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Detection improvement of off-pin targets in FMCW radars

Mohamed G Shehata^{1,2}, Fathy M Ahmed^{1,3}, Sameh ghanim^{1,4} and Hazem Zakaria^{1,5}

¹Radar Department, Military Technical College, Cairo, Egypt

E-mail: ²semba45@gmail.com, ³fkader@mtc.edu.eg, ⁴Samehghanim1@gmail.com and

⁵hKamel @mtc.edu.eg

Abstract. Frequency Modulated Continuous Wave (FMCW) radars get target range and Doppler information by extracting the target beat frequency and phase exchange based on the well-known Two-Dimensional Fast Fourier Transform (2D-FFT) processing algorithm. Target whose beat frequency does not lie on the FFT grids suffers from great detection degradation. Doubling the number of FFT points, and consequently, the hardware processing complexity is a common solution to solve this problem. In this paper, a proposed method to increase the detection performance of these targets and avoid increasing system complexity is introduced. The proposed method depends on applying a proposed filter following the first and second FFT algorithms. The filter order and weights are chosen so that only one peak from the adjacent peaks of off-pin targets are distinguished. The superiority of the proposed method over the traditional one is validated for different scenarios through the Receiver Operating Characteristic (ROC).

Keywords: FMCW radars, FFT, off-pin targets, signal processing.

1. Introduction

FMCW radars are commonly used to measure target range and speed. The target range is proportional to the beat frequency defined by the difference between transmitted and received frequency. The target speed is proportional to the doppler frequency [1-3]. Probability of detection and false alarm rate are two important indicators in FMCW radar systems [4]. In FMCW radar signal processing, the target range is measured using Fast Fourier Transform (FFT) due to its low computational complexity [5]. In FFT, the spectrum of each frequency bin has a sinc-shaped spectrum [6]. When the beat frequency of the target falls in the middle of frequency bins between FFT grids, the detection performance is degraded because of two issues. First one, the output amplitude signal of target is reduced, which decreases the SNR (signal to noise ratio) and the detection probability. Second issue, multiple targets signals present on different FFT grids, which increases the false alarm rate [7]. As a result, the detection of FMCW radars is degraded. This paper introduces a method to improve the detection of off-pin targets by using a proposed filter that located after FFT whether in range or in doppler or both.



This paper is organized as follows; after the introduction, traditional signal processing in FMCW radar is discussed in Section (2), Section (3) introduces the proposed signal processing in FMCW radar. Section (4) contains computer analyzes and describes the measurement results to evaluate the capability of the proposed signal processing. Finally, conclusion comes in section (5).

2. Traditional signal processing in FMCW radar

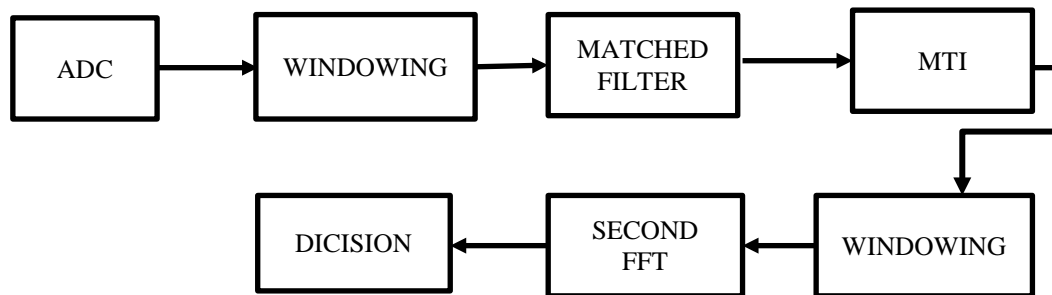


Figure 1. Block diagram of traditional signal processing in FMCW radar

Figure (1) represents the block diagram of traditional signal processing in FMCW radar. The transmitted signal of FMCW radar can be modeled as shown in Equation (1)[1].

$$s_T(t) = A_T \cos \left(2\pi f_c t + 2\pi \int_0^t f_T(\tau) d\tau \right) \quad (1)$$

