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Performance of Excision Switching-CFAR in K distributed sea Clutter

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Abstract- **In this paper a new CFAR detector which is composed of an excision processor and a switching-CFAR detector, in an environment with K distribution, has been introduced. The new detector is named an excision switching CFAR. Performance of EXS-CFAR is derived and compared with the some other detectors like CA-CFAR, GO-CFAR and SO-CFAR for Swerling I target model in homogeneous and non-homogenous noise environments such as those with multiple interferes and clutter edges. The results show that EXS-CFAR detectors considerably reduce the problem of excessive false alarm probability near clutter edges while maintaining good performance in other environments.**
Keywords: Clutter, excision, multiple targets, Switching.

I. INTRODUCTION

In a radar receiver, after amplitude detection, backscattered signal is sampled in Range, Doppler or both of them and a one or two dimensional reference window will be formed. The detection in radar means existence or non-existence a target in the middle cell or cell under test (CUT) of a reference window. Estimated noise will be achieved based on samples surrounded CUT and different CFAR algorithms. A well-known processor is mean-level detectors like cell averaging CFAR (CA) [1]. Unfortunately because of differences in environmental conditions like change in clutter edge, multiple targets or jamming, the target detection will be corrupted. As cures for these problems, various CFAR schemes are proposed. Examples are greatest of CFAR (GO-CFAR), smallest of CFAR (SO-CFAR), order-statistics CFAR (OS-CFAR) excision cell-averaging CFAR (EXCA-CFAR) and excision greatest of CFAR (EXGO-CFAR) [2]. These schemes have advantages and disadvantages but none of them shows considerably good performance in all types of environments. An EXCA is different from other types in that it assumes the situation that *a priori* knowledge of the maximum clutter level is available. Before averaging cells from noise level estimation, EXCA discards large samples exceeding a predetermined threshold called the excision threshold, with the intention of removing the samples from interferes. In this paper, refer to the switching processor in [3, 4], it is focused on its excision type of it in environment of sea clutter with K distribution to cover the previous CFAR detectors' problem in non-homogeneous environments (existence of clutter edge and multiple targets). Many researches show that k-distribution has arisen mainly to represent radar sea clutter [5]. Then in this paper, performance of excision switching CFAR (EXS-CFAR) is analysed in comparison of conventional CFAR processors in the presence of clutter edge and multiple targets. Also with the help of simulation, it can be considered that achieved threshold by EXS is optimized. Then after describing the mentioned algorithm of EXS in section 2, in the section 3 mathematical and related probabilities of detection and false alarm are presented. In section 4 the performance and simulation of the EXS processor in the homogenous and non-homogenous environment will be analysed and at the last section, the results will come.

II. DESCRIPTION OF EXS-CFAR METHOD

In this paper, it is assumed that the CFAR processor's input are range samples (range cells) which are received from square law detector. Considering the sea clutter background and target change as Swerling I, the output samples will be iid K pdf (with shape parameter 1.5 [6]) as (1):

$$f_{X_i}(x_i)=\frac{1}{\lambda^2}x_i\,e^{-\frac{x_i}{\lambda}},\; x_i\geq 0, \lambda\geq 0,\; 1\leq i\leq 2N \qquad (1)$$

which X_is are 2N windows samples (except CUT) and λ is the total background clutter-plus-thermal noise power. If cell contains thermal noise then $\lambda=\lambda_0=2\eta$ and if cell consists of clutter then $\lambda=\lambda_c=2\eta(1+\sigma_c)$. If cell consists of multiple (not primary) targets then in equation (2) it has $\lambda=\lambda_i=2\eta(1+\sigma_I)$. Also σ_c is the ratio of clutter's power to the noise power and σ_i is the ratio of multiple targets' power to the noise.

