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A Proposed FrFT Based MTD SAR Processor

M. Fathy Tawfik, A. S. Amein,Fathy M. Abdel Kader, S. A. Elgamel, and K.Hussein
Military Technical College,
Cairo, Egypt

***Abstract* - Existing Synthetic Aperture Radar (SAR) Moving Target Detection (MTD) schemes suffer from calculation and hardware complexity. Traditional MTD used in Linear Frequency Modulation Pulse Compression (LFMPC) radars is characterized by its simplicity, compared to SAR MTD processors, and a remarkable performance in detection and parameters estimation of slowly moving targets.**

In the present work, a suggested MTD SAR processor is proposed. The proposed SAR MTD processor is based on using Fractional Fourier Transform (FrFT)in conjunction with the traditional MTD. FrFT concentrates the energy of the desired chirp signal permitting a good separation between it and the chirp like noise.

The suggested combination achieves chirp like noise reduction, compared to traditional MTD and less hardware complexity, compared to existing SAR MTD processors.

The Receiver Operating Characteristics (ROC), as a performance measure, is used to validate the superiority of the proposed MTD SAR processor over the traditional MTD, especially in the presence of chirp like noise

Keywords: SAR, MTD, and FrFT.

1. INTRODUCTION

The Ground Moving Target Detection (GMTD) in SAR is very important in many SAR applications. Different Ground Moving Target Indication (GMTI)techniques are used in SAR systems. Examples of these techniques are SAR Along Track Interferometry (SAR-ATI), Displaced Phase Center Antenna (DPCA), and Space Time Adaptive Processing(STAP) [1]. To achieve moving target parameters estimation, a combination between two or more GMTI technique is required [2, 3]. This leads to more calculation complexity, dependence on hardware (using two or more antennas), and using more than one technique at the same time to achieve the required performance.

Modern LFMPC radars achieve moving target detection and parameter estimation with a noticed performance using traditional MTD schemes.

When compared with existing MTD SAR processors, from complexitypoint of view, traditional MTD processors can be implemented with less resource and less calculation complexity.

Applying traditional MTD processors in SAR systems is challenged by chirp like noise and moving platform errors. The problem of moving platform errors can be solved with the aid of SAR motion sensors and by applying different autofocusing techniques.

The problem of chirp like noise can be analyzed and solved based on FrFT tool. FrFT concentrates the energy of the desired chirp signal permitting a good separation between the desired chirp signal and the chirp like noise.

In the present work, a suggested MTD SAR processor is proposed. The proposed SAR MTD processor is based on using FrFT in conjunction with the traditional MTD toachieve chirp like noise reduction with less hardware complexity.

The rest of this paper is organized as follows; after the introduction, chirp noise removal using FrFT is introduced in section 2. The proposed SAR MTD processor is presented in section 3.Performance evaluation of theproposed SAR MTD processoris presented in section 4.Finally, conclusion comes in section 5.

2. CHIRP NOISE REMOVAL USING FRFT

FrFT is one of the most important mathematical tools used in physical optics, linear system theory, signal processing, communications, quantum mechanics and else. One of the most important applications of the FrFT is chirp detection and chirp like noise removal.

The fractional Fourier transform of a general complex signal *x(t)* is[4-6]:

$$X_\theta(t_a) = \int_{-\infty}^{\infty} x(t) K_\theta(t, t_a)\, dt \tag{1}$$

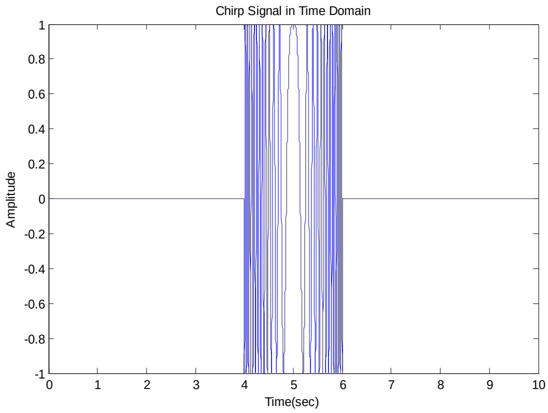
Where, the kernel, Kθ, is defined as:

$$K_\theta(t,t_a) = \begin{cases} \sqrt{\dfrac{1 - j\cot\theta}{2\pi}}\, e^{j\frac{t^2 + t_a^2}{2}\cot\theta - j t_a t \csc\theta} & \theta \text{ not multiple of } \pi \\ \delta(t - t_a) & \theta \text{ is multiple of } 2\pi \\ \delta(t + t_a) & \theta + \pi \text{ is muliple of } 2\pi \end{cases} \tag{2}$$

Where:
θ is the fractional rotation angle and
a is the fractional order.

