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# ESTIMATION OF RADAR JAMMING WAVEFORMS WITH CFAR ALGORITHMS FOR DIFFERENT TARGET SITUATIONS

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## ABSTRACT

This paper focuses on target detection, emphasizing its significance and exploring the implementation of Constant False Alarm Rate (CFAR) detection algorithms. Explores the performance of CA (Cell Average), GO (Greatest of), and SO (Smallest of) detectors in the existence of many jamming techniques including Barrage Jamming, Spot Jamming, Sweep Jamming, Noise AM Jamming, and Noise FM Jamming signals. Evaluate the CFAR algorithm's realization with various scenarios like Single target, Closed multi-target, Multi target, and the presence of a Clutter edge environment. The study aims to assess the behavior of detection algorithms for accurate detection and how they perform in challenging environments.

## KEYWORDS

Radar; CFAR algorithms; Barrage jamming; Spot jamming; Sweep jamming; Noise AM and FM jamming.

## 1. INTRODUCTION

Radar is a fundamental tool in electronic warfare, widely utilized in applications such as air traffic control, aircraft collision avoidance systems, flight control, and anti-missile systems. Because the working of radar is more important and in wide ranges, it's often targeted by adversaries seeking to exploit or disrupt their functionality. Moreover, the environment that radar works on it could affected by many electronic countermeasures like jammers (Aziz, M.M., Maud, A.R.M. and Habib, A., 2021).

Generally, Jammers are devices that are designed to generate and emit a jam signal to the intended device (radar), which works to deceive and disrupt there detection capabilities (Aref, M.A., Jayaweera, S.K. and Yepez, E., 2020). For more precisely, Noise Jamming (NJ) is defined as an electronic countermeasure (ECM) used to give false detection and measurement for the target's information, for a more accurate definition, NJ works by generating a distribution signal at the receiver side that aims to cover the targets. Therefore, decrease the sensitivity of the radar system because of the increase in the threshold of constant false alarm rate (CFAR) with the increased noise level (Orlando, D., 2016).

One of the primary functions of a radar system is to declare if the target was detected or not (Mboungam, A.M., Zhi, Y. and Youani, W.A.T., 2023) Before extracting the required parameters by the radar device. However, this decision-making process becomes more complex in environments with significant noise and interference (Jalil, A., Yousaf, H. and Baig, M.I., 2016). This detection process has many techniques that will be illustrated in this literature. The essential technology is to set a fixed threshold on the returned (echo) signal which is usually entombed in noise, clutter, and interference signals; if any part of the echo signal passes the threshold level, then it will be declared a target (Mboungam, A.M., Zhi, Y. and Youani, W.A.T., 2023). However, fixed-threshold methods are no longer valid because of the unpredictable nature of the surrounding area, therefor most radar designers use a constant false alarm rate (CFAR) detection algorithms which provide more accurate detection result (Liu, X. and Li, D., 2018).

CFAR detectors create an adaptively changed threshold to be compatible with available noise backgrounds. Locks like the essential technology CFAR detectors compare the returned signal with the adaptive threshold if the signal passes the threshold, then will be declared as a target, and if not declared as a no-target it may classified as an interference signal, noise, or clutter (It's classified as an adverse signal may result from changes in weather conditions, trees, building, towers, etc.(G.M. Hatem, 2020; Björklund, S., 2017). The false alarm is declared when the noise signal passes the threshold level and is detected as a target (Sahal, M., Said, Z.A., Putra, R.Y., Kadir, R.E.A. and Firmansyah, A.A., 2020). The general structure of the CFAR detector is shown in Fig.1 below (Sahal, M., Said, Z.A., Putra, R.Y., Kadir, R.E.A. and Firmansyah, A.A., 2020; Hatem, G.M., Sadah, J.A. and Saeed, T.R., 2018).

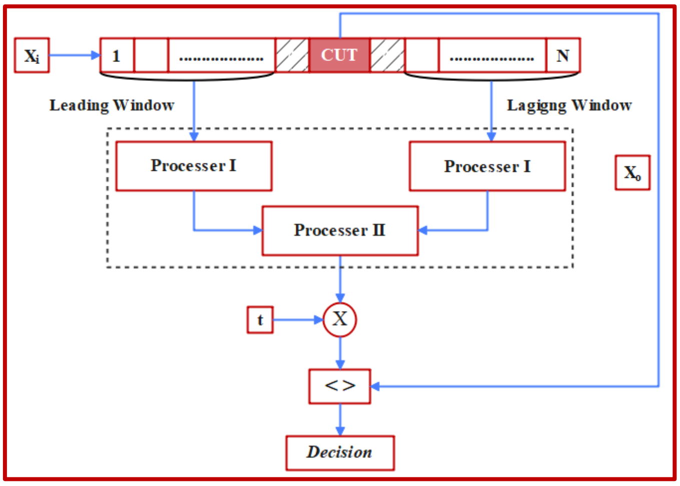


**Fig. 1. General structure of the CFAR detector (Sahal, M., Said, Z.A., Putra, R.Y., Kadir, R.E.A. and Firmansyah, A.A., 2020; Hatem, G.M., Sadah, J.A. and Saeed, T.R., 2018).**

The general structure CFAR detectors consist of test cells, reference windows, and guard cells. Reference window comprises of lagging and leading windows that border the guard cell. Depending upon the data in the leading and lagging window, the CFAR detector threshold will be determined by multiplying the background noise power by a fixed scaler factor. Then compare each data simple with the value of CUT(Cell Under Test) and declare if the tested cell is being targeted or not (Hatem, G.M., Sadah, J.A. and Saeed, T.R., 2018; Sim, Y., Heo, J., Jung, Y., Lee, S. and Jung, Y., 2023; Alaa, R., Hussein, E.A. and Al-libawy, H., 2024).

