-18.013 1335.405 94.046 730.357 1227.642 1-17.499 8435.081 04.643 827.390 4229.954 6-18.480 9536.815 14.003 346.314 3186.324 2-12.091 1 $400$ 636.562 75.402 028.768 1297.271 7-20.284 8738.061 95.227 937.077 4286.587 7-17.763 0837.495 24.141 536.190 4205.171 3-15.070 5937.550 74.972 243.118 4336.493 3-17.846 31034.174 65.867 024.865 5428.713 2-24.731 41-33.060 16.841 3348.711 842.816 718.217 12-31.644 84.413 7212.128 346.943 613.100 53-32.951 96.420 0415.384 537.887 020.799 2 $\frac{k}{\Psi}$ 5-35.321 66.816 7377.121 438.614 819.794 6 $\frac{1}{\Psi}$ 6-34.457 97.079 8390.931 848.520 318.123 5 $\frac{9}{\Psi}$ -30.655 13.934 5229.783 936.612 9 <td>饵</td> <td>/ 0</td> <td>1.801 4</td> <td>1.808.3</td> <td>79.049 3</td> <td>83.973 5 87 185 6</td> <td>-0.7293</td>	饵	/ 0	1.801 4	1.808.3	79.049 3	83.973 5 87 185 6	-0.7293
$\begin{array}{cccccccccccccccccccccccccccccccccccc$		0	0.877 5	1.203.3	89,795,0	00 101 0	-1.9439
102.114 40.101 00.101 00.101 00.101 00.101 0135.574 15.402 541.983 5254.564 9 $-15.654 4$ 236.365 36.558 342.552 4338.515 1 $-18.013 1$ 335.405 94.046 730.357 1227.642 1 $-17.499 8$ 435.081 04.643 827.390 4229.954 6 $-18.480 9$ 536.815 14.003 346.314 3186.324 2 $-12.091 1$ $11/1$ 636.562 75.402 028.768 1297.271 7 $-20.284 8$ 738.061 95.227 937.077 4286.587 7 $-17.763 0$ 837.495 24.141 536.190 4205.171 3 $-15.070 5$ 937.550 74.972 243.118 4336.493 3 $-17.846 3$ 1034.174 65.867 024.865 5428.713 2 $-24.731 4$ 1 $-33.060 1$ 6.841 3348.711 842.816 718.217 12 $-31.644 8$ 4.413 7212.128 346.943 613.100 53 $-32.951 9$ 6.420 0415.384 537.887 020.799 2 $\frac{1}{2}$ $\frac{1}{4}$ $-29.530 9$ 5.626 6243.904 337.648 616.229 4 $\frac{1}{2}$ $-31.464 9$ 7.671 7335.712 347.825 016.926 28 $-30.655 1$ $3.934 5$ 229.783 936.612 915.953 79 $-32.23 2$ $6.966 7$ 317.339 338.292 418.368 210 $-30.794 9$ $4.992 1$ <		10	1.072.8	0.781.0	64 647 5	91.962.6	-3.061.2
135.574 15.402 541.983 5254.564 9-15.654 4236.365 36.558 342.552 4338.515 1-18.013 1335.405 94.046 730.357 1227.642 1-17.499 8435.081 04.643 827.390 4229.954 6-18.480 9536.815 14.003 346.314 3186.324 2-12.091 1636.562 75.402 028.768 1297.271 7-20.284 8738.061 95.227 937.077 4286.587 7-17.763 0837.495 24.141 536.190 4205.171 3-15.070 5937.550 74.972 243.118 4336.493 3-17.846 31034.174 65.867 024.865 5428.713 2-24.731 41-33.060 16.841 3348.711 842.816 718.217 12-31.644 84.413 7212.128 346.943 613.100 53-32.951 96.420 0415.384 537.688 020.799 2 $\frac{1}{17}$ -35.321 66.816 7377.121 438.614 819.794 6 $\frac{1}{17}$ -31.146 97.671 7335.712 347.825 016.926 28-30.655 13.934 5229.783 936.612 915.953 79-32.223 26.966 7317.339 338.292 418.368 210-30.794 94.992 1289.023 644.707 616.211 0		10	2.114 4	0.701.0	04.047.5	91.902.0	5.001 2