To illustrate the superiority of FrFT in noise and chirp noise removal, three scenarios are introduced; the first scenario is an ideal chirp signal, the second scenario is a real chirp signal immersed in Additive White Gaussian Noise (AWGN), and the third one is a real chirp signal contaminated by both chirp like noise and AWGN.

Chirp signal is represented in time, frequency, and fractional domains as shown in Figure 1. The same chirp signal was contaminated in AWGN with Signal to Noise Ratio (SNR) = -3dB as shown in Figure 2.



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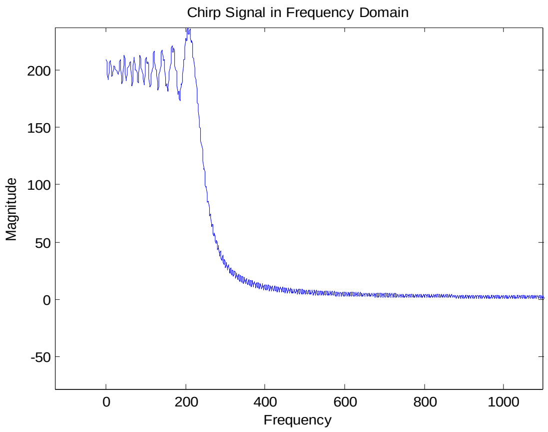

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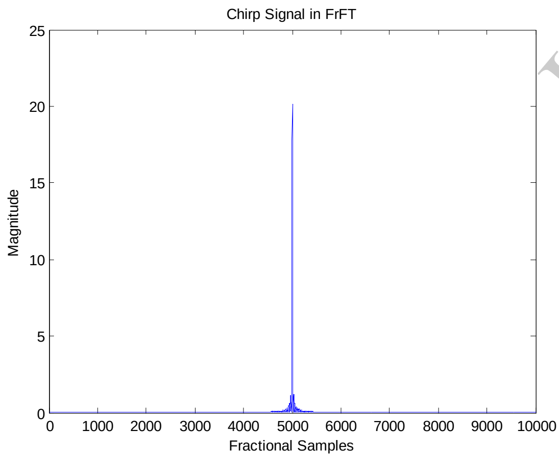

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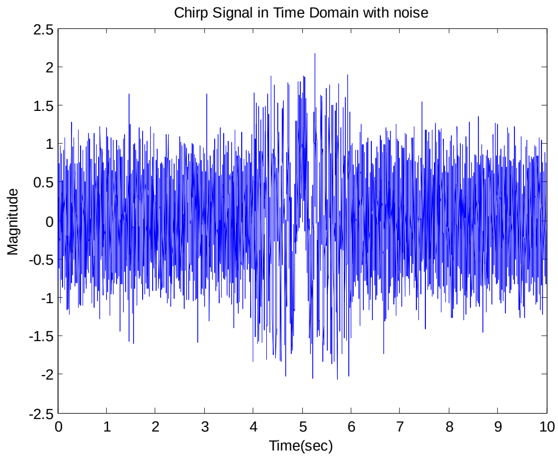
Figure 1Chirp signal without noise: (a) time domain, (b) frequency domain, and (c) fractional space.



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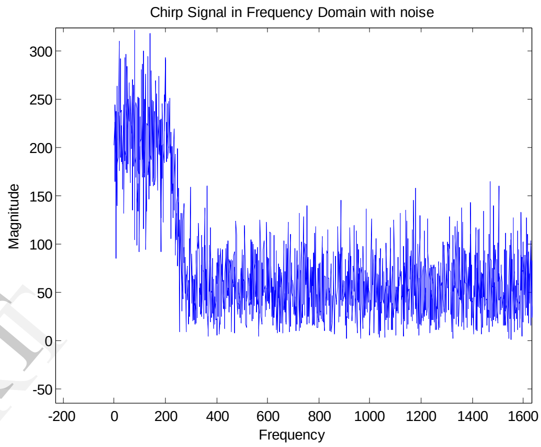

