EXTENDED ANALYSIS OF CLUTTER MAP-CFAR

Salih M. Salih *, Nikolaos K.Uzunoglu*, Laith A. Al-Mayahi Ahmed A.L. Abbass***,**

*School of Electrical and Computer Engineering, National Technical University of Athens, Division of Information Transmission Systems and Materials Technology, Microwave and Fiber Optics Laboratory, Athens/Greece

*E-mail: dr_salih_moh@yahoo.com

** Electrical and Electronic Department, University of Technology, Baghdad, Iraq

E-mail: laithawda@yahoo.com

*** Electrical Department, University of Anbar/ Iraq

E-mail: shemary2007@yahoo.com

Abstract

The performance of the Clutter Map-Constant False Alarm Rate is evaluated to determine the signal-to-clutter ratio required achieving a particular probability of detection in clutter environments whose amplitude statistics are modelled by the Rayleigh distribution Since, the Clutter Map-CFAR has a settling time of several seconds; the responses of the Clutter Map-CFAR will reduce when a target of low speed remains within the same map cell for more than one scan. This method is not affected by nonhomogeneous environments that affects on the performance of simple CA-CFAR. The Number of scans that required achieving detection probabilities is calculated.

1. INTRODUCTION

Automatic detection radar requires some techniques of adaptation against variations in the background clutter in order to control their false alarm. In generally there are two main methods that are widely used in the receiver; those are spatial and temporal methods. The first method, by using returns from adjacent cells of interest sets the threshold level. The second method is based on gathering the returns from previous scans in the same cell of interest to sets the threshold level. The first method can be used if the

background is statistically homogeneous. When the background is not homogeneous then, the use of Clutter Map-CFAR (Clutter Map-Constant False Alarm Rate) is preferable. A clutter map divides the radar coverage area into range-azimuth cells on a polar or rectangular grid. Detection of a target close to the surface is complicated by background environmental noise, 'land or sea clutter'. An obvious problem from point of view is the range of the environmental parameters that may have an effect, countered by the theoretical desire to form physical theories that led to optimum target detection schemes.

In (1870) Lord *Rayleigh,* who first studied scattering by small particles [1]. The original publication of ***Swerling*** models in (1955), a great deal of effort has been devoted to the statistical modeling of target signatures. In (1960) Swerling had calculated the detection probabilities for different fluctuation models of cross section [1]. Ramon Neitzberg (1986) had analyzed a Clutter Map-*CFAR* [2].

2. CLUTTER MAP-CFAR

The clutter echo stored in each cell of the map then can be used to establish a threshold for that range and azimuth. It is, therefore, a form of *CFAR*. The size of each *Clutter-Map* cell is equal to or greater than the radar resolution cell. At each of the range-azimuth cells of the clutter map, a number proportional to the amplitude of the clutter within the cell is stored in the map memory. Since clutter can change with time, the value of clutter in each cell is updated periodically by averaging over a large number of scans (for example, 5 to 10 scans). The larger number of scans the more accurate will be the estimate of the clutter, the lower the loss, and the less the effect of a target that moves through the cell. On the other hand, the averaging time (determined by the number of scans) should be shorter than the limited dwell time in which moving clutter (rain or chaff) is within the cell. Shorter averaging time also allows the threshold to recover to its proper state within a few scans after a target has passed through the cell.

A *Clutter Map CFAR* has an advantage over the *CA-CFAR* in that it is not affected by nonhomogeneous clutter (edge effect). The responses of the *Clutter Map CFAR* will be reduced when a target of slow speed remains within the cell longs enough to affect the

threshold. Making the map cell greater than the radar resolution cell can reduce this effect [3]. Increasing the size of the C*lutter Map* cell should not be carried too far, however, since it reduces the interclutter visibility. The loss of *signal-to-noise* ratio in the *Clutter Map* will depend on the averaging time. The longer time, the less the loss. The equations of the basic CA-CFAR should apply. The settling time increases as the memory weight (**F**) approaches to unity. The settling time gives an indication of the time needed to fill the clutter map. A fast settling time is required in particular against movable clutter and chaff so that the limited time in which the clutter occupies a certain cell of the map should be far greater than the settling time.

3. SELF AND MUTUAL MASKING

Target "*Self-Masking"* may occur in slowly moving targets, when the radar resolution cell is poor or when the size of the map cell is comparable in size with that of the radar cell [3]. The useful target remains in a certain cell; its power produces an increase of the detection threshold with a corresponding decrease of the P_d. A remedy for this undesired phenomenon relies on masking the map cell much greater than the radar cell. In this way, the percentage of target power in the map cell is lowered.