Where $f_T(\tau) = \frac{B}{T} * \tau$, is the transmitted frequency function of time, f_c is the carrier frequency, B is the bandwidth, A_T represents the transmitted signal amplitude, and T is the time duration. Considering a reflected signal with a time delay t_d and Doppler shift $f_D = \frac{2 \cdot f_c \cdot v}{c}$, c is the speed of light and v is the target relative velocity. the received frequency ($f_R(t)$) is expressed as shown in Equation (2)[1].

$$f_R(t) = \frac{B}{T} (t - t_d) + f_D \quad (2)$$

The received signal can be described as shown in Equation (3).

$$\begin{aligned} s_R(t) &= A_R \cos \left(2\pi f_c (t - t_d) + 2\pi \int_0^t f_R(\tau) d\tau \right) \\ &= A_R \cos \left\{ 2\pi \left(f_c (t - t_d) + \frac{B}{T} \left(\frac{1}{2} t^2 - t_d \cdot t \right) + f_D \cdot t \right) \right\} \end{aligned} \quad (3)$$

Here, A_R represents the amplitude of the received signal. To obtain information of target range and speed, $s_T(t)$ and $s_R(t)$ are mixed by multiplication in frequency domain by using matched filter. Hamming window is used before matched filter to reduce the level of side lobes in range pins. Figure (2) shows the matched filter realization.

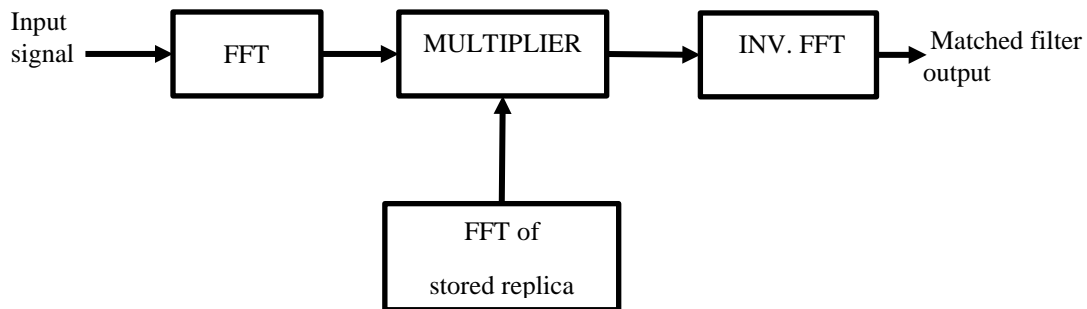


Figure 2. Block diagram of matched filter in frequency domain

Moving Target Indicator (MTI) filter is used after matched filter to distinguish between fixed targets and moving targets.

MTI filters can be implemented using delay line cancelers such as single, double or triple delay line canceler. In this paper, single delay line canceller is used to detect small doppler targets with structure shown in figure (3).

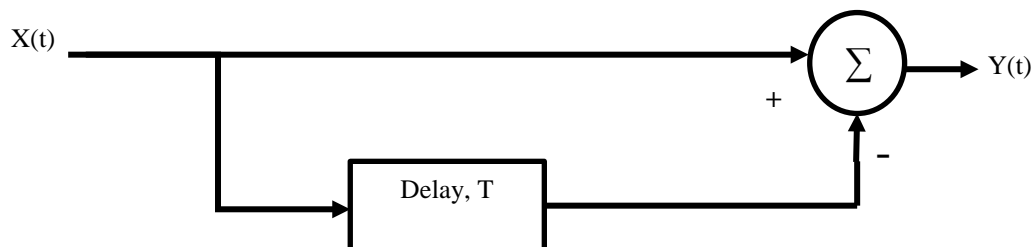


Figure 3. Block diagram of single delay line canceller

The output of MTI filter is moving targets only. To reduce the level of side lobes in doppler pins, hamming window before second FFT is used. Second FFT is used to extract doppler frequency to measure velocity. Constant False Alarm Rate (CFAR) is used after second FFT to maintain constant false alarm rate. Finally, the decision is sent to the display. In this traditional signal processing, if target falls on the middle of doppler pins, reduction in detection occurs. This problem may be solved by doubling the number of samples in FFT. But this method increases the complexity. Another method introduced in [7] uses frequency shifts, but this method is complicated by using two branches consist of two FFT and frequency shift, and take the maximum of the square law detector output. In the present paper, a proposed method in signal processing is used to achieve improvement in detection of targets that falls on FFT grids (off pin targets).

