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Optimum Detection of Multiple Targets by Improved Switching CFAR Processor

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***Abstract*-In radar signal processing, distinction of false targets from real targets and fixing their rate in different radar environments is desirable. In this paper, performance of Improved Switching Constant False Alarm Rate (ISCFAR) in homogenous and non-homogenous environments consisting clutter and multiple targets in comparison of conventional CFAR processors is derived. The results of detection and false alarm relations of ISCFAR in all radar environments, homogenous and non-homogenous, shows the higher probability of detection with less detection loss in comparison with conventional CFAR processors. Also, simulation results confirm the achievement to an optimum detection threshold in homogenous and non-homogenous radar environment by the mentioned processor. The equations have been achieved by assuming the targets in the Swerling I and closed form.**

Keywords: Clutter, multiple targets, Switching CFAR

I. INTRODUCTION

In a radar receiver, after amplitude detection, backscattered signal will be sampled in Range and/or Doppler and a one or two dimensional reference window is formed. The detection in radar means existence or non-existence a target in the middle cell of a reference window or a cell under test (CUT). Estimated noise is achieved based on samples surrounded CUT and different CFAR algorithms. For this purpose, different processors have been introduced. A well-known group for noise estimation is mean-level detector, which cell averaging CFAR (CA), greatest of CFAR (GO) and smallest of CFAR (SO) are from this group [1]. Unfortunately because of differences in environmental conditions like change in clutter edge, multiple targets or jamming, the target detection will be corrupted.In a homogenous environment, CA has a higher detection probability than the two other kinds but by change in the radar environment, false alarm probability will increase strongly. In an environment with radar clutter, GO processor has higher detection probability and in the case of existence the multiple targets, SO has higher detection probability [2].

Another groups of CFAR processors has been introduced that based on the ordering of the reference windows samples. Ordered Statistics CFAR (OS), Trimmed-Mean CFAR (TM), Censored Mean Level Detector CFAR (CMLD) and Ordered Data Variability (ODV) are from this group [3, 4]. In general, the processors which use ordering, have better performance than mean-levels. Each one of the introduced processors in different radar environments has different performances. In this paper, mention to the switching processor in [5, 6], it is focused on its improved type or Improved Switching CFAR (IS). IS is practical especially in non-homogenous environment and in this paper its performance will be 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 IS is optimum. Then after describing the mentioned algorithm of IS 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 IS processor in the homogenous and non-homogenous environment will be analysed and at the last section, the results will come.

II. DESCRIPTION OF ISCFAR 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 background Gaussian noise and target change as Swerling I, the output samples will be iid with exponential pdf as (1):

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

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

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

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

For a better definition of ISCAR, the SCFAR algorithm will be described at first. The switching operation is carried out in two phases: 2N existing cells in the reference window are compared with the scaled CUT by α ($\alpha<1$). If a cell is less than αX_0 it will be saved in group S_0 otherwise will be saved in S_1 as in (3):

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

If the number of samples saved in group S_0 is assumed to be n_0, then the target will exist in the case of satisfying each one of these two conditions:

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If $X_0 > \frac{\beta_0}{n_0} \sum_{X_i \in S_0} X_i$ when $n_0 > N_T$ (4)

or

If $X_0 > \frac{\beta_1}{2N} \sum_{X_i \in 2N} X_i$ when $n_0 \le N_T$ (5)

where β_0 and β_1 are constant to achieve the desired false alarm probability and N_T is the threshold integer. Inequalities (4) and (5) mean that the SCFAR switches between S_0 and whole of the window's samples depending on the value of n_0. In this paper, suggestion of choosing S_1 at the case of $n_0 \le N_T$ has been proposed. Then in (5), 2N should change by $2N\text{-}n_0$. Such a selection can further improve of the SCFAR processor especially at clutter edges. This type of processing means selecting optimum threshold of detection in homogenous and non-homogenous environment.

III. Mathematical Analysis of ISCFAR

Considering the described algorithm in section 2, it is assumed that in a reference window with size equal to 2N, there is M interference and 2N-M thermal noise samples. The detection probabilities in ISCFAR and according to the existence of n_0 samples in S_0 and $2N\text{-}n_0$ samples in S_1, referred to the (4) and (5) in ISCFAR will be as follows. First, the probability of existence of a sample with thermal noise in S_0 group is calculated according to (3):

$$P_0 = P(X_i < \alpha X_0) = \frac{\alpha\lambda_s/\lambda}{1+\alpha\lambda_s/\lambda} \tag{6}$$