In this study, several noise jamming techniques are applied across four different target situations: single target, multi-targets, closed multi-targets, and a clutter edge environment in the multi-targets case; while studying the effect of clutter edge in the detection process. The three primary CFAR detection types—Cell Average (CA), Greatest Of (GO), and Smallest Of (SO)—are evaluated in both homogeneous (single and multiple targets) and non-homogeneous (closely spaced targets and clutter edge) environments. The rest of this paper is organized as follows: the main CFAR algorithms are discussed briefly in Section 2. Section 3, presents the used jamming techniques, Section 4, explores the four target situations, results and discussion are illustrated in Section 5, and eventually, Section 6, highlights the conclusion.

## 2. CFAR ALGORITHMS

There are three essential parts in radar jamming technology: realization of jamming techniques, selection of radar waveform, and mode of signal processing (Hu, Y., Wang, Z., Chen, H. and Jiang, Y., 2023; Blunt, S.D. and Mokole, E.L., 2016).

The classification of CFAR Algorithms depends upon processing the contained data in the range cells. regardless of the achieved development of CFAR algorithms, but all these algorithms rely on a Cell Average (CA-CFAR) detector which first proposed by Finn and Johnson in 1968 (Blunt, S.D. and Mokole, E.L., 2016; Hatem, G.M., Sadah, J.A. and Saeed, T.R., 2018). Works by taking the average of the sum data in the reference cells, in noise conditions CA is the ideal detector because it maximizes the probability of detection to enhance an accurate detection (HM, F., 1968; Ismael, H.H., Jasim, M.A., Sharif, M.A. and Jasim, F.Z., 2025). Unfortunately, its performance deteriorates in the clutter edge environments and in the presence of other interfering targets' echoes (Liu, X. and Li, D., 2018).

When dividing reference cells into two parts two more algorithms will be produced which are GO-CFAR(Greatest of) and SO-CFAR(Smallest of) algorithms (Liu, X. and Li, D., 2018) estimate the threshold value after selecting the largest or the smallest data (Ismael, H.H., Jasim, M.A., Sharif, M.A. and Jasim, F.Z., 2025).

Hansen and Sawyers (Hansen, V.G. and Sawyers, J.H., 1980; Hashim, A.A. and Mazinani, M., 2025) proposed GO-CFAR algorithm to overcome the deterioration in CA performance in the nonhomogeneous environment. This algorithm works by selecting the greatest value ($Z_{GO}$) of the sums in the leading ($Z_1$) and lagging ($Z_2$) windows and then comparing the selected value with the CUT. If the magnitude of CUT exceeds the greatest value then will be declared as a target and the threshold will be calculated as seen in the equation below (Hatem, G.M., Sadah, J.A. and Saeed, T.R., 2018).

$$Z_{GO} = \max(Z_1, Z_2) \tag{1}$$

SO-CFAR proposed by Trunk (Safir Shbat, M. and Tuzlukov, V., 2014), which selects the smallest value ($Z_{SO}$) of the sums in the leading and lagging windows and then compares the selected value with the CUT to obtain the threshold value. The threshold equation is illustrated as (Hatem, G.M., Sadah, J.A. and Saeed, T.R., 2018):

$$Z_{SO} = \min(Z_1, Z_2) \tag{2}$$

## 3. RADAR JAMMING TECHNIQES

### 3.1. Barrage Jamming

This is the most effective noise jamming technique, it generates and radiates an extensive range of high-power noisy jamming frequencies (Cao, Z., Li, J., Song, C., Xu, Z. and Wang, X., 2020). Working by transmitting noisy signals across a wide range of frequencies to the radar signal (Aref, M.A., Jayaweera, S.K. and Yepez, E., 2020). Fig.2 shows the spectrum barrage gamming and Fig.3 shows the simulation of generated barrage jamming signal.

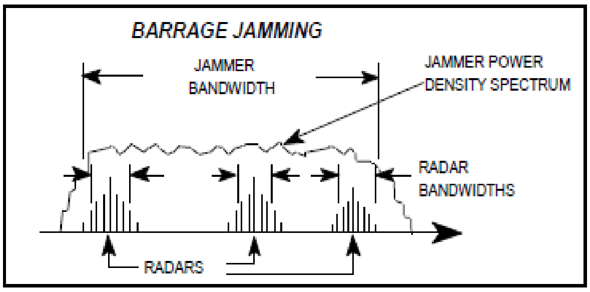


**Fig. 2. Spectrum of Barrage Jammer** **(Khadka, S., Anuradha, M.S. and Padmasree, C., 2015; Electronic Warfare - RADAR NOISE JAMMING, 2018).**

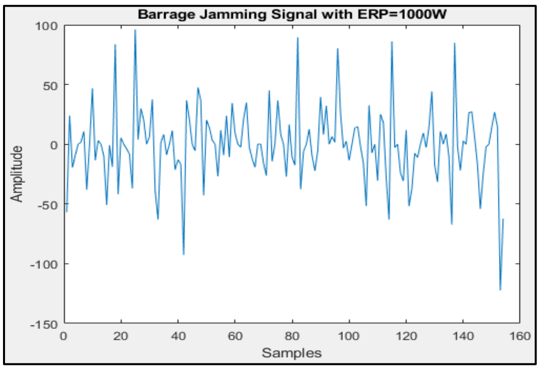


**Fig. 3. Generated Barrage Jamming Signal.**

### 3.2. Spot Jamming

This type of jamming aims to target and disrupt a specific area or spot rather than a broader range of frequencies (Cao, Z., Li, J., Song, C., Xu, Z. and Wang, X., 2020). working by targeting spot frequency (single frequency), which is done by transmitting all jamming energy to a narrow spectrum (Aref, M.A., Jayaweera, S.K. and Yepez, E., 2020). Fig.4 shows the spectrum of spot Jammer and Fig.5 shows the generated spot jamming signal.