3. Proposed signal processing in FMCW radar

When target frequencies fall between FFT grids, the worst case falls in the middle of Doppler pins. Without using window functions, false targets would possibly appear in all Doppler cells. At the output of the FFT after using Hamming window (There is no universal approach for selecting a window function), the spectral leakage is reduced, but there are still two false targets associated with the main target. The problem of these false targets can be resolved by using the proposed filter after FFT in range or in Doppler, or in both domains.

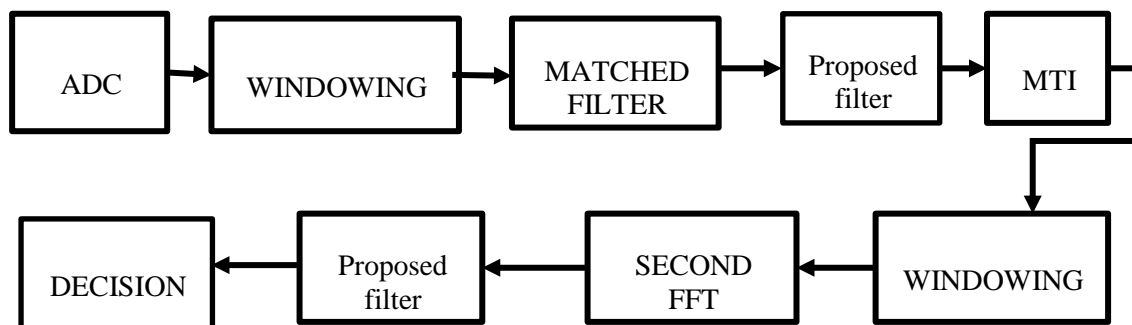


Figure 4. Block diagram of using the proposed filter in FMCW radar

Figure (4) represents the block diagram of the proposed signal processing with addition of the proposed filter after range FFT and doppler FFT. The function of the proposed filter is the same idea of the window. Window function in time domain is a multiplication between the input signal of FFT and a window function with length equal to the signal length. This multiplication is achieved by convolution in frequency domain. The proposed filter coefficients are chosen by more trials, to get the optimum solution of the worst case which occurs when target frequency shift lies in the middle of two pins. By more trials the coefficients (1, -0.5) is the optimum to solve the problem. The realization of this filter is shown in figure (5).

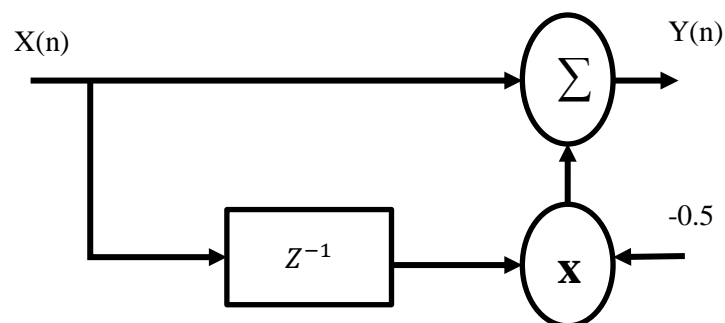


Figure 5. The proposed filter block diagram.

The difference equation of the proposed filter can be written as.

$$Y(n) = X(n) - 0.5X(n-1) \quad (4)$$

Where $x(n)$ represents the output of FFT, $Y(n)$ represents the output after the proposed filter. Equation (5) in z-domain is written as.

$$Y(Z) = X(Z)(1 - 0.5Z^{-1}) \quad (5)$$

Consequently, the transfer function, $H(Z)$, is written as.

$$H(Z) = 1 - 0.5Z^{-1} \quad (6)$$

The impulse and frequency response for the proposed filter are shown in figure(6-a), (6-b) respectively.