For "*Mutual Masking*", the target or interference sources occupy a map cell at a given scan angle. Given scan angle may cause an excessively high threshold at successive radar scans. As a consequence, the probability of detecting a target passing in that cell depends on the number of scans elapsed since the previous target or clutter leaves the cell. The remedy to the masking effect, especially in the case with a filter weight (*F*) approximately equal to unity, is the same as that applied in the self-masking situation. Figure 1 shows the meaning of radar cells and the map cells (clutter) [4],

4. CLUTTER MAP-CFAR ANALYSIS

The past M returns of each cell must be available in order to perform averaging in the same way as in *CA-CFAR* (called moving window averaging).

If $\hat{y}_{n-1(k)}$ is the last background estimate and Z_n is the present input (both normalized) from the k th cell, then the present background estimate will be given by [2, 5]

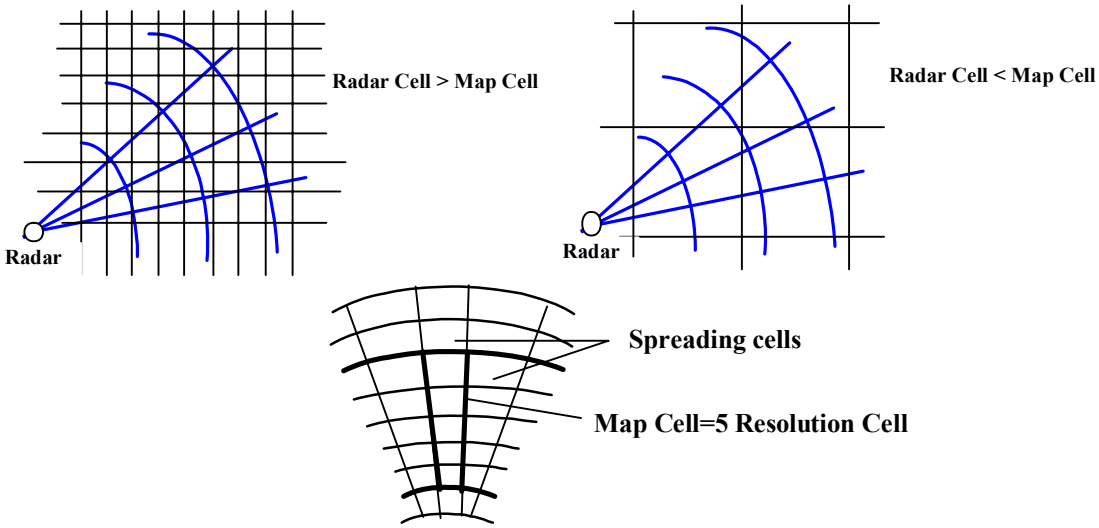


Fig. (1) Two Method of Mapping Ground Clutter to Radar Space for Ground-Based Radar

$$\hat{y}_n(k) = (1-F)\,\hat{y}_{n-1}(k) + F\,Z_n(k) \tag{1}$$

where **F** is a filter weight between zero and one. A block diagram of such an implementation is shown in fig. (2) [6, 7]. Note that the delay represented by $\mathbf{Z^{-1}}$ should be equal to the delay between scans and not between pulses. The number of successive radar scans **N** is given by [5, 7];

$$N = (2-F)/F \tag{2}$$

The threshold is set by

$$Z_{Tn} = \alpha\,\hat{y}_{n-1} \qquad , M \to \infty \tag{3}$$

The false-alarm probability is [2];

$$P_{fa} = \prod_{m=0}^{M} \left[1 - \alpha F (1-F)^m\right]^{-1} \quad , M \to \infty \tag{4}$$

The detection probability is given by a similar expression

$$P_d = \prod_{m=0}^{M} \left[1 + \alpha_d F (1-F)^m \right]^{-1} \quad , \; M \to \infty \tag{5}$$

where $$\alpha_d = \frac{\alpha}{1+\overline{SNR}} \tag{6}$$

The clutter map cell may not have dimensions smaller than the radar resolution cell and therefore the minimum map free velocity in the range dimension is given by

$$Vmf = \left(\frac{C\tau/2}{T_P} \right) \tag{7}$$

where T_P is the scan period (Second)

And $(C\tau/2)$ is the pulse length converted to range units.

Where N_r is the number of range resolution cells collapsed into one map cell. Finally, the range spreading cells N_{rs} are used to reduce the effect of slowly moving targets.