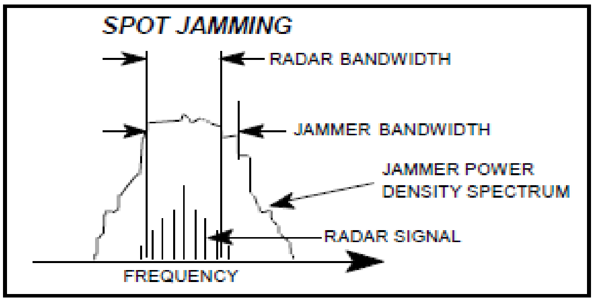


**Fig. 4. Spectrum of Spot Jammer** **(Khadka, S., Anuradha, M.S. and Padmasree, C., 2015; Electronic Warfare - RADAR NOISE JAMMING, 2018).**

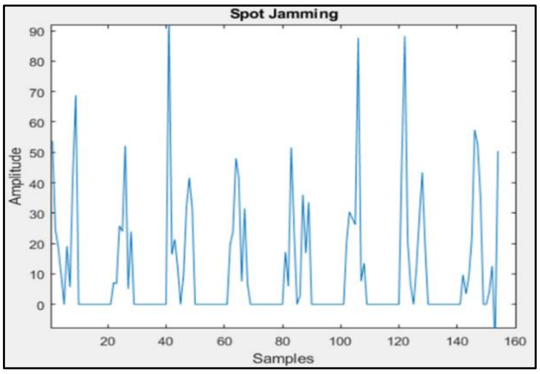


**Fig. 5. Generated Spot Jamming Signal.**

### 3.3. Sweep Jamming

Barrage jammer emits a broad of frequencies so it will jam the radar definitely, but a lot of the jamming power will be lost. Otherwise, spot jamming could be an effective jammer if the frequency of the jammer matched with the radar operation frequency. Thus, sweep jammers are found to solve this problem that has transmitting a narrow band jamming signal with a swept frequency across the wide spectrum so that different radars will be jammed (Hansen,V.G.and Sawyers, J.H.,1980; Trunk, G.V.,1978). The generated barrage jamming signal is shown in Fig.6.

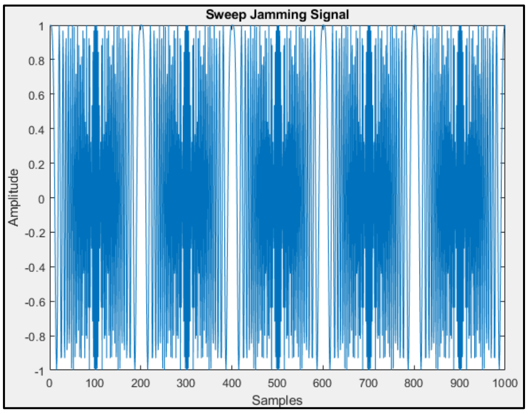


**Fig. 6. Generated Sweep Jamming Signal.**

### 3.4. Noise AM Jamming

Before generating noise AM jamming, RF noise interfering was introduced by using low noise power BPF then the amplification process was applied to perform RF noise interfering signal, and as the following equation (Alaa, R., Hussein, E.A. and Al-libawy, H., 2024; Hu, Y., Wang, Z., Chen, H. and Jiang, Y., 2023):

$$J(t) = U(t)\cos(w_o t + \emptyset(t)) \tag{3}$$

Where $U(t)$ is Rayleigh distribution (Hu, Y., Wang, Z., Chen, H. and Jiang, Y., 2023) the amplitude of the RF noise interfering signal was modulated to generate the noise AM jamming signal and as the following equation:

$$J(t) = [U_o + U_n(t)]\cos(w_o t + \emptyset_o) \tag{4}$$

Where:

$U_o$ Signal amplitude,

$U_n(t)$ Amplitude-modulation noise,

$w_o$ Center frequency,

$\emptyset_o$ Initial phase with zero mean (Ammar, B.K., Albattat, H.J., Wadday, A.G. and Al-Ja'afari, M.A., 2021; Ammar, B.K., Albattat, H.J., Wadday, A.G. and Al-Ja'afar, M.A., 2023) uniform distribution (Hu, Y., Wang, Z., Chen, H. and Jiang, Y., 2023). The generated noise AM jamming is shown in Fig.7.

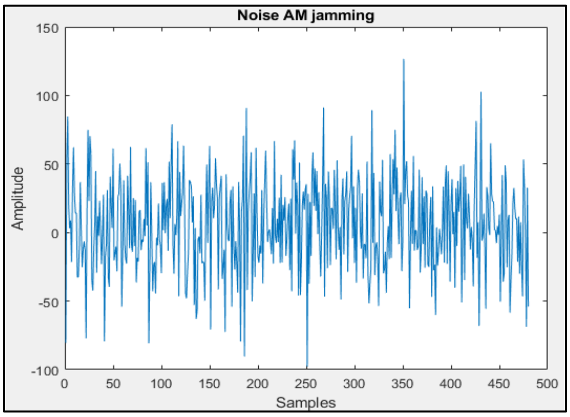


**Fig. 7. Generated Noise AM Jamming Signal.**

### 3.5. Noise FM Jamming

noise FM hamming is generated by modulating the frequency of RF noise interfering signal and as the below formula:

$$J(t) = U_o \cos(w_o t + 2\pi K_{FM} \emptyset_o) \quad (5)$$

$K_{FM}$ is the slope of frequency modulation (Alaa, R., Hussein, E.A. and Al-libawy, H., 2024; Hu, Y., Wang, Z., Chen, H. and Jiang, Y., 2023). The generated noise FM jamming is shown in Fig.8.