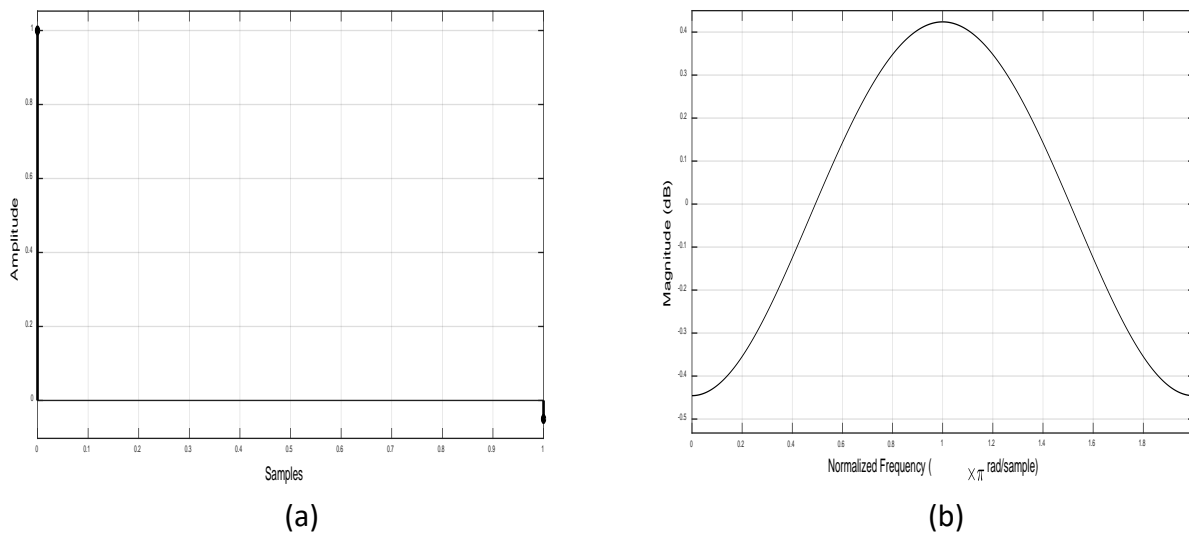


Figure 6. (a) Impulse response of the proposed filter. (b) Frequency response of the proposed filter

To explain the effect of this filter, assuming a target located in Doppler pin =4.5, then after using hamming window the output of FFT is shown in figure (7). This figure shows that two false targets located in two pins (4) and (5). This problem is solved by using the proposed filter and the output is shown in figure (8). The target is located in only one pin.