2 $36.3653$ $6.5583$ $42.5524$ $338.5151$ $-18.0131$ 3 $35.4059$ $4.0467$ $30.3571$ $227.6421$ $-17.4998$ 4 $35.0810$ $4.6438$ $27.3904$ $229.9546$ $-18.4809$ 5 $36.8151$ $4.0033$ $46.3143$ $186.3242$ $-12.0911$ 6 $36.5627$ $5.4020$ $28.7681$ $297.2717$ $-20.2848$ 7 $38.0619$ $5.2279$ $37.0774$ $286.5877$ $-17.7630$ 8 $37.4952$ $4.1415$ $36.1904$ $205.1713$ $-15.0705$ 9 $37.5507$ $4.9722$ $43.1184$ $336.4933$ $-17.8463$ 10 $34.1746$ $5.8670$ $24.8655$ $428.7132$ $-24.7314$ 1 $-33.0601$ $6.8413$ $348.7118$ $42.8167$ $18.2171$ 2 $-31.6448$ $4.4137$ $212.1283$ $46.9436$ $13.1005$ 3 $-32.9519$ $6.4200$ $415.3845$ $37.8870$ $20.7992$ $\frac{1}{17}$ $-35.3216$ $6.8167$ $377.1214$ $38.6148$ $19.7946$ $\frac{1}{17}$ $-31.1469$ $7.6717$ $335.7123$ $47.8250$ $16.9262$ 8 $-30.6551$ $3.9345$ $229.7839$ $36.6129$ $15.9537$ 9 $-32.2232$ $6.9667$ $317.3393$ $38.2924$ $18.3682$ 10 $-30.7949$ $4.9921$ $289.0236$ $44.7076$ $16.2110$		1	35.574 1	5.402 5	41.983 5	254.5649	-15.654 4
335.405 94.046 730.357 1227.642 1 $-17.499 8$ 垂435.081 04.643 827.390 4229.954 6 $-18.480 9$ 536.815 14.003 346.314 3186.324 2 $-12.091 1$ 化636.562 75.402 028.768 1297.271 7 $-20.284 8$ 738.061 95.227 937.077 4286.587 7 $-17.763 0$ 837.495 24.141 536.190 4205.171 3 $-15.070 5$ 937.550 74.972 243.118 4336.493 3 $-17.846 3$ 1034.174 65.867 024.865 5428.713 2 $-24.731 4$ 1 $-33.060 1$ 6.841 3348.711 842.816 718.217 12 $-31.644 8$ 4.413 7212.128 346.943 613.100 53 $-32.951 9$ 6.420 0415.384 537.887 020.799 2 $\overset{\mathbb{R}}{\Psi}$ 5 $-35.321 6$ 6.816 7377.121 438.614 819.794 66 $-34.457 9$ 7.079 8390.931 848.520 318.123 57 $-31.146 9$ 7.671 7335.712 347.825 016.926 28 $-30.655 1$ $3.934 5$ 229.783 936.612 915.953 79 $-32.23 2$ 6.966 7317.339 338.292 418.368 210 $-30.794 9$ $4.992 1$ 289.023 644.707 616.211 0		2	36.365 3	6.558 3	42.552 4	338.515 1	-18.013 1
垂直         4         35.081 0         4.643 8         27.390 4         229.954 6        18.480 9           5         36.815 1         4.003 3         46.314 3         186.324 2         -12.091 1           化         6         36.562 7         5.402 0         28.768 1         297.271 7         -20.284 8           7         38.061 9         5.227 9         37.077 4         286.587 7         -17.763 0           8         37.495 2         4.141 5         36.190 4         205.171 3         -15.070 5           9         37.550 7         4.972 2         43.118 4         336.493 3         -17.846 3           10         34.174 6         5.867 0         24.865 5         428.713 2         -24.731 4           2         -31.644 8         4.413 7         212.128 3         46.943 6         13.100 5           3         -32.951 9         6.420 0         415.384 5         37.887 0         20.799 2           水         4         -29.530 9         5.626 6         243.904 3         37.648 6         16.229 4           5         -35.321 6         6.816 7         377.121 4         38.614 8         19.794 6           化         6         -34.457 9         7.079 8         390.931 8 <td></td> <td>3</td> <td>35.405 9</td> <td>4.0467</td> <td>30.357 1</td> <td>227.642 1</td> <td>-17.499 8</td>		3	35.405 9	4.0467	30.357 1	227.642 1	-17.499 8