The target detection in CUT is carried out by estimating the 2N reference window cells that surrounds it. The pdf of CUT is the same as equation (1) in the case of thermal noise with $\lambda=\lambda_0=2\eta$ and in the case of primary (main) target as equation (2) $\lambda=\lambda_s=2\eta(1+\sigma_s)$ while σ_s is the ratio of the signal power to the noise power [7, 8]

$$f_{X_0}(x_0)=\frac{1}{\lambda}e^{-\frac{x_0}{\lambda}},\; x_0\geq 0, \lambda\geq 0 \qquad (2)$$

Structure of an EXS is shown in Fig.1. In determining the detection threshold, samples exceeding the excision threshold ($\lambda\gamma$) are first discarded by the excisor. γ is a coefficient between 0 and 1 and λ was described in (1). This process gives the detector an ability to suppress the masking effect caused by interfering targets besides clutter edge. After excision, and assumption K_p remained samples, the switching will be carried out in two phases:

i) K_p existing cells in the reference window will be compared with scaled CUT by α ($\alpha<1$). If a cell be less than αX_0 it saved in group S_0 if not in S_1 as (3).

$$X_i \underset{S_0}{\overset{S_1}{\gtrless}} \alpha X_0,\; i=1,2,\ldots,K_p \qquad (3)$$

ii) If the number of samples saved in group S_0 assumed n_0 then the target will exist in CUT according to the below conditions:

$$\text{If } X_0 > \frac{\beta_0}{n_0} \sum_{X_i \in S_0} X_i \quad \text{when } n_0 > N_T \tag{4}$$

or

$$\text{If } X_0 > \frac{\beta_1}{k_p} \sum_{X_i \in K_p} X_i \quad \text{when } n_0 \le N_T \tag{5}$$

Here β_0 and β_1 are constant scale factor used to achieve a desired constant false alarm probability for a given window of size 2N when the total background noise is homogeneous and N_T is threshold integer.

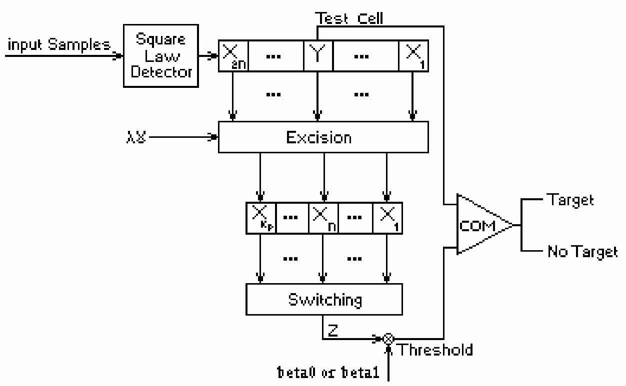

Figure 1. Block diagram of EXS-CFAR.

Inequalities (4) and (5) mean that in the EXS, after excision, switches between S_0 and whole of reference window (with the size K_p) dependent on the value of n_0. Then, for example, if the number of samples which are less than scaled CUT and are saved in S_0, be more than considered threshold ($N_T=K_p/2$), noise level estimation is carried out by averaging of those homogenous saved samples in S_0; but if the number of samples which are less than scaled CUT and are saved in S_0 be less than considered threshold, noise level estimation is carried out by averaging of non-homogenous saved samples in whole of window. This type of processing by EXS processor means selecting optimized threshold of detection in homogenous and non-homogenous environment.

III. Mathematical Analysis of EXS-CFAR

Considering the described algorithm in section 2, it is assumed that in a remained reference window with size equal to K_p, there is M interference and K_p-M thermal noise samples. The detection probabilities in EXS and according to the existence of n_0 samples in S_0 and K_p-n_0 samples in S_1, referred to the (4) and (5) in EXS will be as follows. At first the existence probability of a sample with thermal noise in S_0 group according to (3) will achieve:

$$P_0 = \frac{1}{1-e^{-\gamma}-\gamma e^{-\gamma}}\left(1-\frac{1}{(1+\alpha)^2}-\frac{2\alpha}{(1+\alpha)^3}\right) \tag{6}$$

which in this equation it is assumed that the samples are independent, the window samples contain thermal noise and the CUT contains signal. Also, the existence probability of a sample with interference noise in S_0 group according to (3) is:

$$P'_0 = \frac{1}{1-e^{-\gamma}-\gamma e^{-\gamma}}\,\frac{\alpha G_s}{1+\alpha\frac{G_s}{G_I}} \tag{7}$$

which G_s is 10log (λ_s/λ) and G_I is 10log (λ_I/λ).

