Influence of ordered and weighted analysis windows on detection in a CFAR radar

H. Mansouri, M. Hamadouche, F. Youcef Ettoumi

Abstract— In this paper, we propose a novel algorithm for a CFAR radar detector. The proposed processor is derivated from OS CFAR one and is based on weighting samples taken for the background level estimate. We assume that targets are embedded in a Gaussian noise and fluctuate according to Swerling I model. First, closed form expressions of the probabilities of detection and false alarm are determined and the performances of the proposed detector referred as WMAX CFAR are investigated when using one weighting coefficient for one window containing N samples of background. Then, we consider the case of a version with two different weighting coefficients each applied on a half window containing N/2 samples.

We present the results of performance analysis in non homogenous environment of the new detector referred as GOWMAX CFAR detector. The results are presented and discussed.

Keywords— GOWMAX-CFAR, OS-CFAR, Radar,WMAX-CFAR

I.INTRODUCTION

Detection of target in a background of clutter is a problem of interest in radar field. In order to improve such detection system, the designer usually prefers a constant false alarm rate. To achieve this purpose, the actual interference power must be estimated from the data in real time, so that the threshold can be adjusted to maintain the desired probability of false alarm (Pfa). A detection processor that can maintain a constant Pfa is said Constant False Alarm Rate (CFAR).

Finn and Johnson [1] have developed a theory based on arithmetic mean of the resolution cells of the test cell. This is known as Cell Averaging CFAR detector. The CA-CFAR detector was shown to be efficient in homogenous environment. In fact, the probability of detection approaches the classical Neyman-Pearson[2] case where the mean level of clutter is known a priori, provided that these cells do not contain interfering samples.

However, the detector based on order statistics (OS-CFAR) proposed by Rohling [3] provides inherent protection against serious performance degradation in presence of non-homogenous environment. Many works have been undertaken subsequently to improve the performance of such detectors based on order statistics. Blake [4] has analyzed the detection performance of the Trimmed Mean CFAR (TM-CFAR) detection in no homogenous situation that can be a trade-off between the CA-CFAR and the OS-CFAR. In this detector, the background level is estimated by a linear combination of ordered input samples. The same idea has been developed by Magaz and *al.*in[5] and [6].

In [7] Bencheikh and *al.* have proposed a new CFAR processor architecture that combines the advantages of both the CA-CFAR and the OS-CFAR detectors and referred as Smoothed OS-CFAR.

Cho and Barkat[8]have proposed a robust Ordered statistic based CFAR scheme, the Moving Ordered Statistics MOS CFAR detector, to estimate the noise level around the test cell in nonhomogenus backgrounds. The rank of the selected sample is a variable and varies depending of the background noise in the reference cell. Kim and *al.* have analysed in [9] the generalized OS-CFAR detector with M pulses noncoherent integration for general chi-square fluctuating targets in non homogenous environment wich covers the various OS and CA CFAR detectors like GOS-CFAR detector. By properly choosing the coefficients of this last, they could realize various kinds of CFAR processors, such as the Censored Mean Level detector (CMLD) and the Trimmed Mean (TM) one. El Mashade[10] extended the performance analysis of this detector to the case where the radar receiver incorporates a post integrator.

In this paper, we propose a novel approach of architecture detection designed as WMAX CFAR (Weighted MAXimum-CFAR [11]. The idea is to exploit the advantages of the OS-CFAR by a faster method which consists on using the statistical order but instead of choosing the kthe cell, we take the greatest and multiply it by a weighting coefficient α to estimate the level of the noise. This estimated power is multiplied by a threshold multiplier to obtain the threshold level.

The threshold is compared with signal resulting from the cell under test to decide for the presence or the absence of the target.

H. Mansouri and F. Youcef ettoumi are with Image Processing and Radar Laboratory, University of Science and Technology Houari Boumediene , Algiers, Algeria. (telecommunication Department),
(email:hmansouri@usthb.dz, fyoucefettoumi@yahoo.com)
M.Hamadouche is with LIMOSE Loaboratory, Department of Infotronic, University of Boumerdes, Boumerdes, Algeria.
(email : hamadouchemhamed@hotmail.com)

We have assumed that targets are fluctuating according to Swerling I model [12]. We have derived closed form expressions for the probabilities of detection and false alarm. The performance of the proposed system is investigated and analysed in section 2 of this paper.