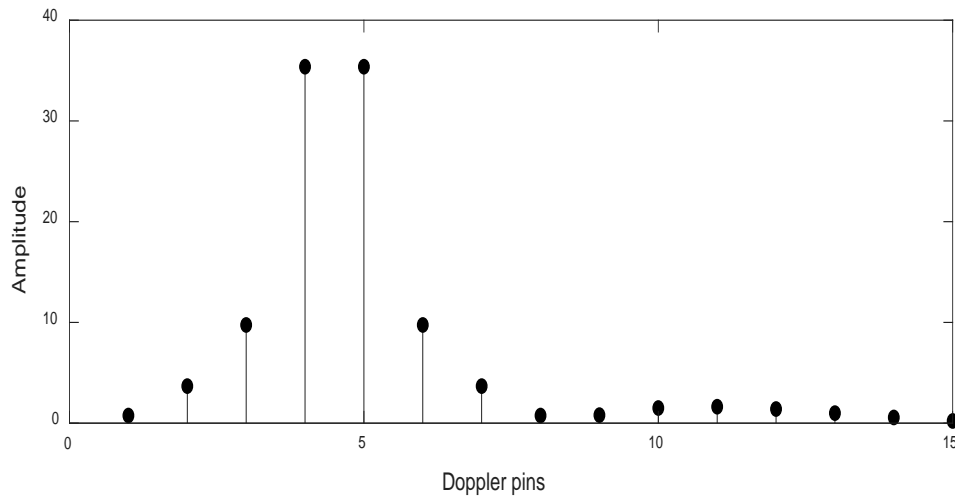


Figure 7. The output of FFT before applying the proposed filter

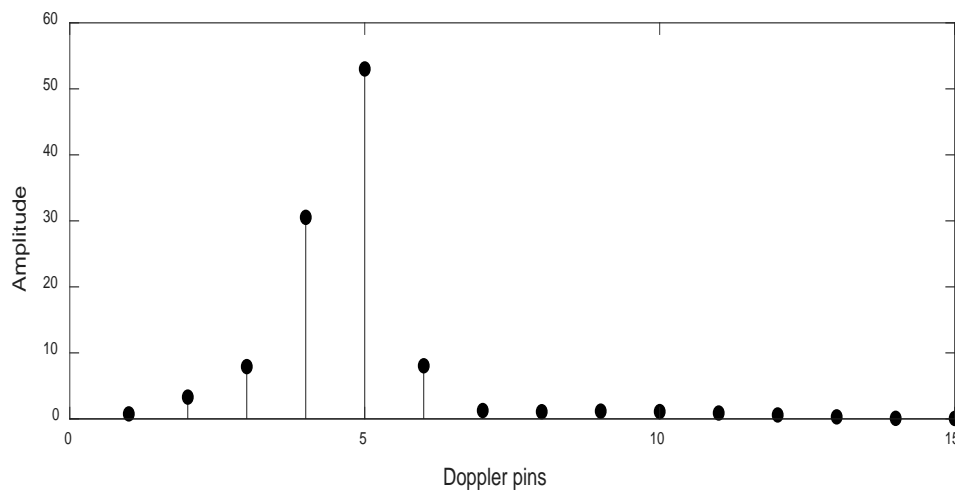


Figure 8. FFT output after using the proposed filter

4. Computer Analysis

The simulation parameters which are used to evaluate the performance of the proposed filter in LFM CW radar are shown in table (1). These simulations are achieved for the case of applying the proposed filter only after second FFT.

Table 1. The simulation parameters

Specification	Symbol	Value
Center frequency (GHz)	fc	24
Bandwidth (MHz)	B	20
Number of transmitting antenna	-	1
Number of receiving antenna	-	1
Modulation period (us)	T	80
Range FFT	N	1024
Waveform generation		sawtooth
Doppler FFT	M	32

The simulation is carried out in different cases. The first case is off-pin moving target, the second case is two off-pin closed targets and the third case is one in-pin and one off-pin targets. Figures (9) through (11) show the comparison between the performance of the traditional LFMCW radar and the proposed one for the tested cases.

4.1. First case

In this case, one off-pin moving target that located in Doppler pin=5.5 is assumed. It is clear from figure (9) that after using the proposed filter, the target peak is located in only one Doppler pin which improve the detection and reduce the false alarm rate.

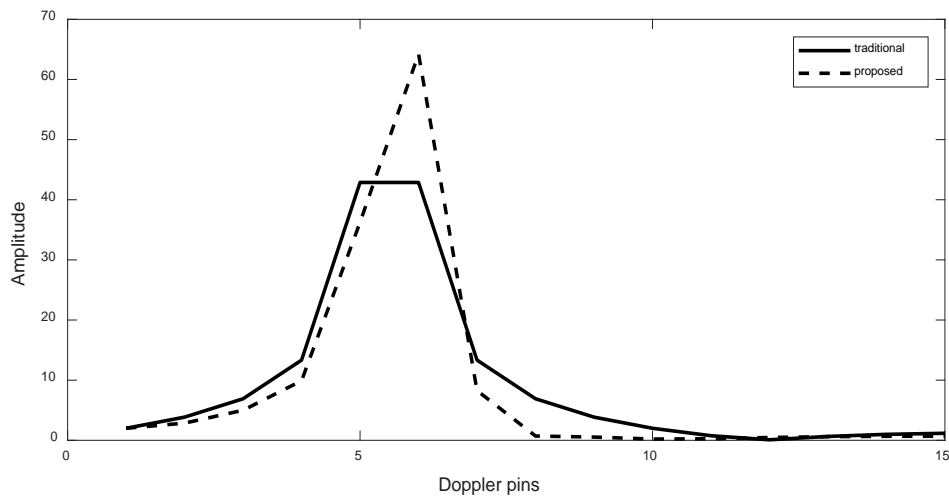


Figure 9. The output of the second FFT for traditional LFMCW radar and the proposed one for first case

4.2. Second case

In this case, two off-pin moving closed target are present in figure (10). The assumed targets are located in Doppler pin =4.5, and Doppler pin =5.25. It is clear from figure (10) that the resolution in Doppler is enhanced when using the proposed filter.