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 S0 group according to (3) is:

$$P_0' = P(X_i < \alpha X_0) = \frac{\alpha\lambda_s/\lambda_I}{1+\alpha\lambda_s/\lambda_I} \tag{7}$$

The probability of saving maximum N_T samples of 2N 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:

$$P_d = P(n_0 \le N_T) \times P(X_0 > \frac{\beta_1}{2N-n_0}\sum_{i=1}^{2N-n_0} X_i) + P(n_0 > N_T) \times P(X_0 > \frac{\beta_0}{n_0}\sum_{i=1}^{n_0} X_i) \tag{9}$$

Calculating the probabilities of (9):

$$P_d(N_T,\alpha,\beta_0,\beta_1) = \sum_{n_0=0}^{N_T}\sum_{m=m_1}^{\min(M,n_0)} \binom{2N-M}{n_0-m}\binom{M}{m} P_0^{n_0-m}(1-P_0)^{2N-M-(n_0-m)} P_0'^{m}(1-p_0')^{M-m} \times \left(1+\frac{\beta_1}{2N-n_0}\frac{1+\sigma_I}{1+\sigma_s}\right)^{m-M}\left(1+\frac{\beta_1}{2N-n_0}\frac{1}{1+\sigma_s}\right)^{(M-m)-(2N-n_0)} +$$

$$\sum_{n_0=N_T+1}^{2N}\sum_{m=m_1}^{\min(M,n_0)} \binom{2N-M}{n_0-m}\binom{M}{m} P_0^{n_0-m}(1-P_0)^{2N-M-(n_0-m)} P_0'^{m}(1-p_0')^{M-m} \times \left(1+\frac{\beta_0}{n_0}\frac{1+\sigma_I}{1+\sigma_s}\right)^{-m}\left(1+\frac{\beta_0}{n_0}\frac{1}{1+\sigma_s}\right)^{m-n_0} \tag{10}$$

In above equations m_1 is equal to max (0, n_0-2N+M).

IV. Studying ISCFAR Under Non-Homogenous Conditions

The performance of the improved switching CFAR processor algorithm, according to (10), is a function of β_0, β_1, N_T and α. 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=N=12 and also by changing the values of α, the Fig. 1 will be achieved.

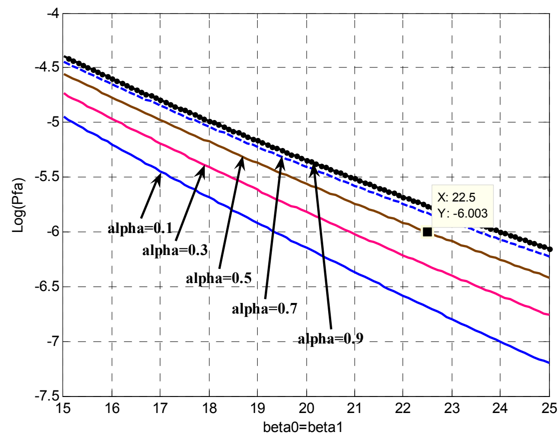

Figure 1. False alarm probability of the ISCFAR processor for $\beta_0=\beta_1$ and different α (2N=24 and N_T=N)

As a result of this figure, for achieving $P_{fa}=10^{-6}$ these parameters should be considered: $\beta_0=\beta_1=22.5$, $\alpha=0.5$ and N_T=N=12. In Fig. 2 probability of CA, GO, SO and IS processors in homogenous environment and for above parameters are drawn. With the definition of detection loss in [2], it is seen that: $Loss_{CA}<Loss_{GO}<Loss_{IS}<Loss_{SO}$.

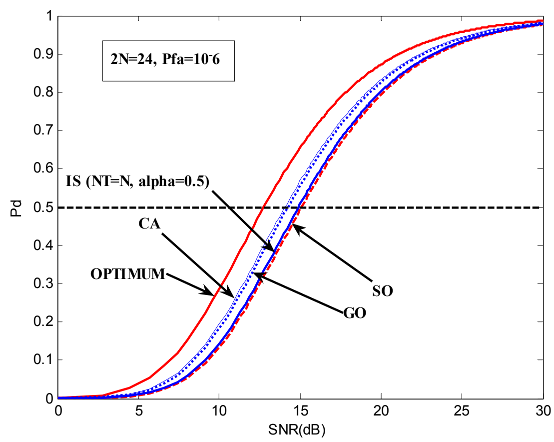

Figure 2. Detection probability of CA, GO, SO and IS processors in homogenous environment (2N=24, N_T=0.5, α=0.5 and $P_{fa}=10^{-6}$).