The obtained results lead us to extend the idea by using two weighting coefficients applied on a leading and a lagging windows composed each one by N/2 samples surrounding the cell under test.

This new algorithm is referred as GOWMAX CFAR [13].

We have reserved the third section of this article for performances analysis of this last.

II. PERFORMANCES ANALYSIS OF A WMAX CFAR DETECTOR

A. *Problem formulation*

The arrangement of the N adjacent cells by ascending order can lead us to various cases as represented in Fig. 1

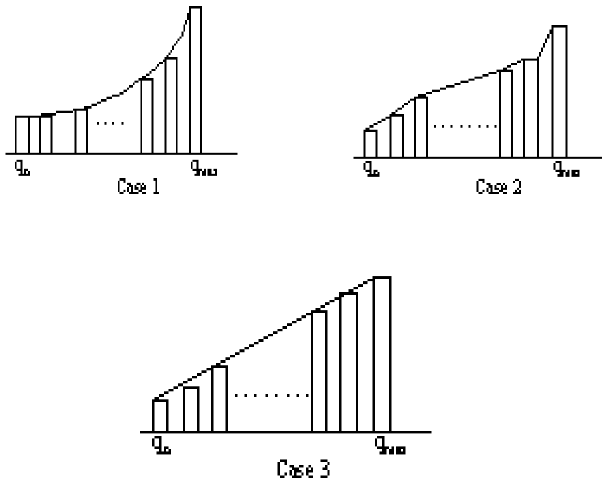

Fig. 1: Different ranging samples situations

In our knowledge the estimation of clutter in the third case may be the best because of the linearity of the samples. So, we can deduce that:

$$q_k = \frac{K}{N} q_{max} \tag{1}$$

Then the coefficient α would be equal to:

$$\propto = \frac{K}{N} \tag{2}$$

If we want to change the order of the chosen cell, it will be sufficient to change the value of α for N fixed. Hence the idea of the proposed technique referred to as Welghted Maximum CFAR (WMAX CFAR) is shown in Fig. 2

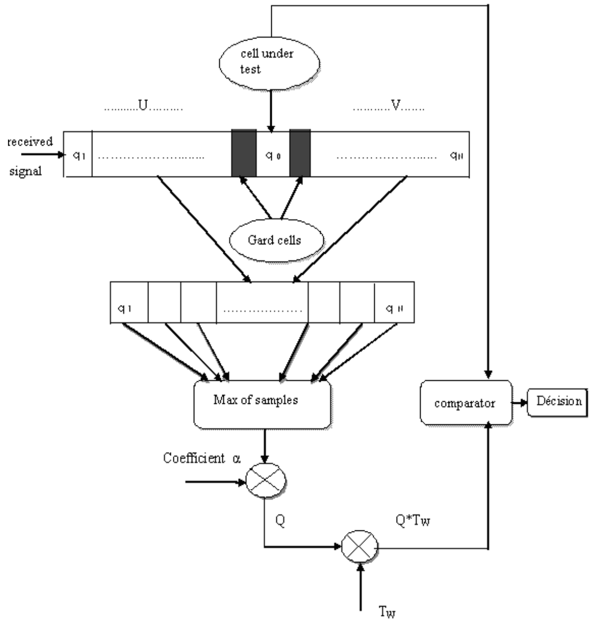

Fig. 2 : The proposed WMAX- CFAR processor

The procedure used, to determine the closed form of the probabilities of detection and false alarm, is the Neyman-Pearson criterion [2] which maximises the probability of detection P_d while limiting the probability of false alarm Pfa to a desired value.

A decision of hypothesis test is made in favour of H_1 or H_0 according to whether

$$X \underset{H_0}{\overset{H_1}{\gtrless}} TZ \tag{3}$$

Where X is the test cell, T is a threshold coefficient to achieve a desired Pfa for a given window size N, and Z is the estimate of background level. The hypothesis H_0 represents the case of noise alone while hypothesis H_1 represents the noise plus target signal case.