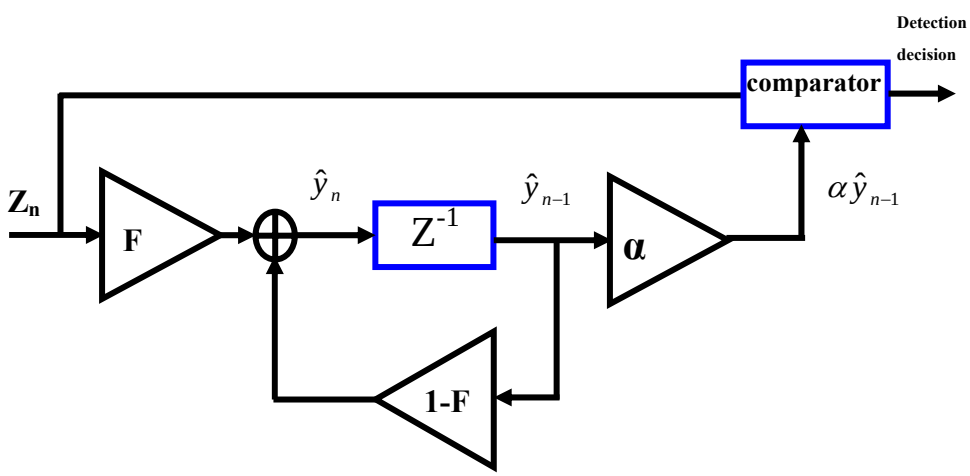


Figure 2. Clutter Map-CFAR diagram

5. RESULTS

5.1 THRESHOLD MULTIPLIER AMPLITUDE

The P_{fa} is now calculated as a function of filter weights (**F**), for $P_{fa}=10^{-4}$ and 10^{-6}. The required values of α can be determined by evaluating Eq. (4). Fig. (3) Shows the relation between α versus **F**. It's clear that the smaller values of α are small when the values of **F** are small, too. This means that the smaller values of **F** represent the using of longer data window processing.

5.2 THE DETECTION PERFORMANCE OF THE DETECTOR

The probability of detection is determined as a function of the primary target SNR value. By evaluating Eq. (5) with the Known values of α (calculated in 5.1) at $P_{fa}=10^{-4}$, also the Non-CFAR performance curve is plotted with clutter map results, as in fig. (4). The P_d increases as SNR increases for all values of **F**, but for **F**=0.1, the P_d are all higher for all values of SNR, and close to the optimum detector (Non-CFAR processor) with small degradation loss. The *Clutter Map-CFAR* loss can be determined as follows. For **F**=0, the case is equivalent to the *Non-CFAR* detection with a predetermined threshold based on a prior knowledge of the background interference. The CFAR loss increases as **F** increases. From figs. (4) and (5), it can be seen that for $0.2<P_d<0.8$. The *CFAR* loss increases by about 2.4 dB for each increment of 0.2 in **F**, while, at $P_{fa}=10^{-6}$, P_d between 0.2 and 0.8, the CFAR loss is increased by about 3 dB for each increment of 0.2 in **F**. From these curves, the loss decreases monotonically as **F** decreases. This occurs because decreasing **F** corresponds to using longer data windows to estimate the resolution cell power.

With reference to figures. 4 and 5, for *SNR*=15 dB, the probability of detection at $P_{fa}=10^{-4}$ decreases from 0.7 to 0.1 as **F** increases from 0.1 to 0.9, while, at $P_{fa}=10^{-6}$, P_d decreases from 0.56 to 0.03 as **F** increases from 0.1 to 0.8. This means that the

probability of detection decreases by about 0.14 as P_{fa} decreases from 10^{-4} to 10^{-6}. When *SNR* increases the probability of detection also increases for all values of **F**.