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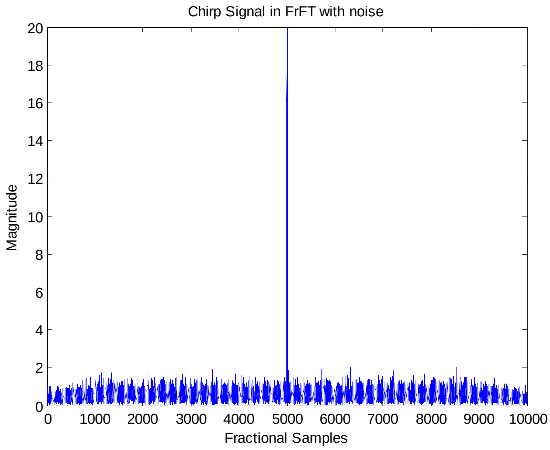
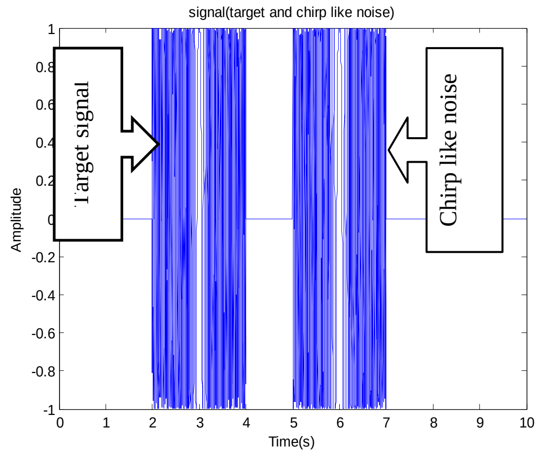


(c)

Figure 2Chirp signal with AWGN (SNR= -3dB); (a) Time domain, (b) frequency domain, and (c) fractional space.

From Figure 2, the chirp detection in Fractional space is better than time and frequency domains.However, to show the superiority of FrFT in chirp like noise removal, a chirp like noise was added to chirp signal with the same power in clear environment asshown in Figure 3.



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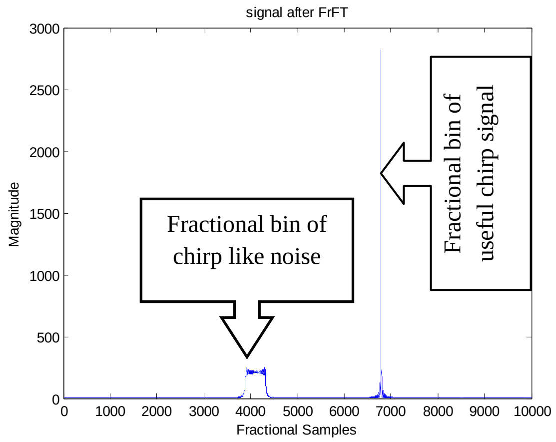
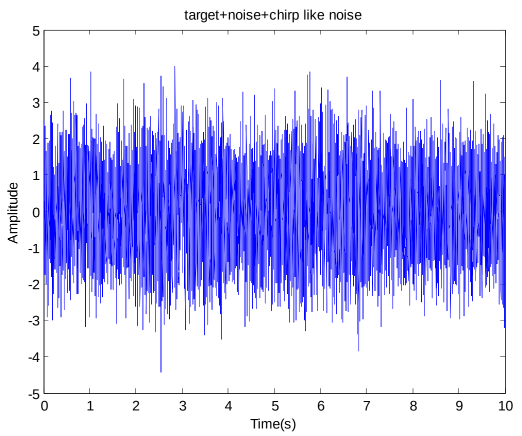


(b)

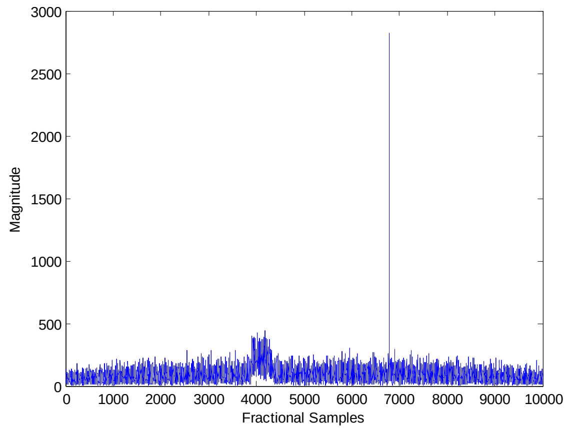
Figure 3 Chirp signal and chirp like noise without AWGN; (a) time domain and (b) fractional space.

Figure 4 shows the same signal presented in Figure 3 in addition of AWGN (SNR= -10dB).