品 化 化 化 传5 $36.8151$ $4.0033$ $46.3143$ $186.3242$ $-12.0911$ 6 $36.5627$ $5.4020$ $28.7681$ $297.2717$ $-20.2848$ 7 $38.0619$ $5.2279$ $37.0774$ $286.5877$ $-17.7630$ 8 $37.4952$ $4.1415$ $36.1904$ $205.1713$ $-15.0705$ 9 $37.5507$ $4.9722$ $43.1184$ $336.4933$ $-17.8463$ 10 $34.1746$ $5.8670$ $24.8655$ $428.7132$ $-24.7314$ 1 $-33.0601$ $6.8413$ $348.7118$ $42.8167$ $18.2171$ 2 $-31.6448$ $4.4137$ $212.1283$ $46.9436$ $13.1005$ 3 $-32.9519$ $6.4200$ $415.3845$ $37.8870$ $20.7992$ $\frac{1}{W}$ $4$ $-29.5309$ $5.6266$ $243.9043$ $37.6486$ $16.2294$ $\frac{1}{W}$ $6$ $-34.4579$ $7.0798$ $390.9318$ $48.5203$ $18.1235$ $\frac{1}{W}$ $7$ $-31.1469$ $7.6717$ $335.7123$ $47.8250$ $16.9262$ 8 $-30.6551$ $3.9345$ $229.7839$ $36.6129$ $15.9537$ 9 $-32.2232$ $6.9667$ $317.3393$ $38.2924$ $18.3682$ $10$ $-30.7949$ $4.9921$ $289.0236$ $44.7076$ $16.2110$	垂	4	35.081 0	4.643 8	27.3904	229.954 6	-18.480 9
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3 $-32.9519$ $6.4200$ $415.3845$ $37.8870$ $20.7992$ $\frac{1}{2}$ 4 $-29.5309$ $5.6266$ $243.9043$ $37.6486$ $16.2294$ $\frac{1}{2}$ 5 $-35.3216$ $6.8167$ $377.1214$ $38.6148$ $19.7946$ $\frac{1}{12}$ 6 $-34.4579$ $7.0798$ $390.9318$ $48.5203$ $18.1235$ $\frac{1}{12}$ 7 $-31.1469$ $7.6717$ $335.7123$ $47.8250$ $16.9262$ 8 $-30.6551$ $3.9345$ $229.7839$ $36.6129$ $15.9537$ 9 $-32.2232$ $6.9667$ $317.3393$ $38.2924$ $18.3682$ 10 $-30.7949$ $4.9921$ $289.0236$ $44.7076$ $16.2110$		2	-31.644 8	4.4137	212.128 3	46.943 6	13.100 5
水 平 平4-29.530 95.626 6243.904 337.648 616.229 4板 化 透5-35.321 66.816 7377.121 438.614 819.794 6化 透6-34.457 97.079 8390.931 848.520 318.123 5第 第7-31.146 97.671 7335.712 347.825 016.926 28-30.655 13.934 5229.783 936.612 915.953 79-32.223 26.966 7317.339 338.292 418.368 210-30.794 94.992 1289.023 644.707 616.211 0		3	-32.951 9	6.420 0	415.384 5	37.887 0	20.799 2
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化       6       -34.457 9       7.079 8       390.931 8       48.520 3       18.123 5         饵       7       -31.146 9       7.671 7       335.712 3       47.825 0       16.926 2         8       -30.655 1       3.934 5       229.783 9       36.612 9       15.953 7         9       -32.223 2       6.966 7       317.339 3       38.292 4       18.368 2         10       -30.794 9       4.992 1       289.023 6       44.707 6       16.211 0	平 极	5	-35.321 6	6.8167	377.121 4	38.614 8	19.794 6
107-31.146 97.671 7335.712 347.825 016.926 28-30.655 13.934 5229.783 936.612 915.953 79-32.223 26.966 7317.339 338.292 418.368 210-30.794 94.992 1289.023 644.707 616.211 0	化	6	-34.457 9	7.079 8	390.931 8	48.520 3	18.123 5
8         -30.655 1         3.934 5         229.783 9         36.612 9         15.953 7           9         -32.223 2         6.966 7         317.339 3         38.292 4         18.368 2           10         -30.794 9         4.992 1         289.023 6         44.707 6         16.211 0	四饵	7	-31.146 9	7.6717	335.712 3	47.825 0	16.926 2
9-32.223 26.966 7317.339 338.292 418.368 210-30.794 94.992 1289.023 644.707 616.211 0		8	-30.655 1	3.934 5	229.783 9	36.6129	15.9537
10 -30.794 9 4.992 1 289.023 6 44.707 6 16.211 0		9	-32.223 2	6.9667	317.3393	38.292 4	18.368 2
		10	-30.794 9	4.992 1	289.023 6	44.707 6	16.211 0