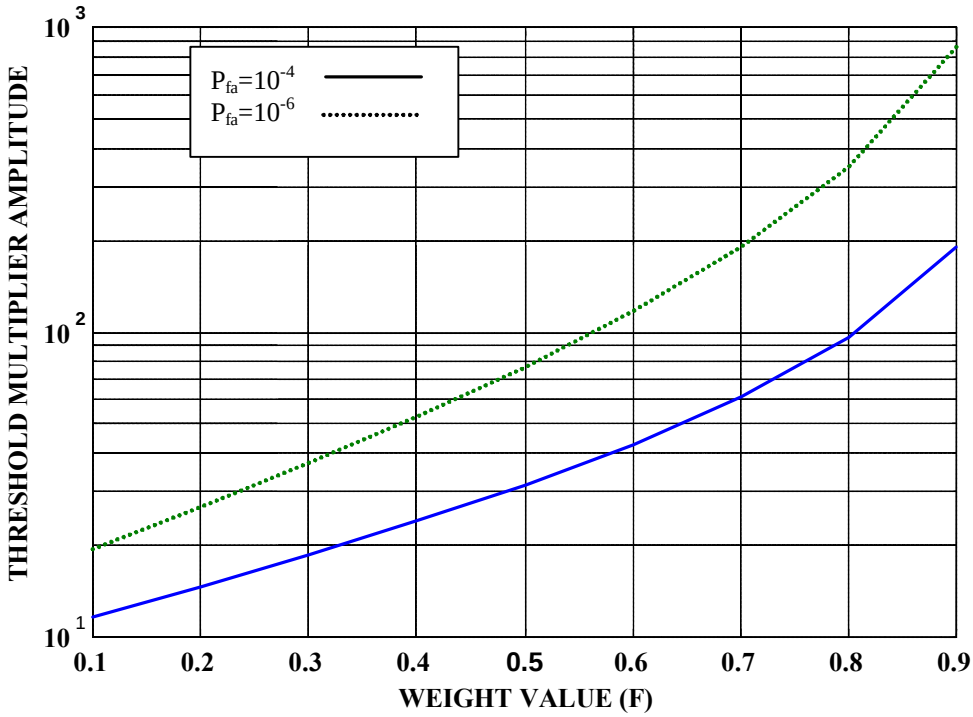


Fig. (3) Threshold Multiplier Amplitude (α) versus the filter weight (F)