From Figure 4 (b), extraction of chirp signal in fractional domain outweighs other domains.



(a)



(b)

Figure 4 Chirp signal and chirp like noise with AWGN (SNR= -3dB);(a) time domain and (b) fractional space.

The greater reduction of chirp like noise is very clear in this Figure compared to useful signal. This is due to the mismatch in the rotation angle between the designed FrFT and the chirp like noise.

Benefiting from the inherent structure of the FrFT for non-stationary digital signal processing and analysis, especially for chirped-type signals in detection and chirp like noise removal, a modified version of SAR MTD system based on FrFT is proposed in this paper.

3. The Proposed SAR MTD Processor

The block diagram of the proposed SAR MTD processor is shown in Figure 5. The proposed processor in general is the same as that of the traditional MTD with adding a block for FrFT processing at its input. The purpose of putting this block is to transform the received chirp signal into fractional space and converting it back into time domain after removing chirp like noise.

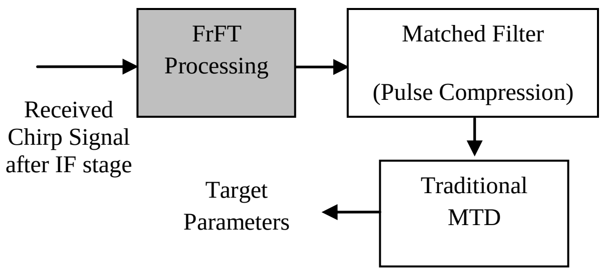
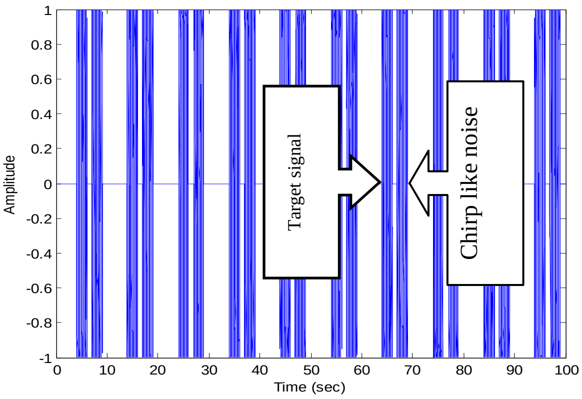


Figure 5 Block diagram of the proposed SAR MTD processor.

To describe the idea and operation of the proposed processor, a simulated received signal shown in Table 1.using Matlab packages after IF stage is generated. Simulated target parameters are chosen such that the simulated target is totally located in one range cell and one Doppler cell. Therefore,neither range nor Doppler straddle occurs. The simulated received signal of the moving target in clear and noisy environment is shown in Figure 6.

Table 1SimulatedRadar and Target Parameters

Radar Parameter	Value	Units
Pulse Width	2	s
Pulse Repetition Interval(PRI)	10	s
Number of pulses	10	
Start Frequency	100	Hz
Stop frequency	400	Hz
Start time for the pulse in the interval	4	s
Signal to noise ratio	-10	dB
Sampling frequency	1000	Hz
Doppler frequency for the moving target	0.5/ PRI	Hz



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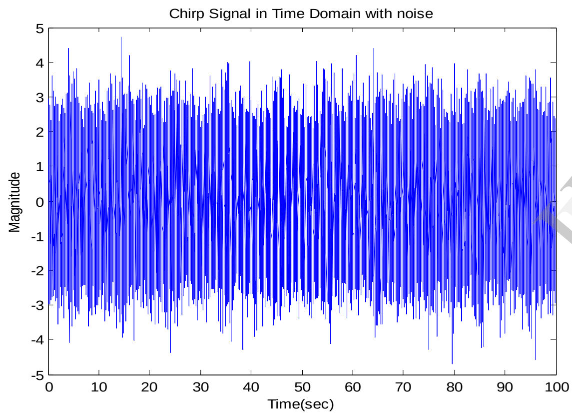


(b)

Figure 6 Simulated received signal of moving target in: (a) clear environment and (b) noisy environment.

3.1 FrFT Processing

The block diagram of this part is shown inFigure 7.