表 2 对上述 4 类极化特征值进行了统计特性分析,可以看到 5 个极化特征均有相对好的稳定性,建

筑物目标和其他有源诱饵的可区分性良好。

表 2 建筑物和有源诱饵的极化特征统计分析

Table 2 Statistic analysis of polarization characteristics of buildings and active decoys										
目标	同极化比		同极化比起伏		同极化通道起伏		交叉通道起伏		起伏比	
	均值/dB	方差	均值	方差	均值	方差	均值	方差	均值/dB	方差
建筑物	13.523 24	0.143 012	0.384 36	0.065 033	3.131 66	1.174 834	22.478 07	3.984 636	-17.540 90	2.810 968
圆极化诱饵	1.315 59	0.458 732	1.326 01	0.289 030	72.768 82	13.879 210	89.658 22	8.909 403	-1.934 84	1.961 011
垂直极化诱饵	36.308 65	1.173 223	5.026 52	0.794 693	35.861 75	7.204 468	279.123 80	70.237 090	-17.743 50	3.153 326
水平极化诱饵	-32.178 70	1.704 289	6.076 31	1.196 910	316.004 10	66.959 970	41.986 89	4.460 478	17.372 34	2.073 536

## 5.4 识别效果分析

如图 4 所示,对表 1 中特征数据的可识别性进行了作图分析,图的横坐标是特征值抽样序号,纵坐标是特征的值,可以看到前 4 种特征用于识别时,建

筑物和3种有源诱饵的差异明显,可识别性良好;对 于第5种特征即起伏特征而言,它和垂直极化诱饵 的特征值之间有重叠区域,区分效果不够好,与其他 有源诱饵区分效果仍然非常好。



图 4 5 个极化特征用于识别的可区分性分析 Fig. 4 Distinguishable ability of the five polarization characteristics

为区分有源诱饵和建筑物,首先录取 1000 次建 筑物双极化回波数据,并依据本文方法计算出建筑 物极化特征的均值和方差作为识别判决的标准值。 表 3 是录取 4 种目标各 100 次回波数据,对 5 种极 化特征根据自适应恒虚警阈值的方法进行目标识别 的成功率,其中设虚警率P<sub>f</sub>=0.05。可以看到前面 4 种单一极化特征用于识别的识别率可达到 95% 以 上,最后一种特征受到垂直极化诱饵的干扰稍多一 些,识别率为 88%。

表 3 识别率表

Table 3 The table of recognition rate					
极化特征	识别率/(%)				
同极化比	98				
同极化比起伏	97				
同极化通道起伏	97				
交叉通道起伏	95				
起伏比	88				