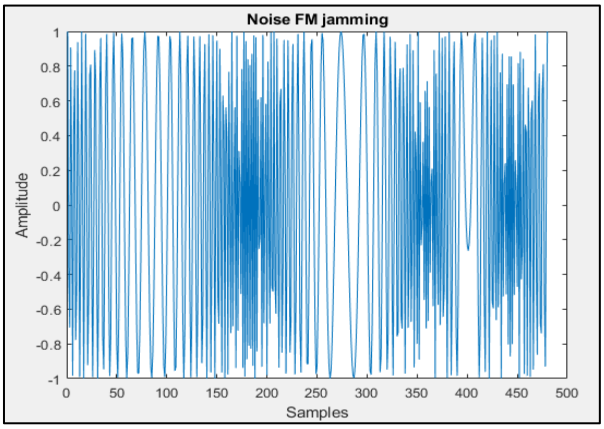


**Fig. 8. Generated Noise FM Jamming Signal.**

## 4. TARGET SITUATIONS

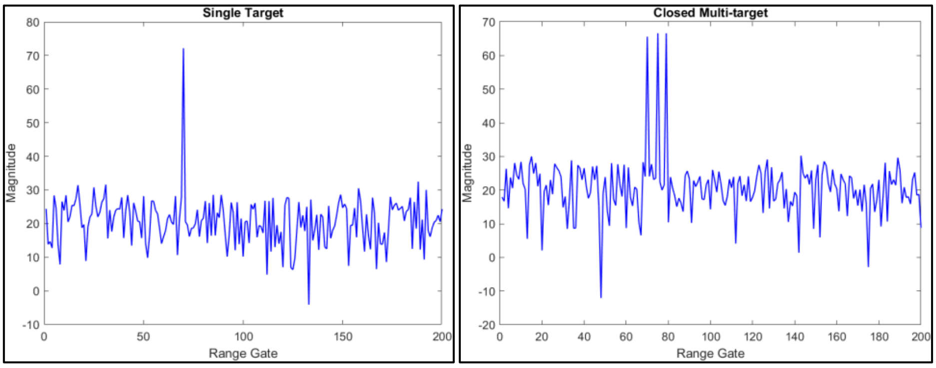
The designed echo signal is classified into two cases:

**a. Echo Signal 1 = Jamming signal + Target Signal + Reflected Radar signal.**

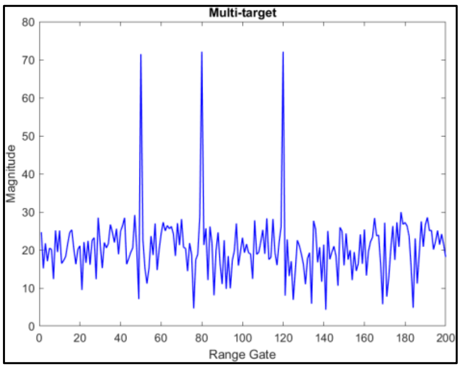
Jamming signals may be barrage, spot, sweep, noise AM, or noise FM signals (as described in detail in the previous section). In the target signal, three target situations are generated and then modulation into the echo signal which is classified into:

- Single target at gate of 70.
- Closed multi-targets at gates 70,75 and 79.
- Multi-targets at gates 50, 80, and 120.

Target signals are shown in Fig.9 (i - iii) below:



**i.Single Target.** **ii. Closed multi-target.**

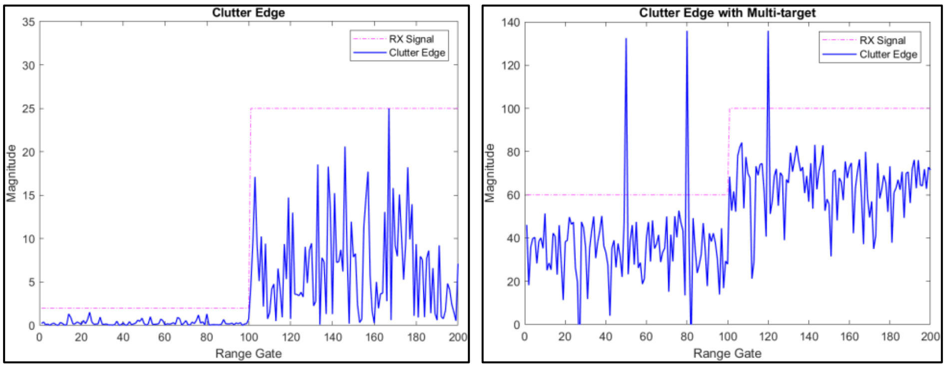


**iii. multi-target.**

**Fig. 9. Target Situations.**

**b. Echo Signal 2 = Jamming signal+ Target Signal+ Reflected Radar signal+ Clutter Edge.**

In this case, the target signal will be just in a multi-target situation. The using of the radar in unlimited environments will cause more undesirable signals which are defined as radar clutter in addition to the jamming and interfering signals, all these signals affect the radar's operating system and target detection process. Clutter signals may be reflected from land, sea, or other objects like buildings, towers, etc. (Pardhasaradhi, A. and Kumar, R.R., 2013). The clutter edge environment and multi-target in the clutter edge are shown in Fig.10 (i, ii) below:



**i.Clutter Edge.** **ii.Multi-target with Clutter Edge.**

**Fig. 10. Clutter Edge signal with multi-target condition.**

## 5. RESULTS AND DISCUSSIONS

In this study two cases are considered based on the flow chart illustrated in Fig.11, two target situation cases were studied (homogeneous represented with single target and nonhomogeneous represented as multitarget and clutter edge) with different types of jamming signals to track to track the performance of CFAR algorithms against homogeneous and non-homogenous environments, the received echo signals will be introduced into each CFAR type.