The probability of saving maximum N_T samples of K_p window's samples that are less than αX_0 in S_0 will be:

$$\sum_{n_0=0}^{N_T}\binom{2N-M}{n_0-m}\binom{M}{m}P_0^{n_0-m}(1-P_0)^{2N-M-(n_0-m)}P_0'^{m}(1-p_0')^{M-m} \tag{8}$$

P_0 and P'_0 were calculated from (6) and (7). Therefore according to (4), (5), (6), (7) and (8), the detection probability will be:

$$P_d = P(n_0 \le N_T)\times P(X_0 > \frac{\beta_1}{k_p}\sum_{i=1}^{2N-n_0}X_i)+$$

$$+P(n_0 > N_T)\times P(X_0 > \frac{\beta_0}{n_0}\sum_{i=1}^{n_0}X_i) \tag{9}$$

Calculating the probabilities of (9):

$$P_d(N_T,\alpha,\beta_0,\beta_1) =$$

$$\sum_{k_p=1}^{2N}\binom{2N}{k_p}((1+\gamma)e^{-\gamma})\left(\frac{e^{\gamma}-1-\gamma}{1+\gamma}\right)^{k_p}\times$$

$$\left\{\sum_{n_0=0}^{N_T}\sum_{m=m_1}^{\min(M,n_0)}\binom{K_p-M}{n_0-m}\binom{M}{m}P_0^{n_0-m}(1-P_0)^{K_p-M-(n_0-m)}P_0'^{m}(1-p_0')^{M-m}\times\right.$$

$$P(x_0>\frac{\beta_1}{K_p}Y_1)+$$

$$\sum_{n_0=N_T+1}^{K_p}\sum_{m=m_1}^{\min(M,n_0)}\binom{K_p-M}{n_0-m}\binom{M}{m}P_0^{n_0-m}(1-P_0)^{K_p-M-(n_0-m)}P_0'^{m}(1-p_0')^{M-m}\times$$

$$\left.P(x_0>\frac{\beta_0}{n_0}Y_0)\right\} \tag{10}$$

which:

$$P(x_0>\frac{\beta_1}{k_p}Y_1)=\left\{\frac{e^{\gamma}}{e^{\gamma}-1-\gamma}\frac{1}{(1+\frac{\beta_1}{k_p}\frac{G_I}{G_s})^2}\left(1-e^{-\gamma(1+\frac{\beta_1}{k_p}\frac{G_I}{G_s})}(1+\gamma(1+\frac{\beta_1}{k_p}\frac{G_I}{G_s}))\right)\right\}^{M}\times$$

$$\left\{\frac{e^{\gamma}}{e^{\gamma}-1-\gamma}\frac{1}{(1+\frac{\beta_1}{k_p}\frac{1}{G_s})^2}\left(1-e^{-\gamma(1+\frac{\beta_1}{k_p}\frac{1}{G_s})}(1+\gamma(1+\frac{\beta_1}{k_p}\frac{1}{G_s}))\right)\right\}^{K_p-M}$$

and

$$P(x_0>\frac{\beta_0}{n_0}Y_0)=\left\{\frac{e^{\gamma}}{e^{\gamma}-1-\gamma}\frac{1}{(1+\frac{\beta_0}{n_0}\frac{G_I}{G_s})^2}\left(1-e^{-\gamma(1+\frac{\beta_0}{n_0}\frac{G_I}{G_s})}(1+\gamma(1+\frac{\beta_0}{n_0}\frac{G_I}{G_s}))\right)\right\}^{m}\times$$

$$\left\{\frac{e^{\gamma}}{e^{\gamma}-1-\gamma}\frac{1}{(1+\frac{\beta_0}{n_0}\frac{1}{G_s})^2}\left(1-e^{-\gamma(1+\frac{\beta_0}{n_0}\frac{1}{G_s})}(1+\gamma(1+\frac{\beta_0}{n_0}\frac{1}{G_s}))\right)\right\}^{n_0-m}$$

In above equations m_1 is equal to max (0, n_0-K_p+M).

