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Target Multiplicity Performance Analysis of Radar CFAR Detection Techniques for Partially Correlated Chi-Square Targets

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Abstract **Most radar targets are complex objects and produce a wide variety of reflections. An important class of targets is represented by the so-called moderately fluctuating Rayleigh targets, which, when illuminated by a coherent pulse train, return a train of correlated pulses with a correlation coefficient in the range $0 < \rho < 1$ (intermediate between SWII and SWI models). The detection of this type of fluctuating targets is therefore of great interest. On the other hand, the CFAR detection is one of the desirable features for radar receivers. Because of the simplicity of cell-averaging (CA) detectors in their implementation, they are commonly used in modern radar systems to automatically adapt the detection threshold to the local background noise or clutter power in an attempt to maintain an approximately constant rate of false alarm. In this paper, we analyze the performance of these detectors for the case where the radar receiver postdetection integrates M square-law detected pulses and the signal fluctuation obeys chi-square statistics with two degrees of freedom. These detectors include the mean-level (ML), the greatest-of (GO) and the smallest-of (SO) schemes. In these processors, the estimation of the noise power levels from the leading and the trailing reference windows is based on the CA technique. Exact formulas for the detection probabilities are derived, in the absence as well as in the presence of spurious targets. The primary and the secondary interfering targets are assumed to be fluctuating in accordance with the chi-square fluctuation model with two degrees of freedom. Swerling's well known fluctuation models I and II represent the cases where the signal is completely correlated and completely decorrelated, respectively, from pulse to pulse. Probability of detection curves are presented for the chi-square family of fluctuations, including the Swerling cases I and II. The ML detector has the best homogeneous performance, the SO processor has the best multiple-target performance, while the GO scheme does not offer any merits, neither in the absence nor in the presence of outlying targets.**

Keywords **Radar receivers, Adaptive detectors, Postdetection integration, Chi-square fluctuating targets, Multiple-target environments**

1. Introduction

Constant false alarm rate (CFAR) processors are useful for detecting radar targets in a background for which the parameters of the statistical distribution are not known and may be nonstationary. The threshold in these detectors is set on a cell-by-cell basis using the estimated noise power level, obtained by processing a group of reference cells surrounding the cell under test [1–5]. As a consequence, much attention has been paid to the task of designing and assessing these adaptive detection techniques.

Naturally, the estimation technique is of primary concern. If the surrounding environment is at least locally homogeneous, namely if the samples of the reference window are independent and identically distributed (IID) exponential variates, then an efficient estimator of the noise power is the sample mean. The corresponding CFAR detector is known as cell-averaging (CA). The CA-CFAR processor uses the maximum likelihood estimate of the noise power to set the adaptive threshold, and therefore, it is still of major importance because it is the optimum CFAR processor when the background environment is homogeneous and the signals in the reference cells are IID and exponentially distributed. Actually, it is not at all uncommon to find an inhomogeneous environment. Generally, causes include spurious targets, entering the reference window, and clutter edges, advancing through the reference window as it slides along the transition zone between regions of different reflectivity. The presence of interferers inside the reference window leads to an overestimate of the actual noise power, while a clutter edge may result either in over- or underestimation, depending on whether the cell under test is in clear or in clutter. Overestimation gives rise to a masking of legitimate targets, while underestimation gives rise to false alarm rate inflation. The CA processor turns out to perform very poorly in these situations, and if some resilience against interferers and/or clutter edges is to be gained, alternative techniques, which trade some additional detectability loss under homogeneity for enhanced robustness in nonhomogeneous environments, must be adopted [7, 10].

Modifications of the CA processor have been proposed to overcome the problems associated with nonhomogeneous noise backgrounds. The greatest-of detector (GOD) and the smallest-of detector (SOD) may be considered as first attempts to combat false alarm rate inflation and the masking effect, respectively. These schemes split the reference window into leading and lagging parts symmetrically about the cell under test, and perform two independent estimates of the noise power, based on the CA technique. The noise power is no longer estimated efficiently,

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and therefore, some loss of detection in the homogeneous reference window is introduced compared with the CA-CFAR detector. As suggested by the names, the GOD selects the larger value as an estimate for the unknown noise power level, while the SOD chooses the smaller one. The first procedure, while performing satisfactorily when more than half of the reference cells are in clutter, is even worse than CA-CFAR scheme in the presence of interferers. The latter one, on the other hand, provides a fair estimate of the noise power only if all the interferers are located in the same half of the reference window, but it offers very little resilience to false alarm rate inflation [7, 8]. A lot of work has been done on Rayleigh clutter statistics and a large variety of operating conditions has been considered [3, 4, 7, 8, 12].