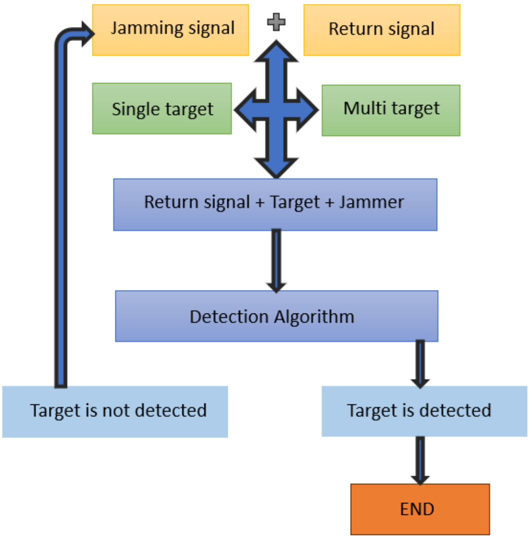
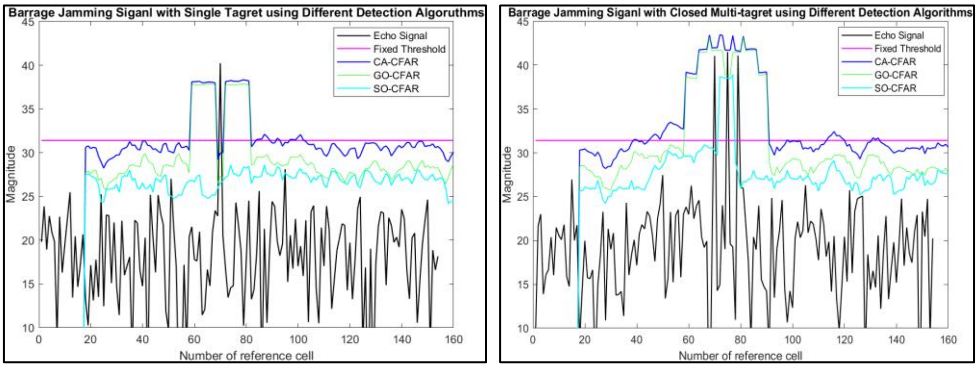


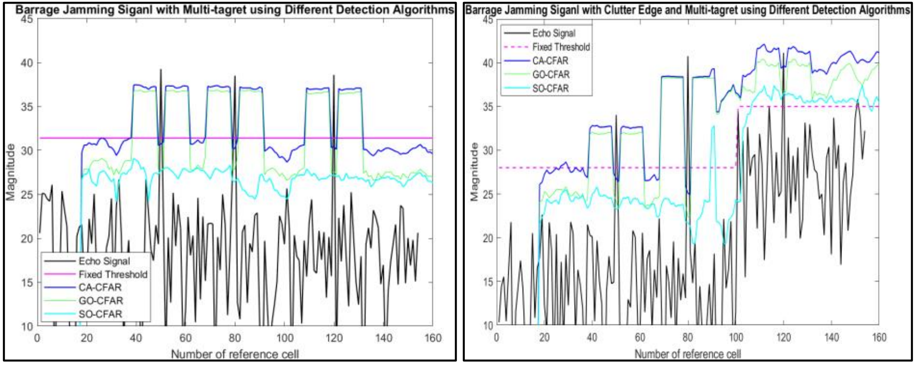
**Fig. 11. The work steps: two Targets (homogeneous and nonhomogeneous)**

### 5.1. Barrage Jammer

A barrage jammer generated using (1000 W) ERP is an acronym for Effective Radiated Power that describes the power radiated by the jammer device and measured in watts, Fig.12-a (i - iv) below shows the behavior of CFAR algorithms against different target situations using barrage jammer. It is obvious from this figure that CA and GO-CFARs have relatively equal target detection performance and overperform in comparison with SO-CFAR which is approximate there is no target detection additionally found false alarms in single and multi-target situations. In the clutter edge environment, GO-CFAR overcomes CA-CFAR by providing more accurate target detection, SO-CFAR is still the weakest algorithm and discovers more false alarm targets. Under the effects of the Barrage jamming technique Fig.12-b, illustrates that the probability of detection for the various CFAR detectors decreased to approximately 65% for CA and GO-CFARs while 35% for SO-CFAR algorithm. This decreased incident due to the use of jamming signal which interfered with the target signal, therefore, affecting the detection process and decreasing the probability. Both CA-CFAR and GO-CFAR algorithms are improved appropriate for control barrage jamming due to their ability to adjust their thresholds dynamically, minimizing false alarm rate and enhancing probability of detection in the presence of jammer signal. CA-CFAR do this by averaging the interference, while GO-CFAR centers on the worst-case cell, creating a robust in targets detection while neglected effect of jamming signal.



**i.Single target.** **ii.Closed multi-target.**



**iii.multi-target.** **iv.Clutter Edge multi-target.**

**Fig. 12-a. Detection algorithms according to target situations using Barrage Jamming.**

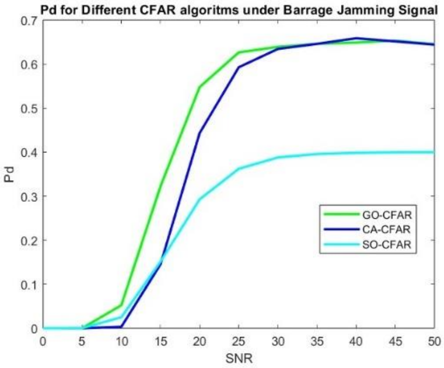


**Fig. 12-b. Probability of detection for various CFAR detectors under Barrage Jamming effects.**

## 5.2. Spot Jammer

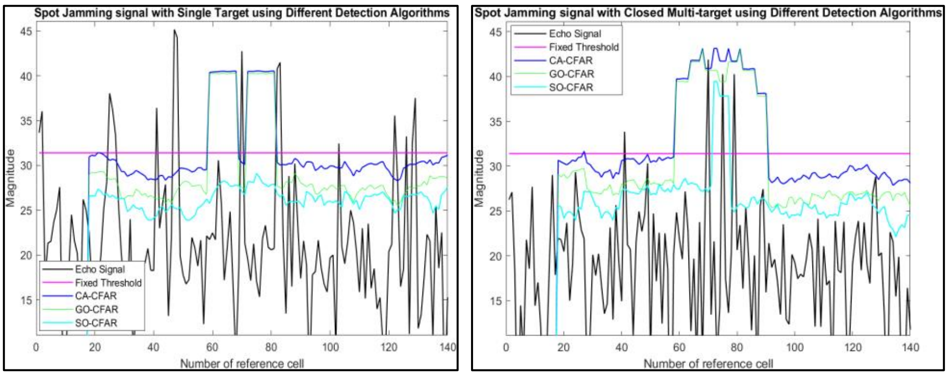
when multiplying the previously generated barrage signal with a pulse signal will get a spot jammer. Fig.13-a (i - iv) below shows the behavior of CFAR algorithms against different target situations using a spot jammer. Spot jammers could be classified as the best jammer device, the detection process being more difficult. CA and GO-CFARs successfully detect targets in both homogeneous and nonhomogeneous environments but with extra false alarms in different gates. Best detection shows in closed multi-target where much fewer false alarm points appeared also in clutter edge cases which detect targets in different environments with approximately no false alarm. While the SO detector is the worst detection algorithm and presents a much higher false alarm rate. Spot jammers provide a much higher jam signal the probability of detection decreased for all algorithms CA, GO, and SO CFARs to be 65%, 64%, and 20%, respectively as shown in Fig.13-b. This is due to the interfered jammed signal which affects the detection process and decreases the probability.