In fact, the IS processor has inherent detection loss in the homogenous environment which increases by α or N_T. For probability of detection equal to 0.5, the detection losses for CA, GO, IS and SO will be: 1.29, 1.48, 2.13 and 2.33dB.

Fig. 3 is the graph of mentioned processors in the presence of clutter edge with clutter to noise ratio (CNR) equal to 15dB and for reference window with the size 2N=24. From [1], it is known that in an environment with non-homogenous noise and presence of clutter edge, GO processor has least probability of false alarm. It is clear from Fig. 3 that with increasing N_T from 12 to 20 and α=0.5, IS can achieve even less false alarm probability than GO which has best performance among all the CFAR processors in the presence of clutter. Of course by Fig. 2, it is clear that increasing of threshold, N_T causes increasing detection loss.

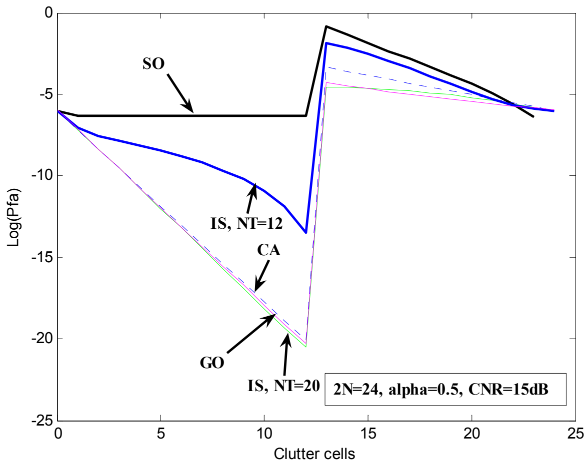

Figure 3. Comparison of P_{fa} for CA, GO, SO and IS processor (α=0.5 & different N_T) in clutter edge (CNR=15dB).

Now, based on Fig. 4, α is changed in ISCFAR and its effect in the case of clutter edge with CNR=15dB is observable. By decreasing α from 0.2 to 0.7 and keeping N_T constant, it is seen that P_{fa} in ISCFAR increases and dose not show good performance. At all for having good performance in reference window with the size 2N=24, the parameters of IS processor should set like this: α=0.5 and N_T=20.

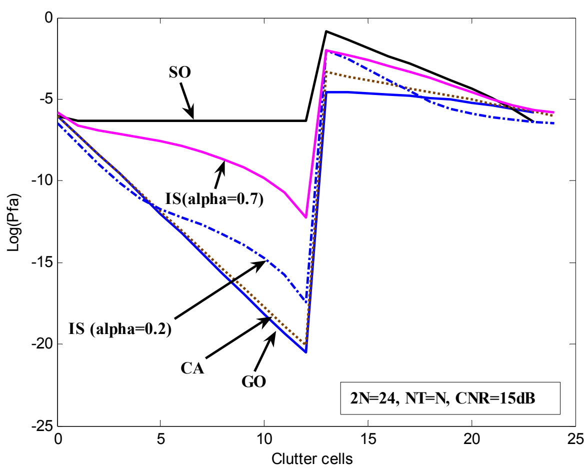

Figure 4. Comparison of P_{fa} for CA, GO, SO and IS processor (2N=24, N_T=N and different α) in clutter edge (CNR=15dB).

The case of presence of multiple targets is another condition in the studying of IS processor. In Fig. 5 one and three interfering targets with interfering to noise ration (INR) equal to SNR and the size of reference window 2N=24 for CA, GO, SO and IS processors are considered. SO processor in the case of 3 interfering targets has the best performance of detection. After that, as it is expected, IS processor has higher probability of detection and with the increasing of scaled factor α it is possible to improve probability of detection. In the mentioned figure and for better comparison, some graphs for different α and N_T=N for CA, GO and IS are drawn. Also it should be noted in Fig.5, IS processor even for 3 multiple targets with increasing SNR more than 23dB has higher probability of detection than CA with one interfering target.

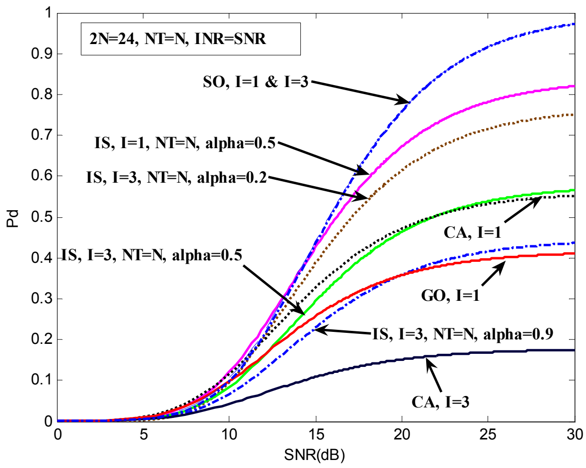

Figure 5. Comparison of P_d of ISCFAR with different α by CA, GO and SO in the case of interfering targets (2N=24 and INR=SNR).