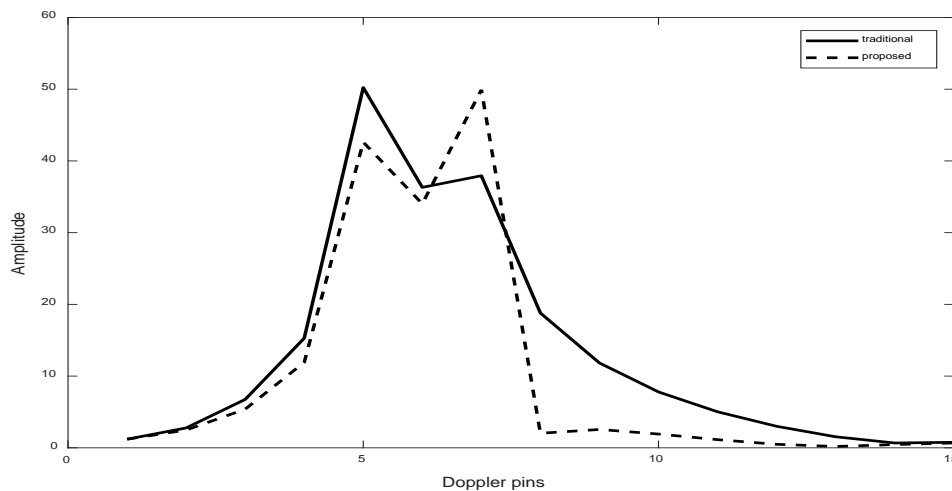


Figure 10. The output of the second FFT for traditional LFM CW radar and the proposed one for second case

4.3. Third case

In this case, one in-pin moving target located in Doppler pin =4.5 and one off-pin moving target located in Doppler pin=10 are assumed. The result of applying the proposed filter are shown in figure (11).

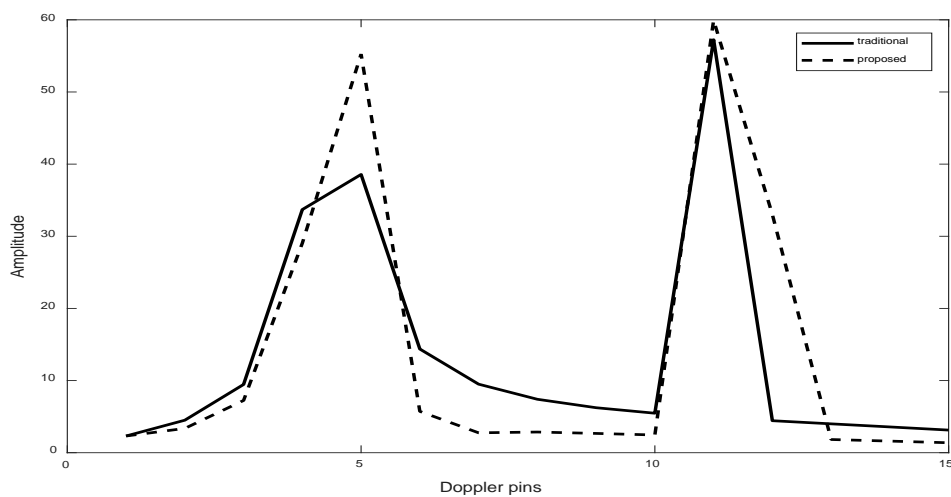


Figure 11. The output of the second FFT for traditional LFM CW radar and the proposed one for third case

It clear that after using the proposed filter, the off-pin target peak is located in only one Doppler pin and the in-pin target is increased in amplitude and degraded in resolution due to the increase in the width of main lobe.

The receiver operation characteristic curves for the complete system is shown in figure (12) with one off-pin moving target located in Doppler pin =3.5 and when applying the proposed filter in doppler domain only.