### 5.3. Sweep Jammer

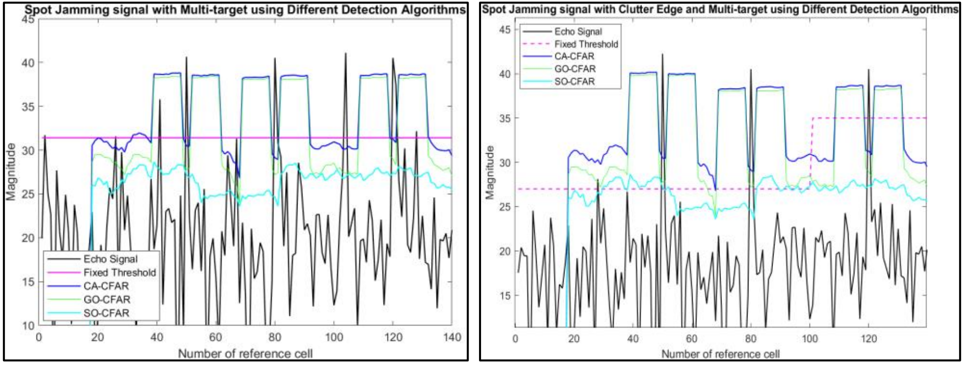
A sweep jammer signal was generated using an LFM (Linear Frequency Modulation) signal then applied a sweep frequency of 5000Hz with sweep duration of 1 second, Fig.14-a (i - iv) below shows the behavior of CFAR algorithms against different target situations using a sweep jammer.

The best target detection and relatively smallest points of false alarm rate when using sweep jamming. All target situations have been detected successfully in both homogenous and nonhomogeneous domains using CA and GO-CFAR detectors.

Under the effects of Sweep jamming signal Fig.14-b, illustrates that the probability of detection for the various CFAR detectors decreased in all target situations to be approximately 66% for CA, 65% for GO-CFARs, and 37% for SO-CFAR, because of the interference between jamming and target signals, therefore that effects on the detection process and decrease the probability.



**i.Single target.** **ii.Closed multi-target.**



**iii.multi-target.** **iv.Clutter Edge multi-target.**

**Fig. 13-a. Detection algorithms according to target situations using Spot Jamming.**

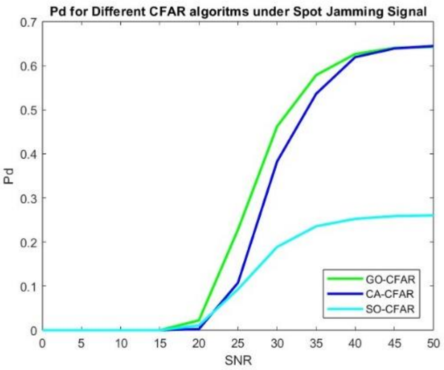
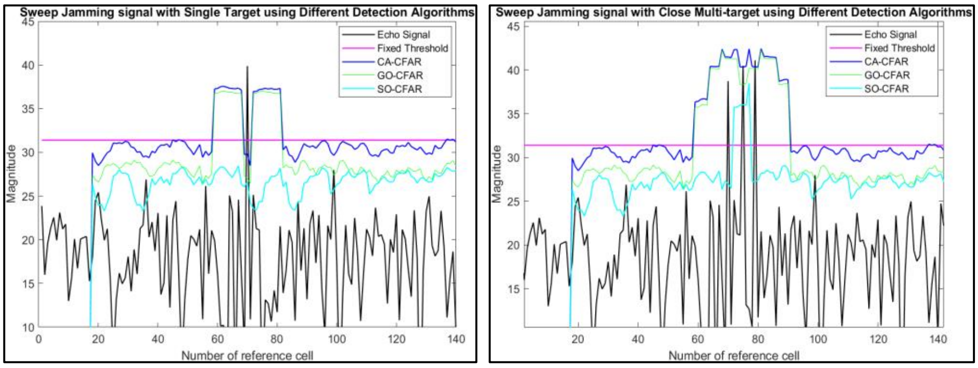
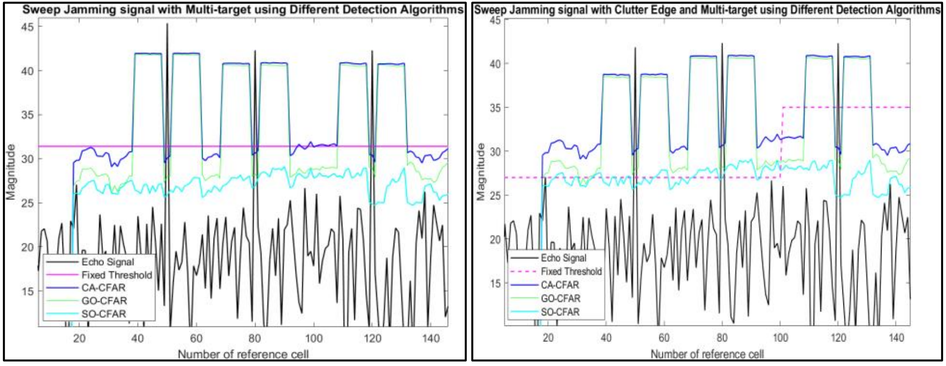