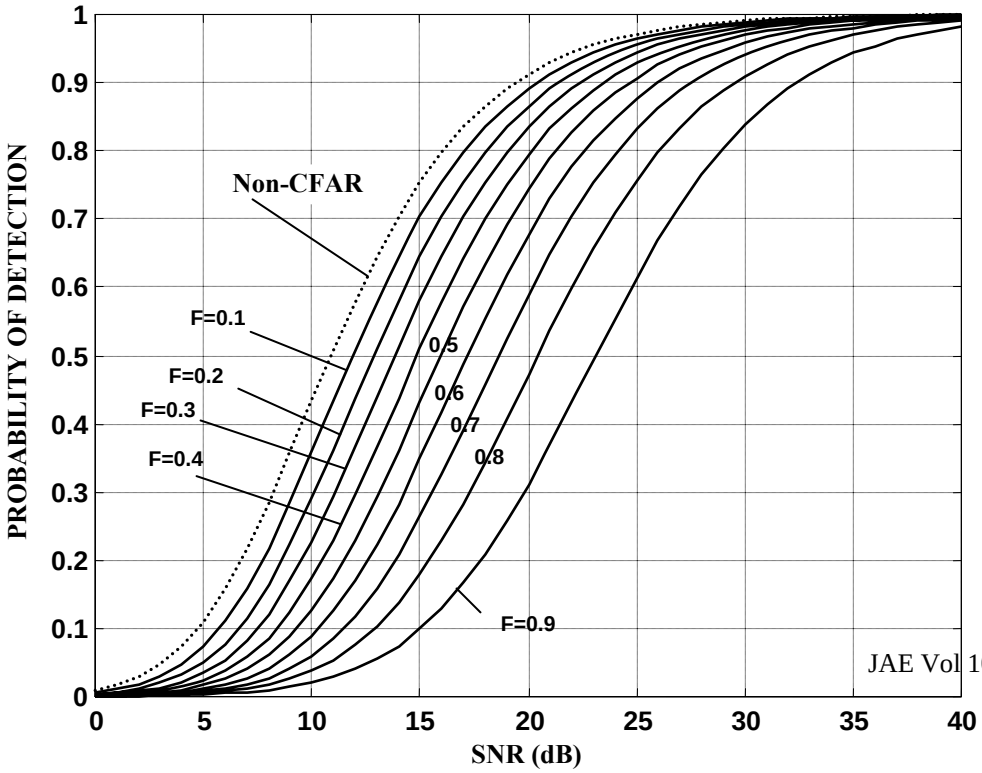


Figure 4: Detection curves for various **F** weights (F), $P_{fa}=10^{-4}$

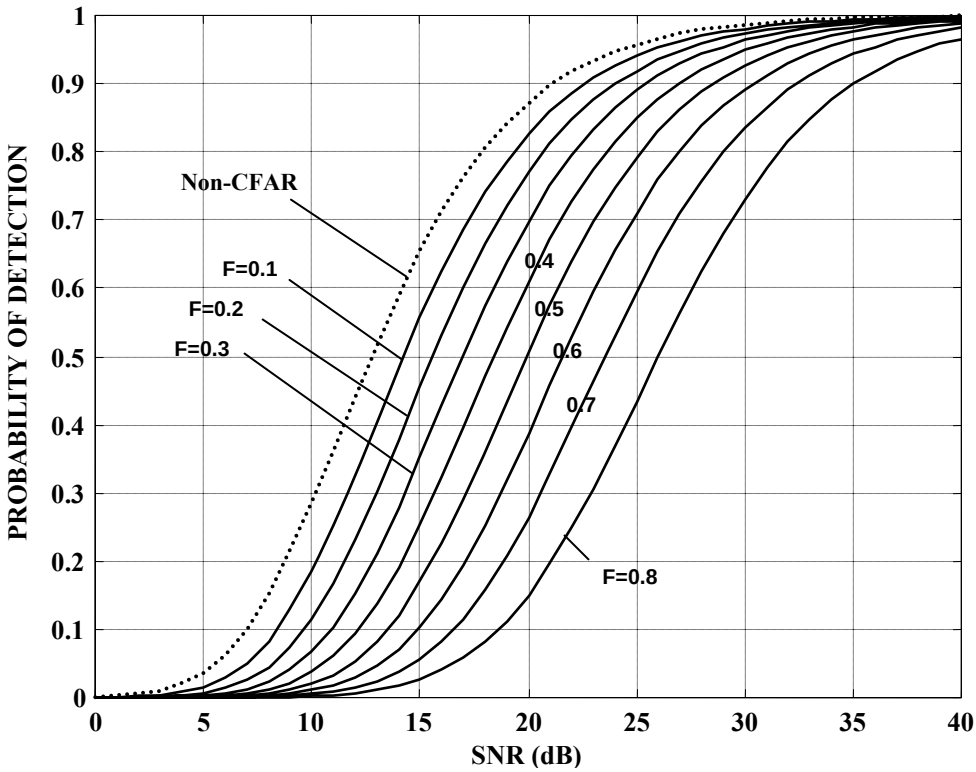


Figure 5. Detection performance $\mathbf{P_d}$ at different weights (**F**), $P_{fa}=10^{-6}$

5.3 CLUTTER MAP WITH M-RETURNS

When the useful target remains in the same cell, its power produces a decrease of P_d. Figure 6 indicates the decrease of P_{fa} as the number of radar scans increases with $P_{fa}=10^{-4}$ and $P_{fa}=10^{-6}$ respectively. As expected the P_{fa} decreases as *M* increases for all weights (F*)*, but faster convergence to the nominal value of $P_{fa}=10^{-4}$, $P_{fa}=10^{-6}$ at higher *F*.

From figure 6a, at $P_{fa}=10^{-4}$ the scan number *M* required to reach a specified $P_{fa}=10^{-4}$ is 4 scans at F=0.8 and 9 scans at F=0.2. Approximately small increasing in the scan number can be obtained at $P_{fa}=10^{-6}$ {figure. 6b}, this is due to the use of different threshold multiplier values for the two cases. The map is built up over a number of antenna scans (typically between 6 and 20), and is continuously updated. It is therefore

adapted to slow changes in weather or ground clutter. In general a value of 13 dB will be sufficient to detect the target [4], but this value depends on many factors such as the way of target fluctuates and the way the signal is processed in the receiver. To find the minimum number of *M* with corresponding weights F at SNR=13 dB, then, from fig. (7) The weighted value corresponding to P_d=0.5 is 0.2. At this value the number of scan *M* that yields $P_{fa}=10^{-4}$ is 9 scan as shown in fig. (6a).

Figure 8 illustrates the response of the *Clutter Map-CFAR* filter when the input clutter signal is constant at 15 dB with two values of filter weight (F). It can be seen that the faster steady state occurs at higher values of F. The amplitude voltage of $\hat{y}_n$ is minimum at small number of scans (M), at this case the output signal from the comparator {figure 2} is set at unity. When the scan number increases, the voltage amplitude $\hat{y}_n$ increases until it's equal to the input signal (Z_n), the output signal from the comparator is reduces to zero. When the target signal exist {as in the scan number 15, the input signal =20 dB, (smooth lines)} the output signal amplitude will be set to unity that represents the presence of target. After one sample the high amplitude of $\hat{y}_n$ is compared with the new present signal to indicate the absence of target. If the velocity of target is very small, then the slowly moving targets or fixed targets remain in the same map cell for more than one scan, so the detection and false alarm probability decreases. The fluctuation in the amplitude corresponds to the fluctuation in the input signal for more than one scan (random input signal). A small value of F gives the best detection performance under different cases.

The choice of number of range cells per map cells depends on the application of the radar. Although the land clutters spikes may have small but zero mean position shifts [5]. Such shifts will cause the land clutter spikes close to the edge of a clutter map cell to oscillate between two map cells causing an increase in false alarm rate. Therefore, even for land-based radar's, a minimum spread of one cell is always acceptable, while, for the ship board radar environment, the received signal must now be compensated for ships motion. Ref. [5] which shows that for N_r=2, N_{rs}=1 provides better protection against ships velocity, and the number of spreading cells in bearing N_{bs}=1 for N_b=1. For example, if

the pulse width ($\tau = 0.5\mu\text{sec.}$), Range $= C\tau/2$ =75m, for N_r=5 cells, then, each cell is equal to 15m in range. If radar scan time is T_p=5 sec., then, the minimum number of target free velocity is V_{mf}=15 m/sec.=54 Km/h., if the range spreading cells are used, (N_{rs}=1) then the map free velocity is V_{mf}=90m/5sec=64.8 Km/h.