The general expressions of the detection probability and the false alarm probability are given, respectively, by

$$P_d = \int_0^{+\infty} P_k(Z) \int_{T_Z}^{+\infty} P_1(x) dx dz \tag{4}$$

$$P_{fa} = \int_0^{+\infty} P_k(Z) \int_{T_Z}^{+\infty} P_0(x) dx dz \tag{5}$$

Where $p_k(z)$ is the pdf of the random variable Z and $p_j(x)$ (j=0,1) is the probability density function (pdf) of the test cell X for the presence $(j=1)$ and absence $(j=0)$ of a target, respectively.

The signal from a target is linked to its reflective power. The value of the Radar Cross Section (RCS) of a target is very difficult to know a priori because of its extreme sensitivity to various parameters like shape, angle of illumination, transmitted frequency, polarization of the transmitted wave, or movement of the target.

The RCS should be considered as a random process defined by its probability density and autocorrelation function.

For aircraft targets, object of our work, the model used is called Swerling 1 type. In this model, it is assumed that the pulses received from the target have a constant amplitude throughout the duration of illumination and statistically independent of a passage from the antenna to another "scan-to-scan fluctuation." This assumption ignores the effect of the antenna on the amplitude of the echo, and the envelope of the reflection to the output of the quadratic detector signal follows an exponential law:

$$f(s) = \frac{1}{\sigma^2} exp\left(-\frac{s}{\sigma^2}\right),\ s \geq 0 \tag{6}$$

σ^2 represents the average received signal power.

The noise is random, following the laws of probability. For reasons of convenience in mathematical modeling, the radar operators have always considered that clutters follow a Gaussian law. Research work has shown that these non-Gaussian clutter follow laws such as the Weibull distribution, the log-normal distribution or distribution K.

In the following study, we assume that the detection is done in Gaussian environment. In this case, its probability density function is given by:

$$f(s) = \left(\frac{s}{\sigma^2}\right) exp\left(-\frac{s^2}{\sigma^2}\right) \tag{7}$$

The homogeneity of the clutter is characterized by the probability of the presence of a single target in the test cell. It is no homogeneous in the case of the presence of one or more interfering targets in the analysis windows, or in the case of clutter edge.

The returns are assumed identical and independent and the output of the law square detector follows the exponential distribution.

$$P_0(x) = \exp(-x) \qquad \text{for } H_0 \tag{8}$$

$$P_1(x) = \frac{1}{1+s} exp\left(-\frac{x}{1+s}\right) \qquad \text{for } H_1 \tag{9}$$

Where S is the target signal to noise ratio.

Substituting expression (9) into (4), the probability of detection becomes

$$P_d = \int_0^{+\infty} p_k(z) \int_{T_z}^{+\infty} \frac{1}{1+s} exp\left(-\frac{x}{1+s} dxdz\right) \tag{10}$$

Which yields

$$P_d = \int_0^{+\infty} p_k(z) exp\left(-\frac{TZ}{1+s}\right) dz \tag{11}$$

For convenience, let be

$$Y = \max(x_i) \quad for\ \ 1 \leq i \leq N \tag{12}$$

Where *N* denotes the number of reference window's cells.

After mathematic manipulations the probability of detection becomes:

$$P_d = N\Gamma\left(\frac{\propto T}{1+s} + 1\right) \frac{\Gamma(N)}{\Gamma\left(N+1+\frac{\propto T}{\Gamma(N+1+\propto T)}\right)} \tag{13}$$

Where Γ is gamma function and T is the threshold multiplier.

The probability of false alarm expression may be obtained by setting S=0 in the probability of detection expression. Hence, $P_{fa} = (P_d)_S$ =0.

B. Results and discussions—

In this section we present the performances of the designed CFAR processor compared to the OS-CFAR. Table 1 presents the threshold multiplier T versus the false alarm rate for different values of the coefficient α, for a number of samples N=16.

Table 1: Values of threshold multiplier versus α and Pfa

α	6/16	7/16	8/16	10/16	12/16	16/16
Pfa=10^{-6}	22	18.86	16.5	13.2	11	8.3
Pfa=10^{-4}	11.9	10.2	8.9	7.17	5.95	4.46
Pfa=10^{-3}	8	6.8	6	4.8	3.98	3

We observe that the threshold multiplier decreases when α or Pfa increases.