IV. Studying EXS-CFAR Under Non-Homogenous Conditions

The performance of excision switching CFAR processor algorithm, according to (10), is a function of β_0, β_1, N_T, α and γ. By plotting the false alarm curve (P_{fa}) for reference window with the size 2N=24 and considering $\beta_0=\beta_1$ and $N_T=K_p/2$ (with the same manner of (10)) and also changing values of α and γ, the Fig. 2 will be achieved.

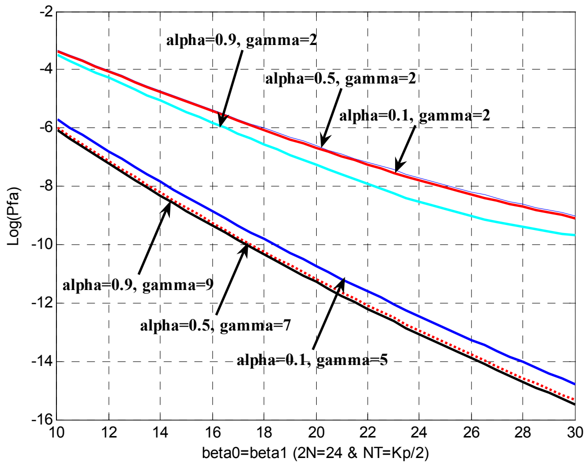

Figure 2. False alarm probability of the EXS-CFAR processor for $\beta_0=\beta_1$ and different α and γ.

In Fig. 3 detection probability of EXS processor in homogenous environment with 2N=24, P_{fa}=10-6 and for mentioned parameters are drawn. Here, with the definition of loss detection in [8], it is seen that EXS processor has inherent detection loss in the homogenous environment which is increased by α and γ that their difference is about a hundred of percent.

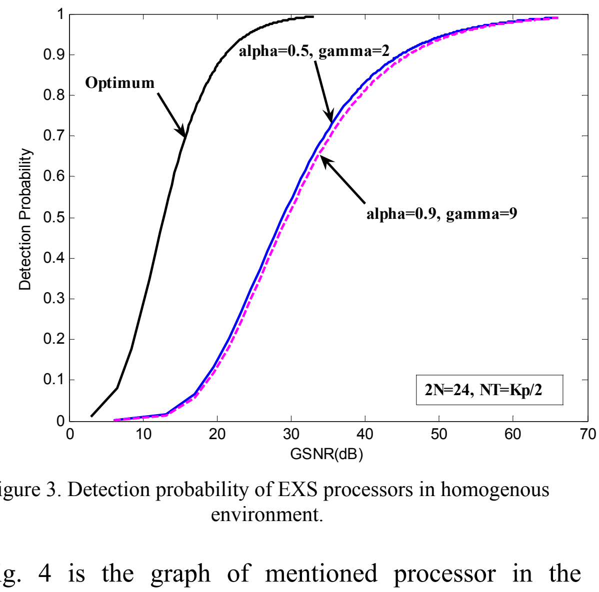

Figure 3. Detection probability of EXS processors in homogenous environment.

Fig. 4 is the graph of mentioned processor in the presence of clutter edge with clutter to noise ratio (CNR) equal to 15dB and for reference window with the size 2N=24. It is known that in environment with non-homogenous noise and presence of clutter edge, GO processor has least probability of false alarm and after it; there is CA and then SO [1]. It is clear from Fig. 4 that with decreasing α from 0.2 to 0.1 in same γ=2, EXS can achieve even less false alarm probability than GO which has best performance among all the CFAR processors in the presence of clutter.