It's clear that the spreading cells reduce the effect of slowly moving targets on the detection probability. For slowly moving targets lying at the end of map cell (mutual masking), these targets must move one cell to update another map cell. This means that the target map free velocity is V_{mf}=15/5=3m/sec.=10.8Km/h., in this case any target will move less than 10.8Km/h. will cause the decrease of P_d and P_{fa}.

5.4 CLUTTER MAP LOSS

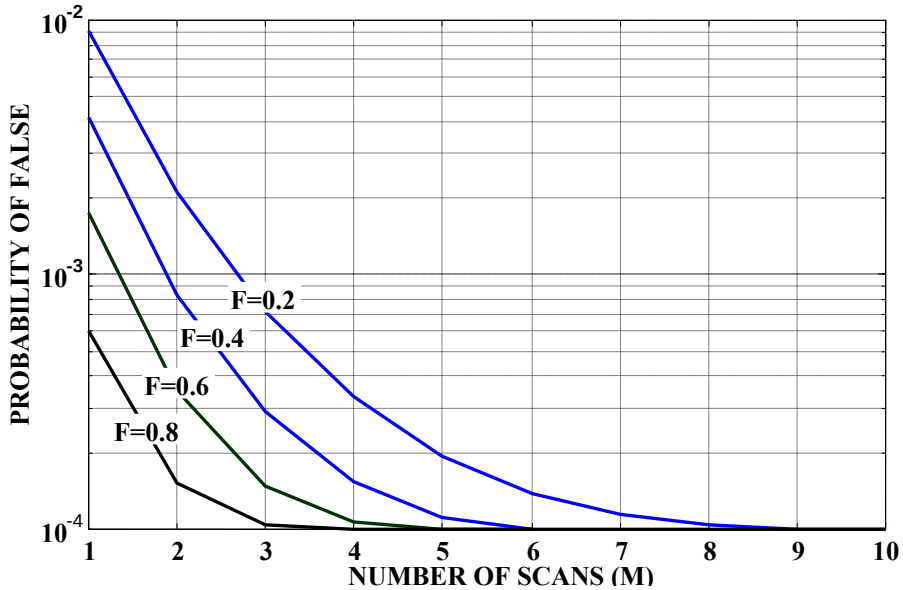
The *CFAR* loss is plotted in fig. (9) for the detection probability equals to 0.5 and 0.9. Small *CFAR* losses are obtained for small weight values. From this figure it can be seen that the CFAR loss increases as the false alarm probability decreases. This result can be obtained by setting the probability of false alarm at the desired value ($P_{fa}=10^{-4}$ and $P_{fa}=10^{-6}$) then, the detection probability at 0.5 and 0.9 is computed for *SNR* values ranging from 0 to 40 dB in 0.1 steps. The increased value in *SNR* from F=0.1 to F=0.9 is the *CFAR* loss. From fig. (4), when F=0 the value of *SNR* that gives P_d=0.5 is approximately 11 dB, so any increase greater than this value for different weights (F) represents the Clutter Map-*CFAR* loss.

By comparing the clutter map approach with the cell averaging approach that analyzed in many papers, the main consequences of setting the detector threshold on a cell-by-cell basis are the capability of interclutter visibility, the signal strength with respect to clutter reflectivity spatial variation, and the capability of dealing with the edges of a clutter patch. On the other hand the cell-averaging device has a settling time of few μs compared with several seconds with the clutter map, which means quick reaction to movable clutter. Mutual masking may occur between targets close in range. Cell averaging is much more sensitive to space variation of clutter reflectivity (i.e. poor interclutter visibility) but it gives a reduced cancellation of slowly moving targets.