To make a comparison we have established the Table 2 for OS CFAR detector when the chosen rank k changes.

k	6	7	8	10	12	16
Pfa=10-6	>100	79.46	56.6	32.9	20.9	8.3
Pfa=10-4	48,68	34.92	26.4	16.6	11.08	4.5
Pfa=10-3	28,88	21.52	16.72	10.88	7.43	3.02

Table 2: Values of threshold multiplier versus K and Pfa

Fig. 3 shows the variations of the threshold multiplier in terms of coefficient α for the WMAX-CFAR processor compared with same variations in terms of rank k of chosen cell for the OS-CFAR. We observe that the threshold of OS-CFAR is higher than the threshold of WMAX CFAR for a probability of false alarm fixed to 10^{-6}.

Fig. 4 shows the variations of the probability of detection versus the SNR for different values of the probability of false alarm for N=16 and α=0.75 (K=12).

As shown in Fig. 5, an investigation of the effect of the weighting coefficient on the detection performance compared to the OS-CFAR was made. The result shows that for α=0.5 the new designed detector presents a very smaller CFAR loss than OS-CFAR in homogenous situation.

The study in presence of interfering targets has been made using Monte Carlo simulations [14].The obtained results are shown in Fig. 6 and Fig.7. In those figures each point has been obtained using i experiments where:

$$i=100/Pfa \qquad (14)$$

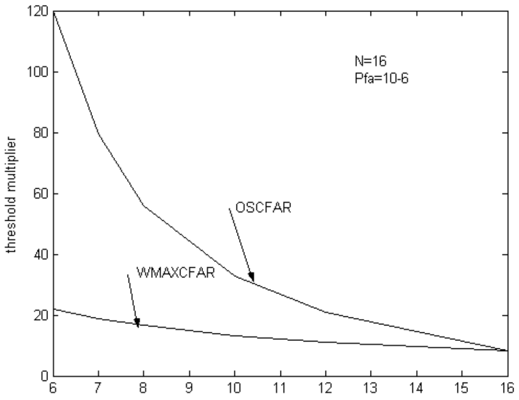

Fig. 3: Threshold multiplier versus α (for wmaxcfar) or k(for oscfar)

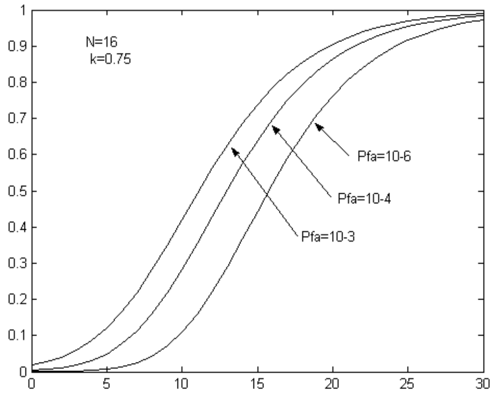

Fig. 4: Probability of detection versus SNR for different values of Pfa (N=16 and α=0.75)

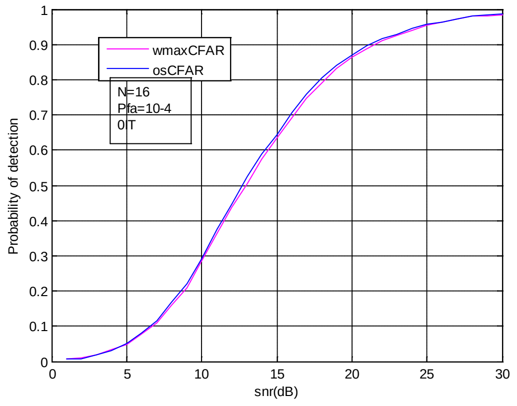

Fig. 5 : Comparaison between OS CFAR and WMAX CFAR in Homogenous environment.