#### 5.5 试验结果

通过上述试验数据的分析可以看出,建筑物与 有源诱饵的双极化回波在极化域和起伏域差异明 显,提取的极化特征有相对稳定的辨识效果,可对建 筑物和有源诱饵进行有效区分,识别效果良好。建 筑物和飞机、舰船等典型雷达目标有类似的极化特 性,所以本文所用极化特征、识别方法和试验结果也 能推广到其他典型雷达目标。

# 6 结束语

本文通过对典型雷达目标和有源诱饵极化特性 的分析,提取极化特征信息,并组建双极化体制测量 雷达系统采集建筑物和有源诱饵的回波数据,验证 了双极化技术对有源诱饵识别的有效性。本文所用 的识别方法只是单一极化特征的识别方法,在实战 场景中雷达回波会受到各种杂波干扰的影响,因此 识别率会有所下降,但双极化识别方法仍有很高的 工程应用价值,在后续工作中有必要研究多种极化 特征的融合识别算法,进一步提高极化识别率。

### 参考文献:

 [1] 张玉玺,王晓丹,杨旭,等. 基于 Η/Α/α 分解的全极化 HRRP 目标识别方法[J].系统工程与电子技术,2013, 35(12):2501-2506.

ZHANG Yuxi, WANG Xiaodan, YANG Xu, et al. Target recognition of fully polarimetric HRRP based on  $H/A/\alpha$  decomposition[J]. Systems Engineering and Electronics, 2013,35(12):2501–2506. (in Chinese)

- [2] 李永祯,肖顺平,王雪松,等.雷达极化抗干扰技术
  [M].北京:国防工业出版社,2010.
  LI Yongzhen,XIAO Shunping,WANG Xuesong, et al. Radar polarization anti-jamming technology[M]. Beijing:National Defense Industry Press,2010. (in Chinese)
- [3] 李永祯,王雪松,王涛,等. 有源诱饵的极化鉴别研究
  [J]. 国防科技大学学报,2004,26(3):83-88.
  LI Yongzhen, WANG Xuesong, WANG Tao, et al. Polarization discrimination algorithm of active decoy and radar target[J]. Journal of National University of Defense Technology,2004,26(3):83-88. (in Chinese)
- [4] 丁维雷. 基于全极化雷达的目标识别方法研究[D]. 哈尔滨:哈尔滨工程大学,2013.
   DING Weilei. The research on target recognition methods based on polarization radar[D]. Harbin:Harbin Engineering University,2013. (in Chinese)
- [5] 张玉玺,王晓丹,姚旭,等. 一种融合多极化特征的雷达目标识别方法[J]. 计算机科学,2012,39(9):208-212.
  ZHANG Yuxi, WANG Xiaodan, YAO Xu, et al. Approach of radar target recognition based on multiple polarization features fusion[J]. Computer Science, 2012, 39(9):208-212. (in Chinese)
- [6] Tait P. 雷达目标识别导论[M]. 罗军,曾浩,李庶中, 等,译. 北京:电子工业出版社,2013:191-199.
  Tait P. Introduction to radar target recognition[M]. Translated by LUO Jun, ZENG Hao, LI Shuzhong, et al. Beijing:Publishing House of Electronics Industry,2013:191-199. (in Chinese)
- Shao Xianhe, Du Hai, Xue Jinghong. Theoretical analysis of polarization recognition between chaff and ship [C]// Proceedings of 2007 IEEE International workshop on Anti Counterfeiting, Security and Identification. Xiamen: IEEE, 2007:125–129.
- [8] Tang Guangfu, Zhao Ke, Zhao Hongzhou, et al. A novel discrimination method of ship and chaff based on sparseness for naval radar[C]//Proceedings of 2008 IEEE Radar Conference. Rome, Italy: IEEE, 2008:1-4.
- [9] 刘勇,李永祯,王雪松,等.基于极化分集接收的 HRRP 欺骗干扰鉴别[J].系统工程与电子技术,2011,33 (6):1247-1255.

LIU Yong,LI Yongzhen, WANG Xuesong, et al. Discrimination of HRRP deception jamming based onpolarization diversity receiving [J]. Systems Engineering and Electronics, 2011, 33(6):1247–1255. (in Chinese)

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