**Fig. 13-b. Probability of detection for various CFAR detectors under Spot Jamming effects.**



**i.Single target.** **ii.Closed multi-target.**



**iii.multi-target.** **iv.Clutter Edge multi-target.**

**Fig. 14-a. Detection algorithms according to target situations using Sweep Jamming.**

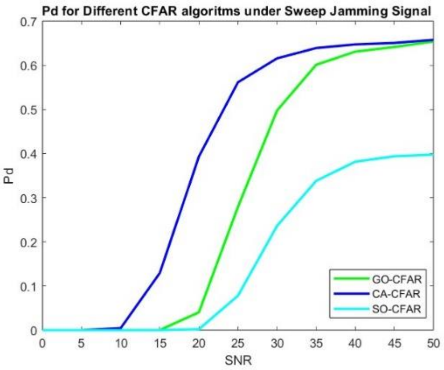
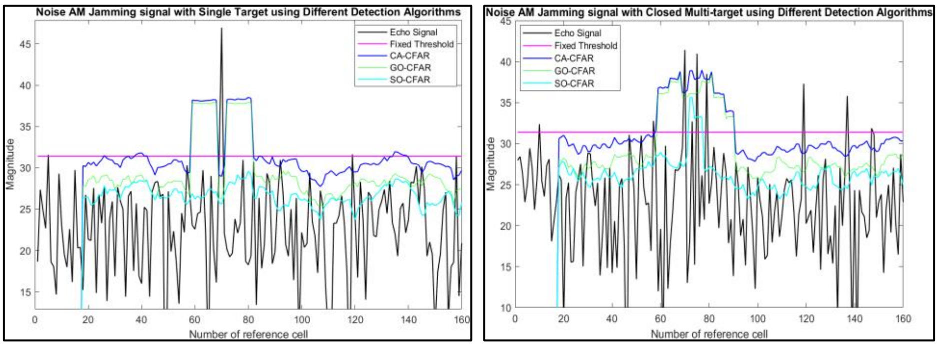


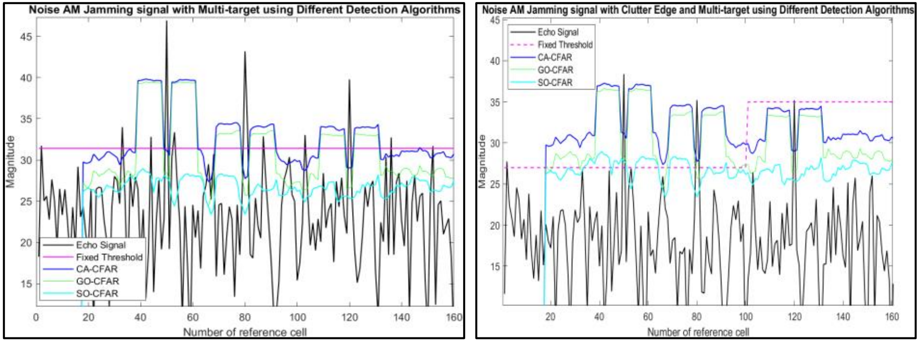
**Fig. 14-b. Probability of detection for various CFAR detectors under Sweep Jamming effects.**

### 5.4. Noise AM Jamming

The formula that used in this study to generate an AM jamming signal is illustrated in the previous section. set the parameters of $U_o$ to 5 and $U_n(t)$ to 2, Fig.15-a (i - iv) below shows the behavior of CFAR algorithms against different target situations using noise AM jammer. From the figure can observe that the detection process has been more difficult due to a broad number of false alarm points appearing in different gates that will cause noise to overpower the targets' signal. However, the single target was successfully detected by the CA and GO detector, in closed multi-target a false alarm point is detected making the process difficult to distinguish if it performs a real target or a false alarm.



**i.Single target.** **ii.Closed multi-target.**



**iii.multi-target.** **iv.Clutter Edge multi-target.**

**Fig. 15-a. Detection algorithms according to target situations using Noise AM Jamming.**

More sharp peaks appear in multi-target while clutter edge environment appears a relatively better detection with the smallest false alarm rate. Noise AM jamming transmits more stronger jam signal so the probability of detection has decreased much higher, achieving 20% for SO detector, 60 and 58% for CA and GO detectors, Fig.15-b, illustrates the decrease due to the interference between jamming and target signals, therefore affecting the detection process and decreasing the probability.

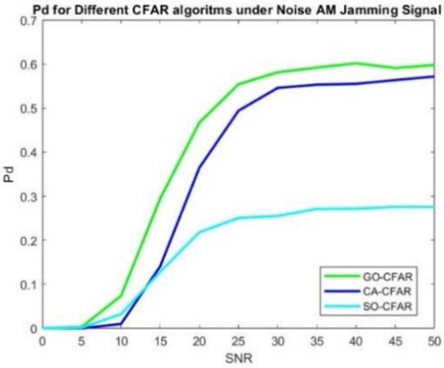


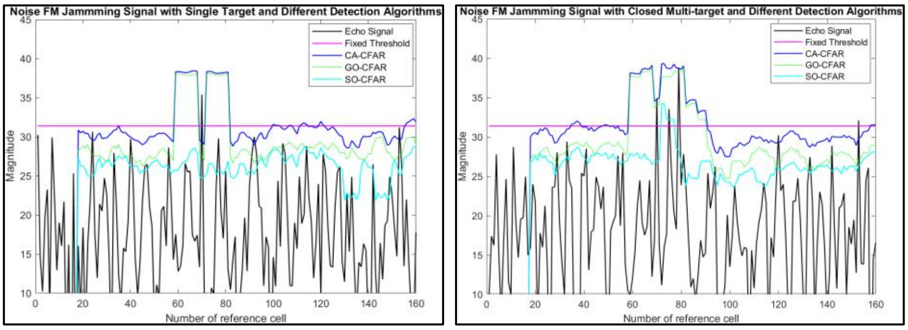
**Fig. 15-b. Probability of detection for various CFAR detectors under Sweep Jamming effects.**