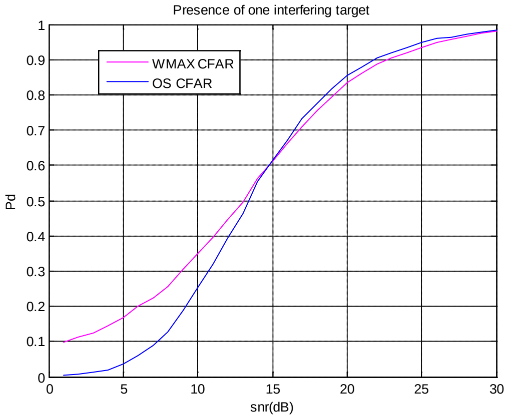

Fig. 6 : Probability of detection versus SNR In presence of one interfering target

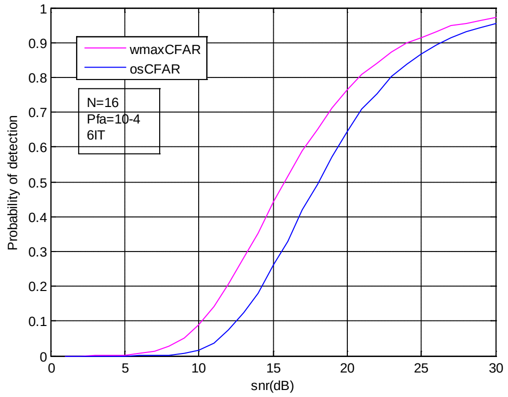

Fig.7 : Probability of detection versus SNR In presence of 6 interfering targets

Fig.7 shows that when the number of interfering targets is superior than (N-K), the OS CFAR detector presents important losses compared to WMAX CFAR.

In Fig. 8 we have presented the Operational Caracteristic of Reception (OCR) for the WMAX CFAR detector compared with the OS CFAR one, in homogeneous environment. We have fixed an SNR=15dB, α=0.5 and k= 0.75.

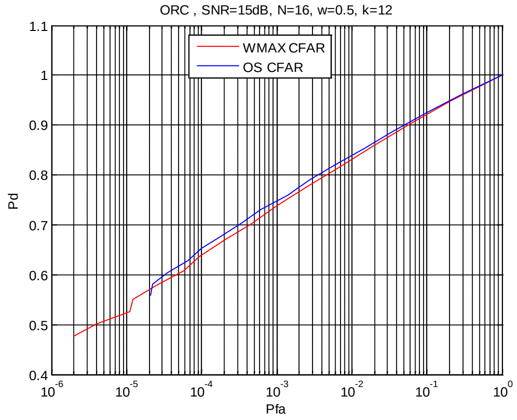

Fig.8: Operational Characteristics of Reception

We have evaluated CFAR losses caused by I interfering targets. The results are given in Table 3. This table has been established for a number of samples N=16, a probability of false alarm Pfa=10^{-6}, and a probability of detection Pd=0.5. The two right columns have been established for OS CFAR under the same conditions and for k=12.

Table 3: Additional CFAR losses in presence of I interfering targets.

I	SNR(dB) WMAX CFAR	Additional CFARLoss(dB) WMAX CFAR	SNR(dB) OS CFAR	Additional CFARLoss(dB) OS CFAR
0	15.73	0	15.65	0
1	16.56	0.83	16.26	0.61
2	16.54	0.81	16.96	1.31
3	16.52	0.79	17.9	2.25
4	16.50	0.77	19.1	3.45
6	16.45	0.72	20.26	4.61

We can deduce that if number of interfering targets increases the WMAX CFAR losses remain constant while the OS CFAR losses increase.

Those results lead us to exploit the idea by consider an algorithm with two half windows each one affected by a weighting coefficient.

This what we expose in the third section of this paper

III. PERFORMANCES ANALYSIS OF A GOWMAX-CFAR DETECTOR

Using Monte Carlo simulations, we present in this part the study of a GOWMAX-CFAR detector.

A. *The GOWMAX CFAR detector*

The bloc diagram of the GOWMAX CFAR detector is given in Fig. 9.

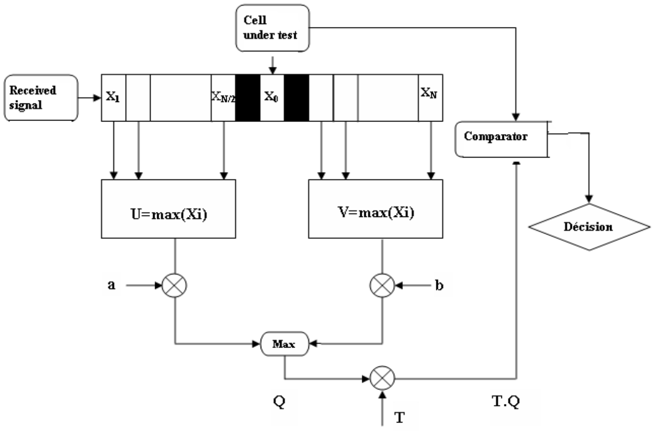

Fig. 9:Diagram block of GOWMAX CFAR detector

In this scheme the estimate of the noise Q is given by:

$$Q = Max(a * U, b * V) \tag{14}$$

The correspondent pdf is given by:

$$p_Q(q) = p_U(q) * P_V(q) + p_V(q) * P_U(q) \tag{15}$$

We can show that the choice of the maximum out of N/2 samples leads to a probability density function given by:

$$p_U(u) = \frac{N}{2}[P_x(u)]^{\left(\left(\frac{N}{2}\right)-1\right)} p_x(u) \tag{16}$$

$$p_V(v) = \frac{N}{2}[P_y((v)]^{\left(\left(\frac{N}{2}\right)-1\right)} p_y(v) \tag{17}$$

The probability of detection is given by equation (8).

The analysis in presence of interfering targets or clutter edge has been made using Monte Carlo simulations. Results will be discussed in the next section.

B. *Results and discussion*

An optimizing study has given the best values of coefficients a and b to be equal to 0.5 when the clutter is homogeneous.

We have shown that detection is efficient only if the condition limit

$$SNR/_{INR} \geq a * T \quad or \; b * T \tag{18}$$

were INR is the level of energy of the interfering target, is realized, and that it depends of position of this secondary target :

This condition has been deducted from Fig.10, for SNR=20dB, and when the secondary target is in the leading window.

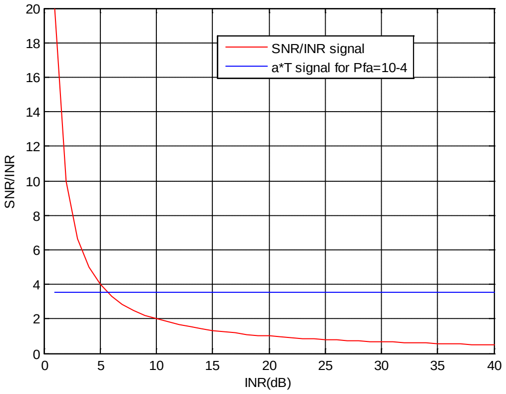

Figure 10 : Limit of detection

We can deduce that in this case, the primary target is detected if the level of secondary one do not exceed 6dB.

When the interfering target is in the lagging half window, fig.11 depicted for SNR= 20dB shows that detection is efficient for all values of INR

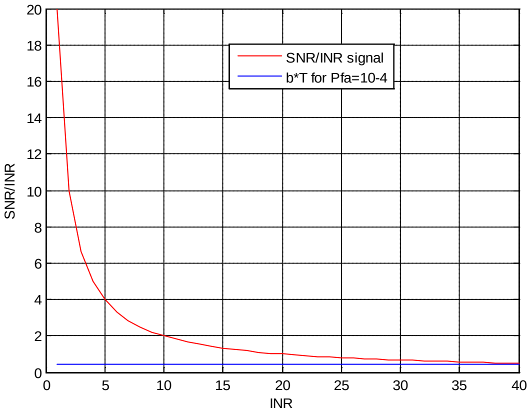

Figure 11 : Limit of detection

Fig. 12 shows that in presence of interfering targets the best performances are obtained for b as smaller as possible. We have chosen to continue the study with a=0.5 and b=0.01.

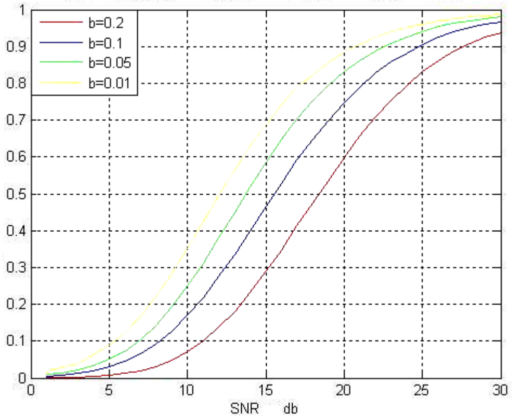

Fig. 12 : Probability of detection versus SNR in presence of one interfering target for a=0.5 and different values of b .