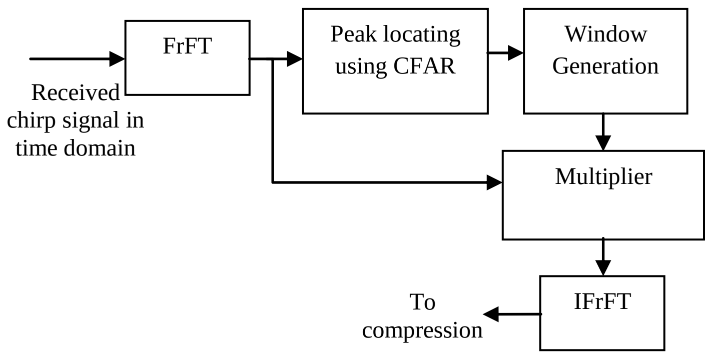
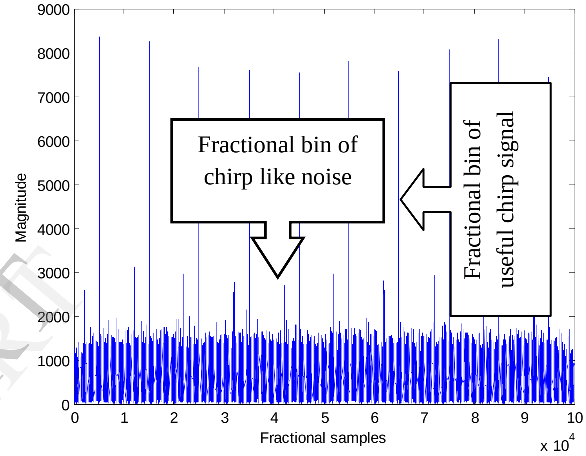


Figure 7 Block diagram of the Fractional Processor.

The core of the proposed SAR MTD processor is the FrFT. The received signal is transformed into fractional space as shown in Figure 8(a). The goal now is to detect the fractional domain peaks location and avoids the AWGN and the chirp like noise. To avoid this noise floora threshold should be set and applied to this signal. The most suitable way to achieve an adaptive threshold is the CFAR operation as shown in Figure 8 (b). After applying a suitable CFAR operation and determining target peaks locations,a suitable window is suggested around target peaks, shown in Figure 8 (d),the output after using the window is shown in Figure 8 (e), which satisfies a decent recovery of the chirp signal after applying the inverse FrFT(IFrFT). By doing so, a recovery of the original signal after reducing the noise and chirp like noise is achieved as shown in Figure 8 (f), which is ready now for matched filtering and traditional MTD operation.



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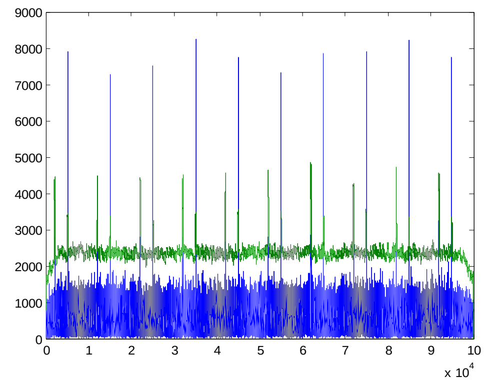

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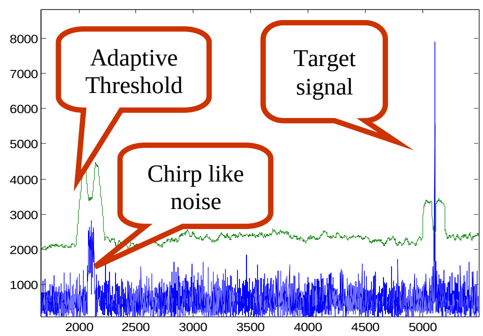

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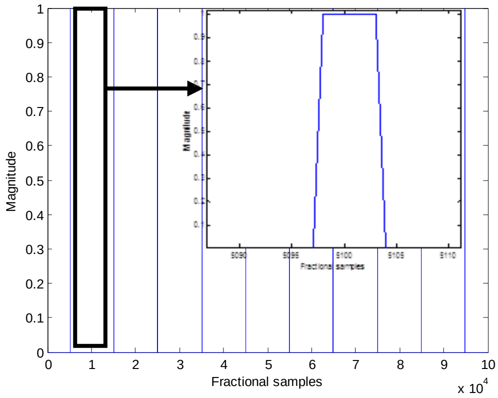