### 5.5. Noise FM Jamming

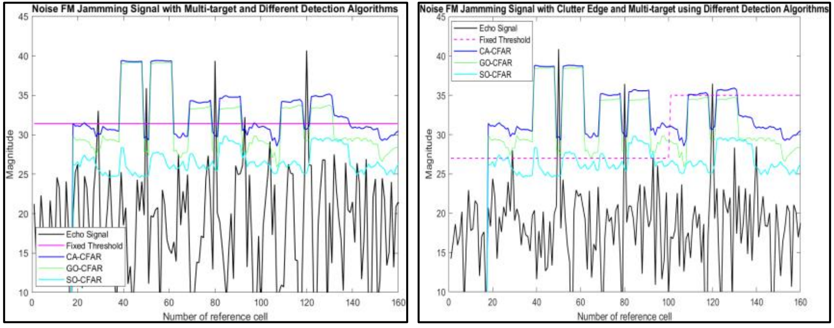
generated using the previously illustrated formula and set the parameter of $K_{FM}$ to be 2000000, Fig.16-a (i – iv) below shows the behavior of CFAR algorithms against different target situations using a noise FM jammer. The detection process is more accurate than using AM jamming, false alarm gates are decreased and the strength of the target signal is much greater than the jam signal. The performance of CA and GO detectors is better than when using AM jamming, the target signal is clear and the detection could be more accurate due to the decrease in the false alarm rates.

Under the effects of Noise FM jamming signal Fig.16-b illustrates that the probability of detection for the various CFAR detectors decreased to approximately 65% for CA and GO-CFARs, 35% for SO-CFAR which is similar to the effect of Barrage jamming.

A summary of CFAR types for single target, closed-multi target and multi-target with the different jamming techniques is shown in Table1 below.



**i.Single target.** **ii. Closed multi-target.**



**iii.multi-target.** **iv. Clutter Edge multi-target.**

**Fig. 16-a. Detection algorithms according to target situations using Noise FM Jamming.**

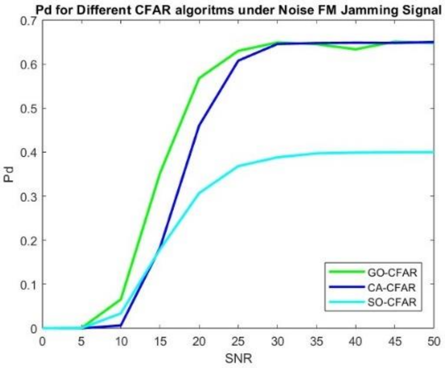


**Fig. 16-b. Probability of detection for various CFAR detectors under FM Jamming effects.**

**Table1. The summary to the CFARs behavior against different jamming techniques.**

| Jammer Type | CFAR Type | Single Target | Close-multi target | Multi-target | Clutter Edge |
|---|---|---|---|---|---|
| Barrage Jamming | CA | Both are good in the detection of a single target (Homogeneous), closed multi-target and multi-target (Nonhomogeneous) | | | Poor in detecting targets in different environments |
| | GO | | | | Accurately detects targets in different environments |
| | SO | Relatively there is no detection in all target situations | | | |
| Spot Jamming | CA | Detected but with more false alarm rate. | Clearly detected with much fewer false alarm points | Detected with extra false alarm rate. | Accurately detect all targets with relatively no false alarm gates |
| | GO | | | | |
| | SO | No detection | No detection | Single detection only in one gate | No detection |
| Sweep Jamming | CA | Best detection in both homogenous and nonhomogeneous environments | | | |
| | GO | | | | |
| | SO | Poor detection in additional detects more false alarm points | | | |
| Noise AM Jamming | CA | Detected but with more false alarm rate | Poor detection, there are many false alarm gates | Detected but false alarm points increased | Decrease in false alarm rates but not successfully detect target in different environments |
| | GO | | | | |
| | SO | Very poor detection in additional detects more and more false alarm points | | | |
| Noise FM Jamming | CA | Both are detecting targets in all cases but a large number of false alarm gates appeared | | | Better than noise AM jamming gives more accurate target detection |
| | GO | | | | |
| | SO | Detect false alarm gates | Detect false alarm gates | Single detection only in one gate | Detect false alarm gates |

## 6. CONCLUSION

The study focuses on the impact of radar jamming techniques on the process of target detection. Five different jamming techniques were estimated over various target situations like single target, multi-targets, closed multi-targets, and clutter edge environments in multi-targets, then utilizing CFAR detectors to perform the detection process. Our results show clear patterns in the effectiveness of different interference techniques. Spot and noise AM jammers were the most effective techniques for detection avoidance, which generated significant interference signals to be modulated in the echo signal which made the detection process more difficult and the radar system couldn't distinguish between target and jamming signals. However, CA and GO detectors succeed in detecting targets with different situations but there are more false alarm gates. For jamming techniques, these methods could be ideal for covering targets.

The results showed that detection in the presence of jammer signals is very difficult, so the existence of a detection algorithm that adapts to this situation is necessary. The SO-CFAR algorithm did not provide efficient detection for any jammer type or target situation. This suggests that this detector may not be suitable for effective detection with these jamming techniques. The CA and GO algorithms are better than the SO detector because the former takes the average and the greatest value, respectively, while the latter only takes the smallest value. Due to the signal discrepancy, only very strong targets are detected in the case of the SO algorithm because it crosses the threshold, so in the presence of a jamming signal, the detection of weak targets is more difficult. On the other hand, the targets were detected accurately by CA and GO algorithms when using Barrage and Sweep jammers, these techniques could be effective if working with anti-jamming. Finally, Noise FM Jamming observed better detection performance than AM Jammer.

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