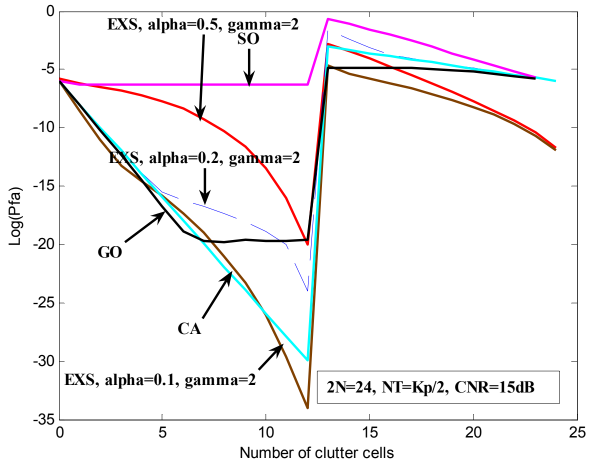

Figure 4. Comparison of P_{fa} for EXS processor (CNR=15dB & $N_T=K_p/2$) in clutter edge.

In Fig. 5, CNR is decreased to 10 dB and its effect is observable. By decreasing α from 0.5 to 0.1 and keeping γ=2 constant, it is seen that probability of false alarm in EXS processor decreases. At all for having good performance in reference window with the size 2N=24, the parameters of EXS processor should set like this: α=0.1, γ=2 and $N_T=K_p/2$.

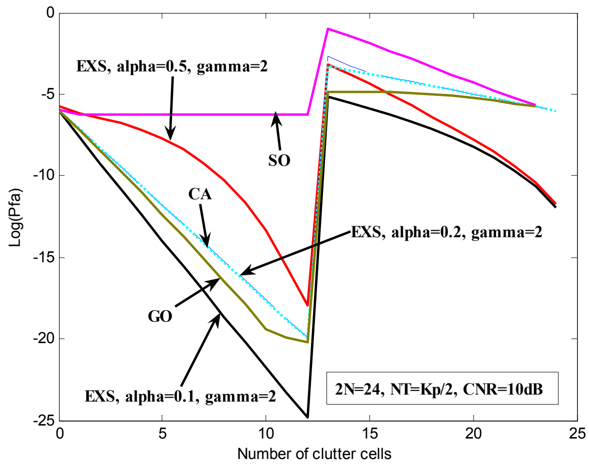

Figure 5. Comparison of P_{fa} for CA, GO, SO and EXS processor (CNR=10dB & $N_T=K_p/2$).

The case of presence of multiple targets is another condition in the studying of EXS processor. In Fig. 6 one interfering target with generalized interfering to noise ratio (GINR) equal to GSNR and the size of reference window 2N=24 for CA, GO, SO and EXS processors are considered. SO processor for GSNR more than 35dB has the best performance of detection. Although EXS processor is better than SO for GSNR less than 35dB. By decreasing α and increasing γ from 5 to 9, it is possible to improve probability of detection. In the mentioned figure and for better comparison, some graphs for CA, GO and SO are drawn.

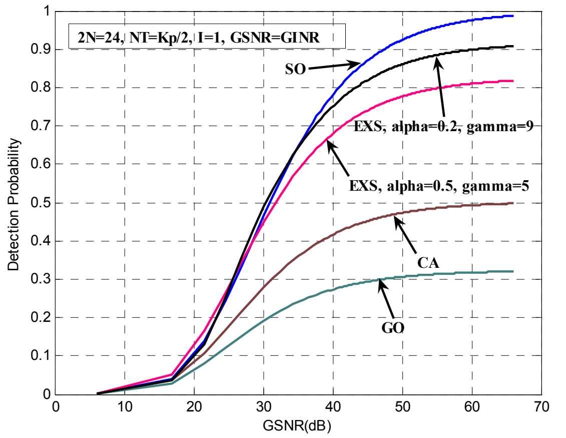

Figure 6. Comparison of Pd between EXS with different α and γ with CA, GO, and SO in the case of one interfering targets (GINR=GSNR).