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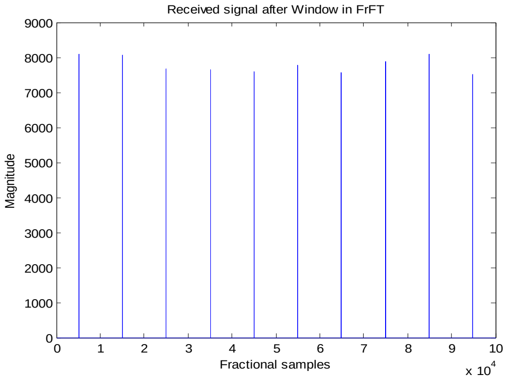

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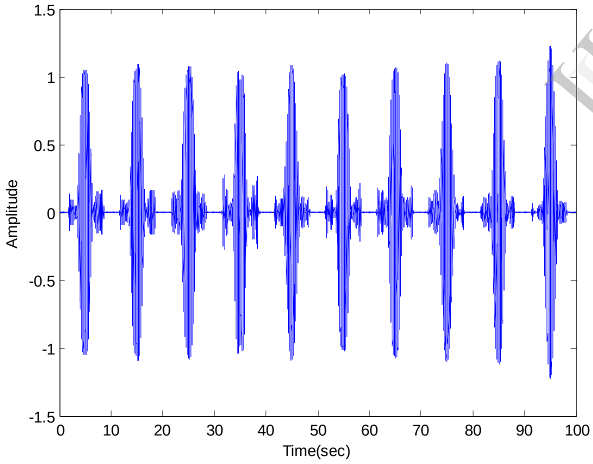


(f)

Figure 8 Signal flow through the FrFT processing stage**:**

(a) the received signal in FrFT space, (b) the received signal with the adaptive threshold, (c) one period of the received signal with adaptive threshold(d) the window used in FrFT processing, (e)the signal in FrFT processor after window, and (f) received signal after FrFT filter**.**

3.2 Matched filter and pulse compression

The block diagram of the matched filter of a chirp signal which is used for compression is shown in Figure 9. The result of applying this matched filter on the obtained signal after the FrFT processing block is shown in Figure 10.

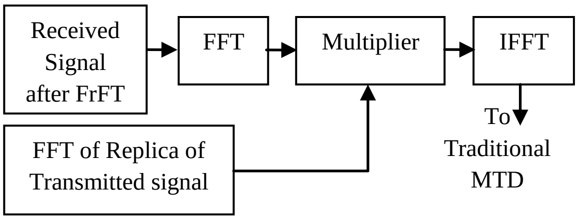
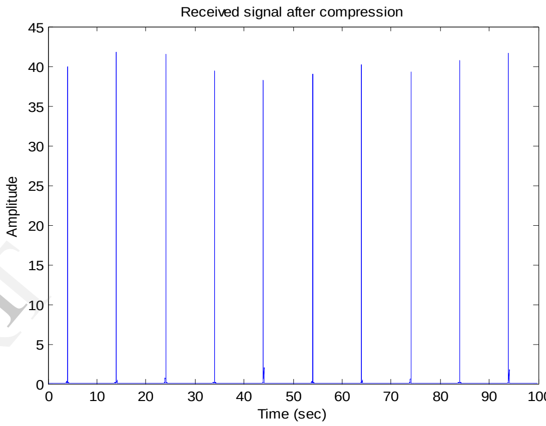
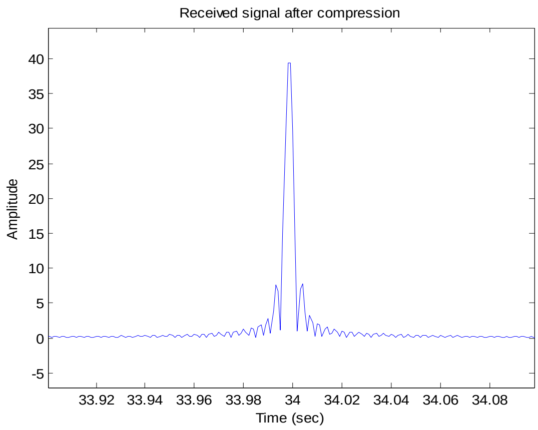


Figure 9 Block diagram of the Compression.

The absolute output of the compression stage is represented in Figure 10.



(a)



(b)

Figure 10 Absolute output of the matched filter stage;
(a) ten periods, (b) singleperiod**.**

It is clear from this Figure that useful target signal is detected in all PRIs. This output is modulated by the Doppler frequency and ready to be processed by the traditional MTD.

3.3 Traditional Moving Target Detection

The block diagram of the traditional MTD is shown in Figure 11[]. It processes the signal in two branches; time and frequency. In this paper the frequency branch is discussed.