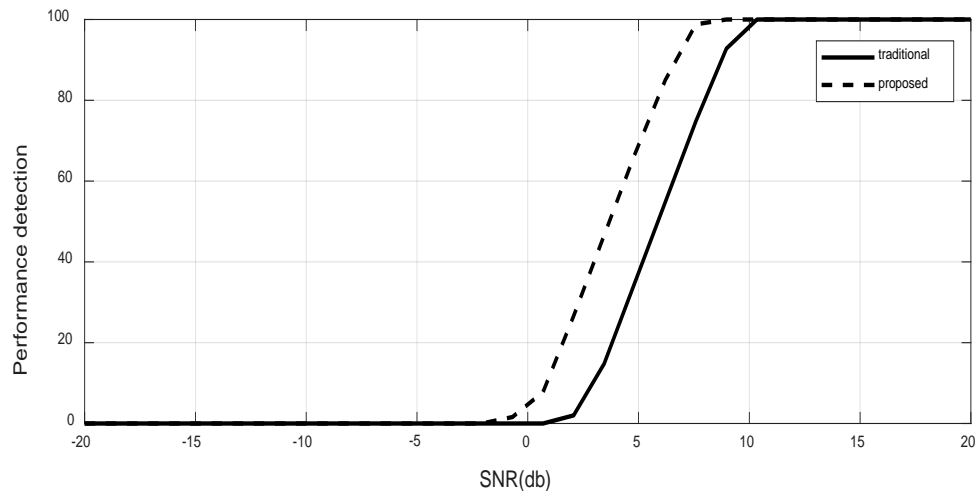


Figure 12. ROC curve for the proposed and traditional signal processing in case of off pin target in doppler domain only.

In figure (12), the detection performance of the proposed method is compared with traditional method at probability of false alarm = 10^{-5} . It is found that, the proposed method improves the detection of targets especially off pin targets. For example, the detection probability at SNR = 5dB, in traditional approach = 40%, and in the proposed method = 65%.

The ROC curve for the complete system is shown in figure (13), when applying the proposed filter after both the first and second FFT for one off-pin moving target which located in pin (4.5) in doppler and pin (251.5) in range.

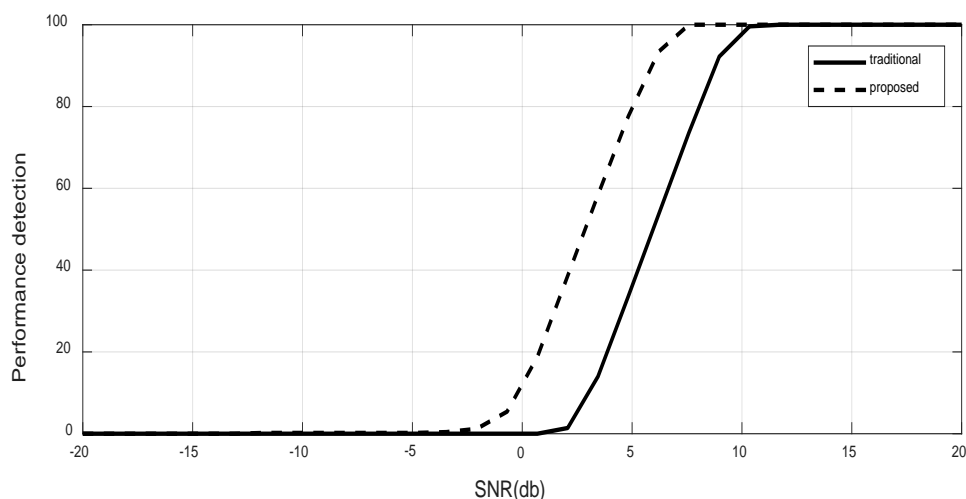


Figure 13. ROC curve for the proposed and traditional method with off-pin target in both (range and doppler)

In this case, the detection performance of the proposed method is improved when applying the proposed filter in range and Doppler compared to the traditional method. The proposed method improves the detection of off-pin targets. For example, the detection probability at SNR = 5dB, in traditional approach = 40%, and in the proposed method = 80%.

5. Conclusion

In this paper, a proposed filter that improve the detection performance of LFM CW radar for off-pin targets has been introduced without increasing the hardware complexity. The proposed filter can be used after the first FFT (in range) or after the second FFT (in Doppler) or in both domains. The detection increases by (25%) due to using the proposed filter in either range or doppler while it increases by (40%) due to using it in both range and doppler domains simultaneously.

6. REFERENCES

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