In those conditions, Fig. 13 and Fig.14 show that in presence of interfering targets, the new detector operates better. Those figures have been established with a comparison between the two detectors, GOWMAX-CFAR and OS-CFAR. The probability of false alarm is set to 10^{-4} for a number of samples equal to 16.

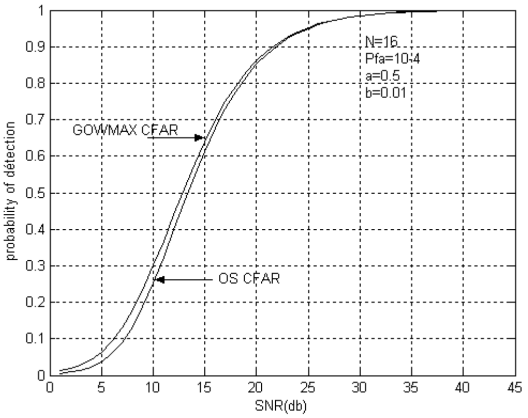

Fig. 13 : Probability of detection versus SNR, in presence of one interfering target.

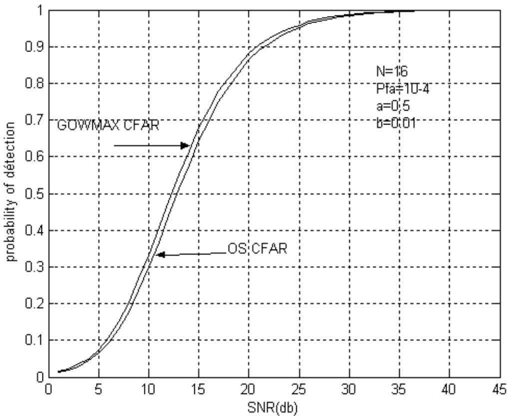

Fig. 14 : Probability of detection versus SNR In presence of 5 interfering targets.

In Fig. 15 we have depicted the operational characteristic of reception of the GOWMAX CFAR detector compared to OS CFAR and WMAX CFAR, for SNR=15dB, in homogeneous environment.

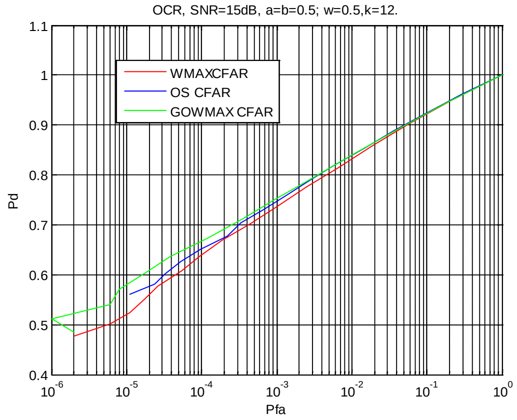

Figure 15: Operational characteristics of reception.

Finally, we have evaluated the CFAR losses for the new detector. This is shown in Table 4, were I is the number of interfering targets.

Table 4: CFAR losses of GOWMAX CFAR in presence of I interfering targets.

I	SNR(dB)	Additional CFAR Loss(dB)
0	14.5	0
1	16.65	2.15
2	16.64	2.14
3	16.64	2.14
4	16.62	2.12
6	16.62	2.12

IV. CONCLUSION

In this paper, we have proposed a new detector referred to as GOWMAX-CFAR to operate in non-homogeneous radar environment. Its algorithm is derivated from WMAX CFAR himself inspired from OS CFAR detector.

The obtained results show that efficiency depends on position and level of targets. And if conditions are respected the proposed detector performs better than the OS-CFAR.

It should be mentioned that the proposed detector presents a low computational burden comparatively to the ordinary OS-CFAR detector, that what we have showed in [13].

REFERENCES

[1] H.M. Finn and R.S. Johnson, “Adaptive detection mode with threshold control as a function of spatial sampled clutter level estimates”, RCA Rev. Vol. 29, September 1968 pp. 414-464.

[2] M.Barkat, P.K.varshney,”On adaptative Cell Averaging CFAR Radar Signal Detection”,RADC-TR-160, October 1987.