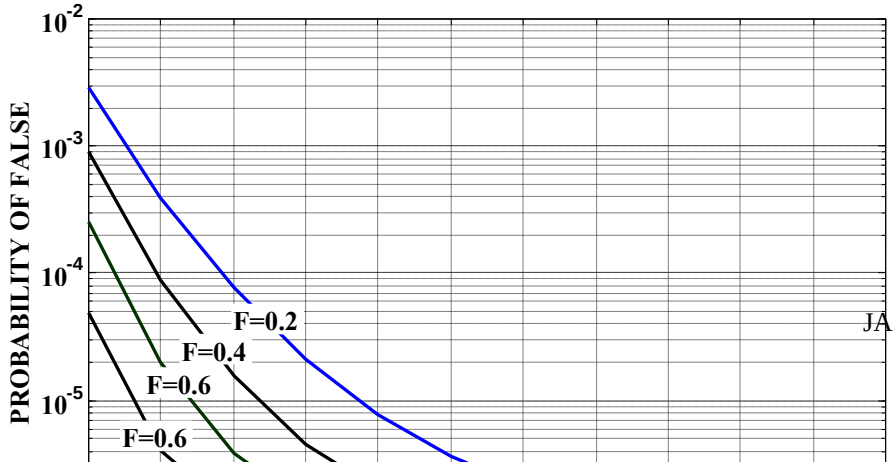
Commonly a Constant False Alarm Rate (*CFAR*) processor is achieved by defining a fixed probability of miss-classification in homogeneous statistics. Any deviation from homogeneity over the observation time will severely decrease the effectiveness of these schemes. An edge, where both the power and type of statistics can vary abruptly, the detector is lowered in performance.

6. CONCLUSIONS

Clutter Map-CFAR has an advantage over the CA-CFAR family in that it's not affected in nonhomogeneous clutter environment. The signal-to-noise ratio depends on the averaging time; the longer time corresponds to less the loss. The response of Clutter Map-CFAR will be reduced when a target of low speed remains within the cell longs enough to affects the threshold. The larger values of memory weights (F) correspond to the larger values of the threshold multiplier (α) and the larger loss can occur. As the scan number and the target velocity increases the detection probability increases. Finally the spreading cells are used to reduce the effect of slowly moving targets.



(a) $P_{fa}=10^{-4}$



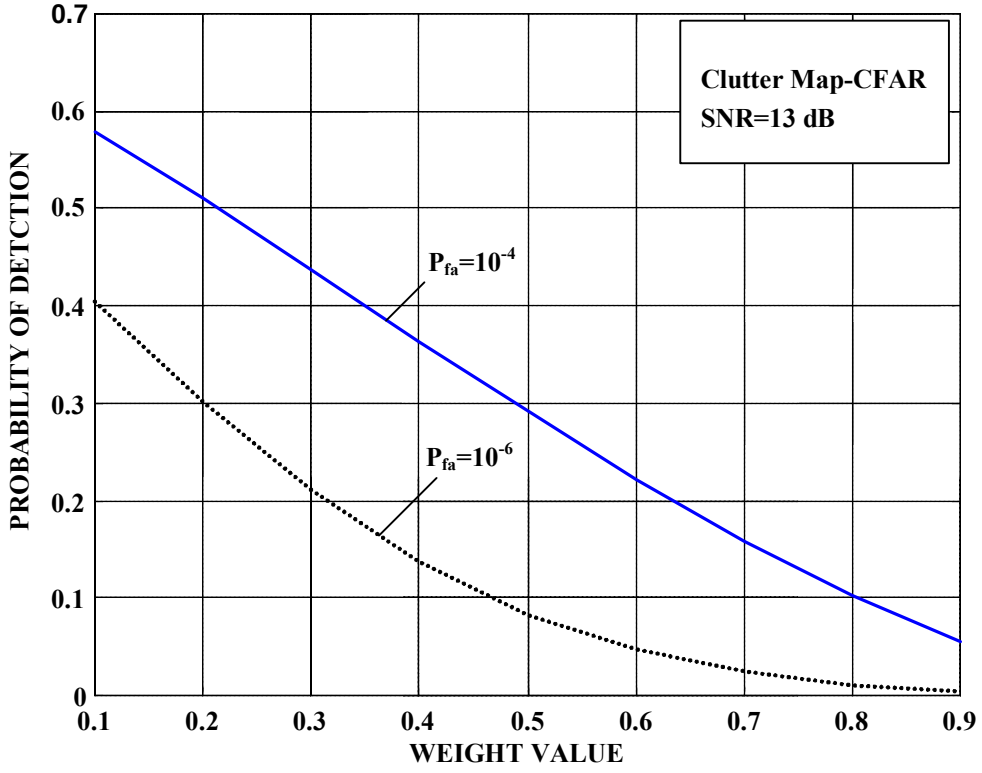
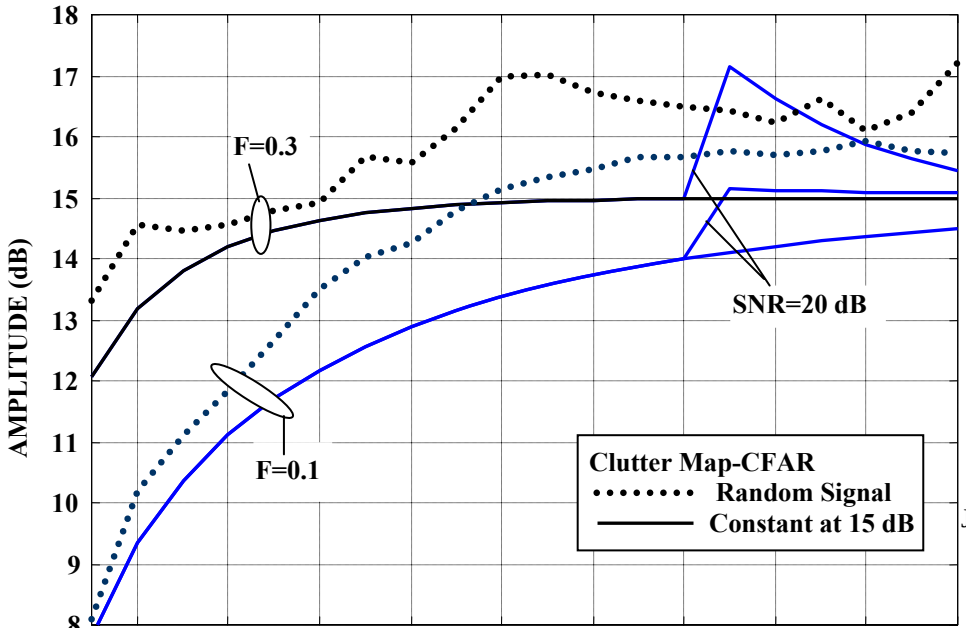