Greater robustness has been obtained with the data censoring algorithms. These systems rely on ordering or ranking the samples in the reference window and estimating the noise power as a linear combination of a fixed number of ordered statistics. This allows censoring of a certain number of outliers, and consequently the censoring schemes perform creditably as long as the number of interfering targets does not exceed the number of top ranked censored samples [7, 11]. However, the large processing time, taken by these techniques in ordering the contents of the reference window, make the CA based algorithms more favorable for practical applications.

It is often assumed that the Swerling cases bracket the behavior of fluctuating targets of practical interest. However, recent investigations of target cross section fluctuation statistics indicate that some targets may have probability of detection curves which lie considerably outside the range of cases which are satisfactorily bracketed by the Swerling cases. An important class of targets is represented by the so-called moderately fluctuating Rayleigh targets, which, when illuminated by a coherent pulse train, return a train of correlated pulses with a correlation coefficient in the range $0 < \rho < 1$ (intermediate between SWII and SWI models). The detection of this type of fluctuating targets is therefore of great interest.

In order that our previous work [8, 12] be sufficiently general to be applicable to a variety of cases, our goal in the present paper is to analyze the performance of the CA based detectors for partially correlated chi-square targets with two degrees of freedom in the absence as well as in the presence of spurious targets. The chi-square target model includes the well known Swerling cases I and II as special cases. In section 2, we formulate the problem and compute the moment generating function of the post-detection integrator output for the case where the signal fluctuation obeys chi-square statistics with two degrees of freedom that is considered for the study of the signal processing algorithms. In section 3, the performance of the processors under consideration is analyzed in ideal background environment. Section 4 deals with the problem of multiple target environment and the performance evaluation of the CA based detectors in these situations. In section 5, we present a brief discussion along with our conclusions.

2. Background and problem formulation

The block diagram of typical CFAR processor with post-detection integration of M pulses is shown in Fig. 1.

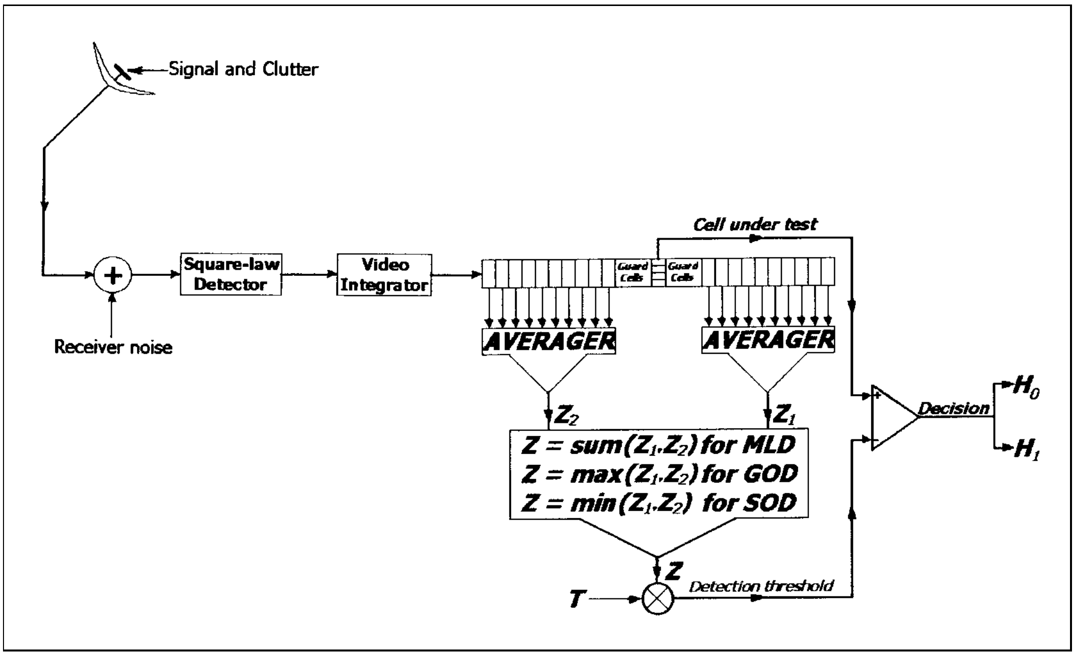

Fig. 1. Block diagram of CA family of CFAR Schemes.