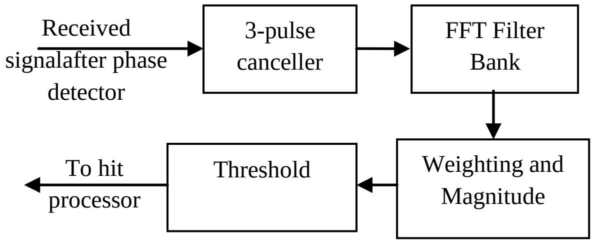
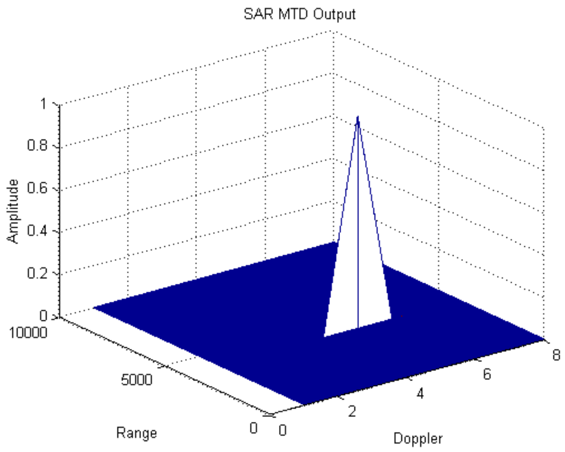


Figure 11Block diagram of the frequency processing of MTD.

MTD is an enhanced configuration of Moving Target Indication (MTI) that combines a series of features to improve clutter rejection and target detection. These features include Doppler filtering scheme, adaptive thresholding and fine ground clutter map. It has been shown that MTD meets the requirements of blind speed elimination and good sub-weather visibility while observing good probability of detection (P_d) and probability of false alarm (P_{fa}).The detection here takes place based on frequency domain. The peak of the Doppler filters bank output is detected after proper thresholding declaring the presence of target. The location of this peak declares the corresponding Doppler frequency.

In Figure 12, the output of the SAR MTD is presented; each signal peak means presence of a moving target, in our case only one moving target. The location of that peak on the Doppler axis declares the Doppler frequency, in our case half the pulse repetition frequency. The location of that peak on the Range axis declares the Range according to time of arrival.



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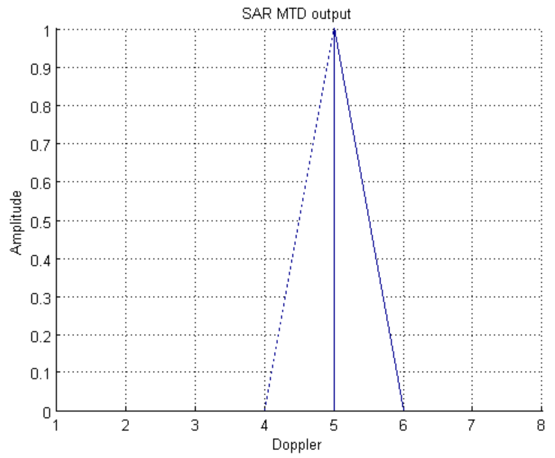

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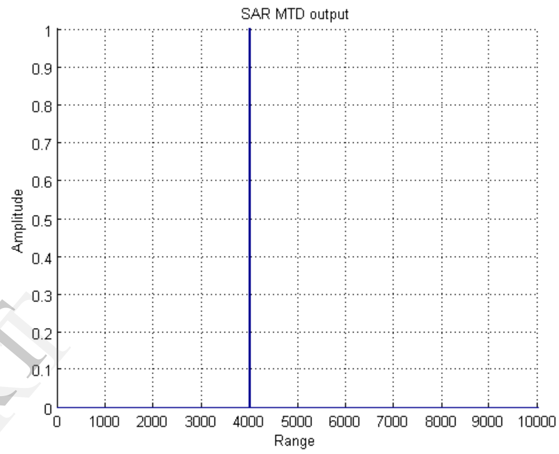


(c)

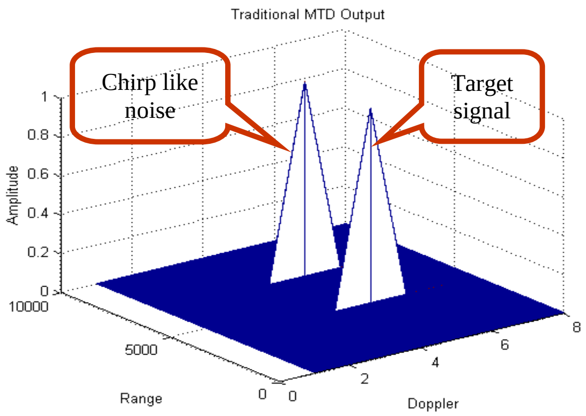
Figure12 Final output of the proposed SAR MTD processor:(a) range Doppler plane, (b) Doppler domain, and (c) range domain.