Fig. (7) P_d versus F at SNR=13 dB



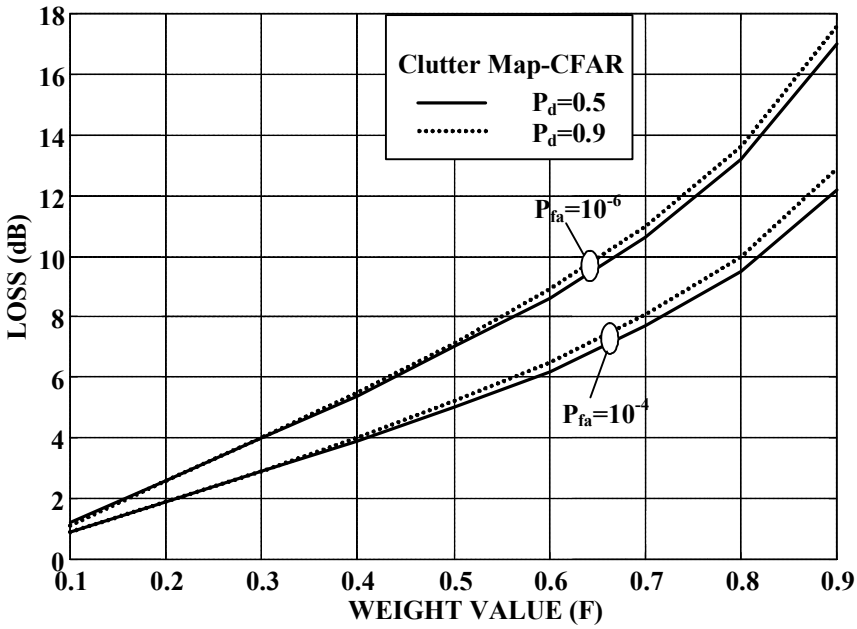


Fig. (9) Clutter Map-CFAR loss at different weights

REFERENCES

[1] SKOLNIK, M. I.” Introduction to Radar Systems”, Mc Graw-Hill, Book Company, New York, (1962).

[2] RAMON NITZBERG, “Clutter Map CFAR Analysis”, IEEE Trans. on AES., vol. 22, No.4, pp. 419-421, July (1986).

[3] Farina A., “Optimized Radar Processors”, IEE Radar, Sonar Navigation and Avionics series1, London, 1987.

[4] Richard L. Mitchell, ”Radar Signal Simulation”, ARTECH HOUSE, INC. Washington (USA), (1976).

[5] KHOURY E. N. and HOYLE J. S., “CLUTTER MAPS: DESIGN AND PERFORMANCE”, IEEE International Radar Conference, pp. 1-7, (1984)

[6] NADAV LEVANON, “Radar Principles”, John wiley and Sons, USA. (1988).

[7] Salih Mohammed Salih, “Analysis and Performance Evaluation of CFAR Techniques”, Master Thesis, Department of Electrical and Electronic Engineering, University of Technology, Baghdad/ Iraq, June, (2003).

[8] Ali Jassim Jhaffory, “Radar Anticlutter Processing By Employing CFAR Techniques”, Master Thesis, University of Technology/ Iraq. June, (2004).