[3] H. Rohling, “Radar CFAR thresholding in clutter and multiple target situations”, IEEE trans; Aerospace Electron. Systems, Vol. AAES-19, July 1983, pp. 608-621.

[4] S.Blake, “OS-CFAR Theory for Multiple Targets and Non uniform Clutter “, IEEE trans. on AES vol. 24, no. 6, November 1988, pp.785-790.

[5] B.Magaz,A.Belouchrani,M.Hamadouche,”A new adaptative linear combined CFAR detector in presence of interfering targets”, Progress In Electromagnetics Research B, Vol. 34, 367-387, 2011.

[6] B.Magaz,A.Belouchrani,M.Hamadouche,”Automatic Threshold Selection in OS CFAR Radar Detection using information Theoretic Criteria”, Progress In Electromagnetics Research B, Vol. 30, 157-175, 2011.

[7] ML.Bencheikh,B.Magaz,M.Hamadoucheand A.Belouchrani, ”Performance analysis of a new CFAR detector”, *proc.International Radar Symposium*,pp.361-365,Cologne,Germany,Septembre 2007.

[8] C.M. Cho and M. Barkat, « Moving ordered statistics CFAR detection For Nonhomogeneous backgrouds », IEE Proceedings, Pt F, Vol 140, N°5, pp 284-290, Octobre 1993

[9] C.T. Kim, D.J. Han and H.S. Lee, « Generalized OS-CFAR detector with non coherente integration », Signal Processing, Vol. 34, pp. 43-56, 1993.

[10] M.B.El Mashade, “Performance Analysis of OS Structure of CFAR Detectors in Fluctuating Target Environments” Progress In Electromagnetics Research C, Vol. 2, 127-158, 2008.

[11] H. Mansouri, M. Hamadouche, F. Youcef Ettoumi, and B. Magaz,“Performance analysis of a Weighted Max CFAR processor,”proc. International Radar Symposium, Wroclaw, Poland, May 2008,pp.321-324.

[12] N.Levanon, “Radar Principles”, A Wiley Interscience Publication, ISBN 0-471-85881-1, 1988.

[13] H. Mansouri, M. Hamadouche, F. Youcef Ettoumi, “Performance analysis in heterogenous environment and implementation on DSP processor of a GOWMAX CFAR detector,”proc. International Radar Symposium, Vilnius, Lituania, June 2010,pp.431-433.

[14] G.V.Weinberg”Estimation of False Alarm Probabilities in Cell Averaging Constant False Alarm Rate Detectors via Monte Carlo Methods”, DSTO-TR-1624.Pdf, November 2004.

MANSOURI Houria received his Engineer degree in Electronics and Magister degree in instrumentation and control from national polytechnic school algiers University in 1980 and 1983 respectively. Since 1990, she works at University of .Sciences and Technologies.Houari .Boumediene (USTHB) as Assistant Lecturer in Electronics at the Faculty of Electronics and Computer Science. She is also a Researcher at the Image Processing and Radiation Laboratory and now preparing her Ph.D. thesis about radar signal processing for targets. Her actual research activities are concentrated around the fields of wave propagation, radar applications, radar statistical modelisation,performance analysis, digital signal processing, and implementation techniques.

HAMADOUCHE M’hamed was born in Yellel, Algeria on 1954. He received his PHD degree in electrical engineering in 2001, from university of constantine.He was with Air defense research and high school of air defense from 1981 to 2007. He is currently associate professor at university of boumerdes and Adjunct associate professor at high school of air defense, of signal processing. His main research interests are: CFAR radar detection-detection and estimation- coding and cryptology He is the author and co-author of several scientific publications in journals and in proceedings of international and national conferences

YOUCEF ETTOUMI Fatiha is a professor of universities graduate. Actually she is teaching at University of Sciences and Technologies Houari Boumediène and Director of research at Image Processing and radar laboratory. She received his PHD degree in electrical engineering in 2002 from Paul Sabatier University.His main research interests are : CFAR radar detection- detection and estimation- Renewable Energy She is the author and co-author of several scientific publications in journals and in proceedings of international and national conferences She received the “Price of Innovative Techniques for design and implementation of an informatic program of Estimated 3D Potential Wind Turbine” awarded at Pollutec lounge, Paris, France, 2010.