4. Performance Evaluation ofthe Proposed SAR MTD processor

The performance of the proposed SAR MTD processor is evaluated and compared to that of the traditional MTD from two pointsof view. The first one is the effect of chirp like noise. The second one is the detection performance.

4.1 Effect of chirp like noise

The output of the traditional MTand the proposed SAR MTD processor is presented in Figure 13 in case of chirp like noise existence. From thisFigure, the proposed SAR MTD processor was able to remove chirp like noise. On the contrary, the traditional MTD considered the chirp like noise as a moving target.



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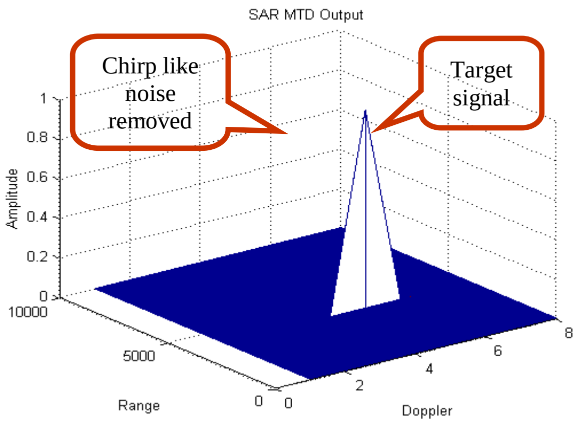
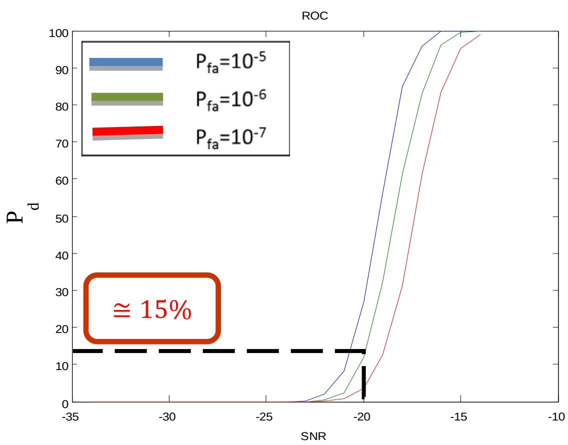


(b)

Figure 13 Final output of: (a) the traditional MTD processor, (b) the proposed SAR MTD processor.

4.2 Detection performance

ROC, as a performance measure, is used to validate the superiority of the proposed MTD SAR processor over the traditional MTD. As shown in Figure 14, the ROC of the traditional and the proposed MTD is presented. To show the difference in performance, a value of SNR= - 20 dB is selected at $P_{fa}=10^{-6}$.The corresponding P_d for the traditional MTD was found to be 15%, while the proposed SAR MTD was 70%.The obtained results from 4.1 and 4.2 validate the superiority of the proposed SAR MTD processor over the traditional MTD.



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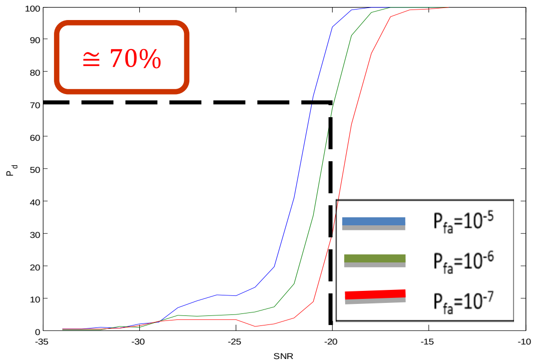

(b)

Figure 14 Comparison between traditional MTD and proposed SAR MTD, using P_d in ROC.

5. CONCLUSION:

In the present work, a suggested SAR MTD processor was proposed. The proposed SAR MTD processor is based on using FrFT in conjunction with the traditional MTD processor.

The proposed SAR MTD processor succeeded to remove the chirp like noise and achieve an extra 50% improvement in detection performance compared to the traditional MTD.

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