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ABORT-like detector to combat active deceptive jamming in a network of LFM radars

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Abstract This paper studies an electronic counter-counter measures (ECCM) scheme combating against deceptive electronic counter measure (ECM) techniques. An adaptive detector exploiting generalized likelihood ratio test (GRLT) criterion is applied to detect the presence of deceptive jamming in fractional Fourier transform (FrFT) domain. First, the generating mechanism of spurious frequencies is analyzed based on the Volterra serial. The proposed nonlinear distortion model based on power amplifier behavior is robust in distortion analysis when the memory effect is considered. Second, a modified adaptive beamformer orthogonal rejection test (ABORT) like detector in closed form is built. The proposed detector can discriminate the echo and deceptive jamming adaptively by exploiting primary data and secondary data. This ECCM scheme is capable of guaranteeing the performance without the restriction of orthogonality, which is essential for the ABORT detectors. The expansion to radar network is discussed as a special case at the final part of this paper. Numerical simulations demonstrate the effectiveness of the proposed method.

1. Introduction

Aimed at generating false targets around real target, main-lobe deceptive electronic counter measure (ECM) techniques are designed to combat against phase array radars.[1] This ECM scheme is often enhanced by using digital radio frequency memory (DRFM) systems. Moreover, for deceiving remote radar stations, power amplifier plays an important role in signal transmission. The high accuracy reconstruction of deceptive jamming (We note here that the notion of deceptive jamming denotes the waveform before matched filter and the notion of false target denotes the target indication after matched filter in this paper.) affects the basic function of tracking radar systems. This makes the cancellation and discrimination of false targets paramountly important. Thus, modern tracking radars have incorporated electronic counter-counter measures (ECCM) techniques to combat against the ECM signals.

The ECCM techniques for tracking radars can be categorized in accordance with tracking procedures. Generally, radar systems conduct target tracking by transmitting an optimal designed signal, receiving targets returns by an array of

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antenna, processing target detection and parameter estimation, and processing targets tracking. Moreover, the network version of radar stations applies information fusion for better targets detection, tracking and ECCM performance. Transmitter-based techniques include pulse diversity,[2,3] frequency agility, and pulse repetition interval (PRI) jitter. These techniques ensure that the jammer cannot easily anticipate the radar pulses. Besides, the application of low probability of interception signals[4] makes it difficult for jammer to estimate the parameters of the victim radar station. Antenna-based techniques are capable of preventing jamming from entering sidelobes of radar through sidelobe blanking and sidelobe canceling. Signal processing-based techniques adaptively cancel the deceptive jamming based on the assumption that jamming signals and echoes are not overlapped in time, frequency, space or transform domains[5–8] after some specific processing. Furthermore, adaptive discriminations of deceptive jamming and echo based on the finger print features[9] and subspace structure differences are also reported. Data processing-based techniques[10–12] apply target tracking and reject false targets through their range, angle, velocity and acceleration under the assumption that the deceptive jamming will introduce a mismatch on motion behavior. However, the limitations of ECCM techniques are also obvious. The complex transmitting signals will increase the computation burden and may decrease detection performance. Antenna-based techniques are only feasible for sidelobe jamming suppression. Signal processing-based techniques are highly affected by signal to noise ratio (SNR) and jamming to noise ratio (JNR). In addition, when the jammer modulates the false targets accurately on both time delay and Doppler frequency, the data processing-based techniques will come to failure. Thus, a network of radar equipped with ECCM techniques can enhance the performance against deceptive jamming.[13,14] Whatever techniques are used, the reaction of the radars must be immediate and adaptive to prevent the ECM.