At last, plotting of probability of detection in the case of multiple targets for reference window with size 2N=24, SNR=INR and $P_{fa}=10^{-6}$ is derived in Fig. 6. In this figure, P_d of IS for different N_T and a fixed α is analysed. It can be seen that SO even in the case of 3 interfering targets has maximum probability of detection and after that and for SNR more than 23dB, IS processor with N_T=12 and α=0.5 and with 3 interfering targets, has higher probability of detection. As Fig. 6 shows with increasing N_T, probability of detection in IS processor decreases and detection loss increases ($P_{fa}=10^{-6}$). It is clear in the case of present multiple targets, GO processor still has worse probability of detection that with increasing the number of interfere ring targets to 3, it will be more worse.

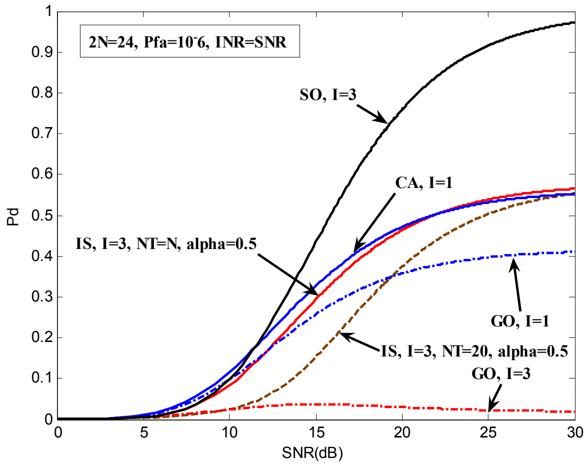

Figure 6. Comparison of P_d of IS with different N_T by CA, GO and SO in the case of multiple targets (2N=24, $P_{fa}=10^{-6}$ and INR=SNR).

The detection threshold simulation can be carried out using Matlab software in two cases: clutter and multiple targets. In Fig. 7 (a) and (b), there are nein targets in ranges 4, 9, 14, 20, 25, 30, 35, 36 and 46 with mentioned SNRs in figure. Considering the reference window's size equal to 2N=24 and $P_{fa}=10^{-6}$, the CA processor can only detect the first target which is located in range of 4 while GO can not detect any target and SO can detect the first and last targets in ranges of 4 and 46, as it was expected. Referring to Fig. 7 (b) OS processor with order k=21 can only detect first, second and last targets in ranges 4, 9 and 46 while S and IS processors with N_T=N=12 and α=0.5, can detect the whole targets.

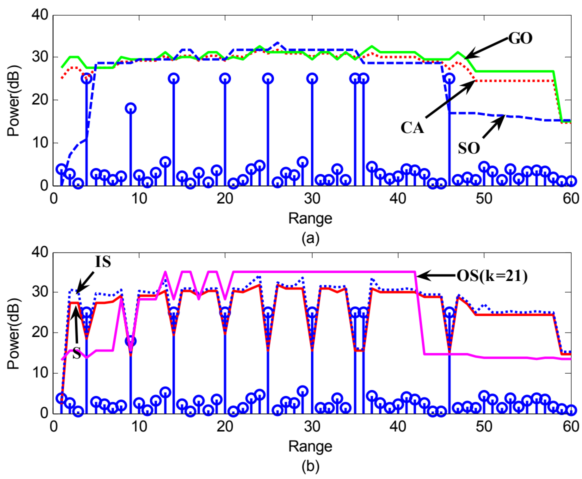

Figure 7. Detection thresholds of different CFAR processors in multiple targets environment (2N=24, N_T=N, α=0.5, $P_{fa}=10^{-6}$).

Now, if clutter edge is added to environmental condition, then result can be considered in Fig. 8. The multiple targets with mentioned SNRs are located in 4, 9, 14, 25, 30, 31, 37 and 46. Also, there is clutter from ranges 47 until 60 with CNR=15dB. It is clear that CA and SO processors can detect only the first target and GO detects any target (Fig. 8 (a)), while OS processor with order k=21 detects targets in ranges 4, 14, 30, 31 and 46 (Fig. 8 (b)). Also Fig. 8 (b) shows that S and IS processors with N_T=N=12 and α=0.5, detect whole targets that it is from their desirable performance in the non-homogenous environment.