At last, probability of detection in the case of five multiple targets for reference window with size 2N=24 and GSNR=GINR again has been performed in Fig. 7. It can be seen again that SO even in the case of 5 interfering targets has maximum probability of detection and after that EXS processor with $N_T=K_p/2$, $\gamma=9$ and $\alpha=0.2$ has higher probability of detection. As Fig. 7 shows with decreasing α and increasing γ, probability of detection in EXS processor increases. It is clear in the case of present multiple targets, GO processor still has worse probability of detection.

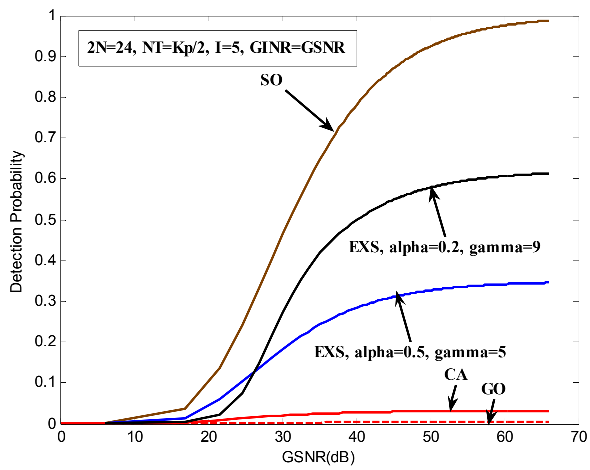

Figure 7. Comparison of P_d of EXS with different α and γ by CA, GO and SO in the case of 5 multiple targets (GINR=GSNR).

The detection threshold simulation can be carried out using Matlab software in present of clutter and multiple targets. In Fig. 8, there are nein targets in ranges 4, 9, 14, 25, 30, 31 and 35 with mentioned GSNRs and also clutter present from rang 46 with the power equal to targets in figure. Considering the reference window's size equal to 2N=24 and $P_{fa}=10^{-6}$, the CA and SO processors can only detect the first target which is located in range of 4 while GO can not detect any target and OS can detect the five targets in ranges of 4, 9,14,30 and 31, as it was expected.

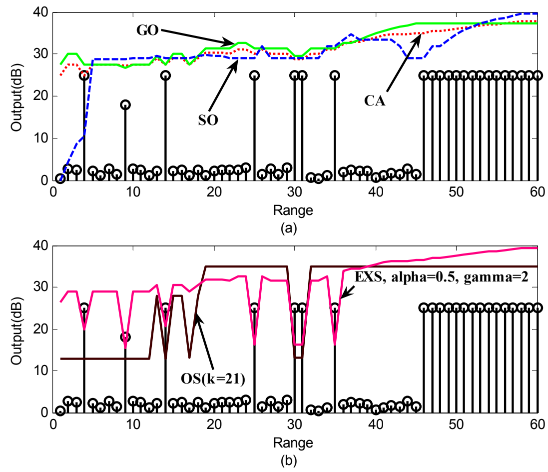

Figure 8. Detection thresholds of different CFAR processors in multiple targets and clutter edge environment (2N=24, $N_T=K_p/2$ and $P_{fa}=10^{-6}$).

Refer to Fig. 8, OS processor with order k=21 can detect first, second and last targets in ranges 4, 9 and 14 while EXS processor (with $\alpha=0.5$, $N_T=K_p/2$ and $\gamma=2$) can detect the whole targets.

V. Conclusions

Considering the results of section 4 and comparison with other processors, the EXS-CFAR processor performance in different radar environments is acceptable. Also this results show that EXS-CFAR processor has good performance with less detection loss not only in homogenous environments but also in non-homogenous like multiple targets and especially in clutter edge. In addition, simulation results confirm that achieved detection threshold of EXS-CFAR will be optimize if the number of interfering targets be less than size of reference window and it will be the only processor which can detect whole of targets. Besides implementation of EXS-CFAR is simpler comparing with samples ordering processors.

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