In this paper, we consider the problem of detecting the presence of deceptive jamming in the cell under test (CUT), and the aim of this paper is to approach the jamming detection problem as a signal processing-based ECCM technique. To achieve this aim, the behavior model of the deceptive jamming emitted by a DRFM jammer is introduced in Section 2, and the fingerprint feature of the spectra based on Volterra serial is also analyzed. In Section 3, we present a method of extracting this fingerprint feature. Besides, we build a detector exploiting the fractional Fourier transform (FrFT) to distinguish between echo and deceptive jamming. In Ref. 15, the authors proposed a detector based on adaptive beamformer orthogonal rejection test (ABORT). The ABORT detector decides if the observed data contain a signal which belongs to one given subspace or a signal which belongs to an orthogonal subspace. The rejection of interfering signals was also considered.[16–19] In those papers, the authors solved the detection problem of extended targets embedded in homogeneous and partially extended interferences embedded homogeneous noise. These papers assume that targets and interferers are multidimensional and linearly independent signals. Unfortunately, for the real scenario, the echo and the deceptive jamming are generally not orthogonal, but their subspaces are different by an angle.[20] Thus, we modify the ABORT detector into our refined model to detect the presence of deceptive jamming only. Finally, we discuss a special case by extending our method to radar network. The numerical results are carried out by Monte Carlo simulation, which are described in Section 4, and we discuss the shortage and perspective of our method in Section 5.

2. Power amplifier distortion model

It is assumed that a phase array radar transmits a coherent linear frequency modulated (LFM) signal for target tracking. The basic structure of DRFM jammer is shown in Fig. 1. Several procedures will introduce a nonlinear distortion. As is discussed in Ref. 20, phase quantifier DRFM jammers will introduce a nonlinear distortion when quantization bits are low. Unfortunately, the advanced DRFM jammer is capable of quantifying intercepted signal in both amplitude and phase. Besides, the quantization bits are generally greater than 6-bits even when the sampling rate is greater than 2 GHz. Thus, it is not accurate for distortion analyses from the analog to digital converter (ADC) point of view. RF means radio frequency and DAC mean digital to analog in Fig. 1.

As an essential part of the DRFM jammer, the power amplifier ensures that deceptive jamming remains a high power for combating against remote radars. Generally, the nonlinear behavior for the power amplifier can be analyzed in physical models using nonlinear coefficient model of the power amplifier.[21,22] For a simple case, we suppose that there is no time delay and false Doppler frequency modulated by the DRFM jammer. The additive noise is set to be zero. The input discrete pulse waveform can then be expressed as

$$x(n) = A\exp\left[-\mathrm{j}2\pi\left(f_0 n + \gamma n^2 + \varphi_0\right)\right] \tag{1}$$

where A is the amplitude, f_0 the video frequency of the DRFM output, γ the chirp rate, and φ_0 the initial phase.

As is discussed in Ref. 22, considering the memory effect and polynomial structure, the distortion of power amplifier for a narrow band LFM input satisfies the Volterra series model. In order to meet the requirement of accurate modeling and low calculation burden, we consider a Volterra series model with memory depth of 5 and a Volterra order of 3, where the output power spectrum has a likelihood ratio greater than 95% compared to the ADS output through the simulations shown below. And there has little effect on likelihood ratio when a greater memory depth and Volterra order are chosen. The Volterra series model for the power amplifier output can then be interpreted as

$$\begin{aligned}
y(n) &= \sum_{i=0}^{p-1} h_1(i)x(n-i) + \sum_{i_1=0}^{p-1}\sum_{i_2=0}^{p-1} h_2(i_1,i_2)x(n-i_1)\cdot x'(n-i_2) \\
&\quad + \sum_{i_1=0}^{p-1}\sum_{i_2=0}^{p-1}\sum_{i_3=0}^{p-1} h_3(i_1,i_2,i_3)x(n-i_1)\cdot x(n-i_2)\cdot x'(n-i_3) \\
&= \sum_{i=0}^{p-1} A h_1(i)\exp[-\mathrm{j}2\pi(f_0(n-i)+\gamma(n-i)^2+\varphi_0)] \\
&\quad + \sum_{i_1=0}^{p-1}\sum_{i_2=0}^{p-1} A^2 h_2(i_1,i_2)\exp[-\mathrm{j}2\pi(2\gamma(i_2-i_1)n + f_0(i_2-i_1)+(i_2^2-i_1^2))] \\
&\quad + \sum_{i_1=0}^{p-1}\sum_{i_2=0}^{p-1}\sum_{i_3=0}^{p-1} h_3(i_1,i_2,i_3)x(n-i_1)\cdot x(n-i_2)\cdot x'(n-i_3)
\end{aligned} \tag{2}$$