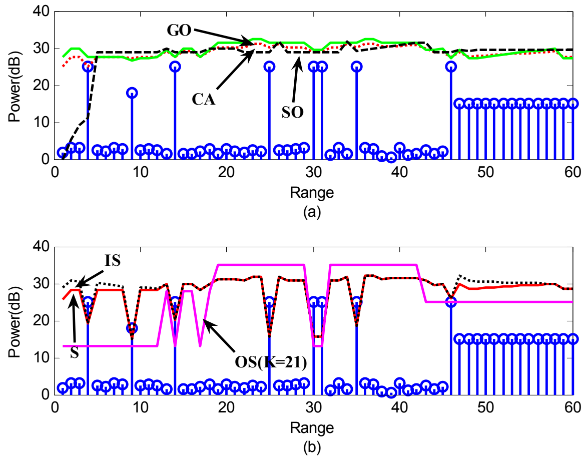

Figure 8. Detection thresholds of different CFAR processors in the presence of clutter (2N=24, N_T=N, α=0.5 and $P_{fa}=10^{-6}$).

Now in Fig. 9, samples are located in ranges from 0 to 90. In the assumed reference window showed in figure with size 2N=24 and $P_{fa}=10^{-6}$, it is seen that because the target's number is less than half of window (N=12), IS processor with N_T=N=12 and α=0.5 can detect all of them. Also because of entering the last and next samples in that reference window during threshold calculation, some of targets remind undetected. This point can also be considered in the start and the end of range samples. As before, it is seen that if the number of targets in reference window be less than half of its size, IS will have the best optimized detection.

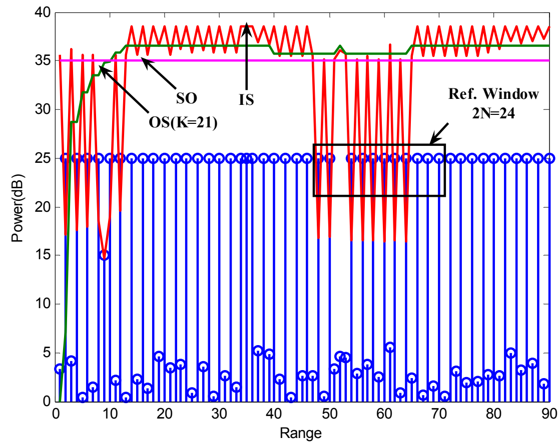

Figure 9. Detection thresholds of SO, OS (k=21) and IS (N_T=N, α=0.5, $P_{fa}=10^{-6}$) in worse case.

V. Conclusions

Considering the results of section 4 and comparison with other processors, the ISCFAR processor performance in different radar environments is acceptable. Also this results show that ISCFAR 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 ISCFAR 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 ISCFAR is simpler comparing with samples ordering processors.

Remark 1. *With attention to the performance of this processor, it can be suggested that selecting threshold* N_T *is acceptable by adaptive methods and testing environment conditions. Then it could be expected that IS Processor will have better performance.*

Remark 2. *In section 4 which studying and calculating of false alarm and detection probabilities are performed,* β_0 *was considered equal to* β_1*; but as another case, these two parameters can be considered not equal and its false alarm and detection probabilities can be calculate and selecting the best of them for achieving less detection loss can be done.*

REFERENCES

[1] P. P. Gandhi and S. A. Kassam, "Analysis of CFAR Processors in non homogenous background" *IEEE Transactions on Aerospace and Electronic systems, 427-445, July 1988.*

[2] H. Rohling, "Radar CFAR Thresholding in Clutter and multiple Target situations", *IEEE Transaction on Aerospace and Electronic Systems, Vol. AES-19, NO. 4, July 1983.*

[3] M. E. Smith and P. K. Vareshney, "Intelligent CFAR Processor Based on Data Variability", *IEEE Transaction on Aerospace and Electronic Systems, Vol. 36, No. 3, July 2000.*

[4] J. Zaho,R. Tao and Y. Wang, "A New CFAR Detector Based on Order Data Variability", Proceedings of the 1st International Conference on Innovative Computing, Information and Control, 2006.

[5] T. V. Cao, "A CFAR Thresholding Approach Based on the Target Cell Statistics", *IEEE 2004 Radar Conference proceedings, pages 349-354, April 2004, Philadelphia.*

[6] T. V. Cao, "A CFAR Algorithm for Radar Detection under Severe Interference", *Intelligent Sensors, Sensor Networks and Information Processing Conference, 2004. Proceedings of the 2004. Volume, Issue, 14-17 Dec. 2004 Page(s): 167-172*

[7] M. Barkat, *Signal Detection and Estimation*, Artech Hause, 2005.