Parameter Extraction of FMCW Radar Signals using Wigner-Ville Distribution(WVD)

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***Abstract*– Modern radar systems employ low probability of intercept (LPI) signals to evade the interception by hostile electronic reconnaissance systems. One of the widely used LPI signals is the frequency modulated continuous wave (FMCW) signal, which is encountered in different radar applications. This is really a challenge to the electronic warfare (EW) because of the hardness of intercept these types of radars and signals. In this paper, we try to solve this problem so we adopt the Wigner-Ville distribution (WVD) to measure the parameters of FMCW signals. To this end, we investigate the performance of the WVD against simulated FMCW signals with different parameters and different operating conditions. Our analysis shows promising results and highlights two main challenges that may impede the use of WVD for intercepting FMCW signals. If these challenges are addressed and endowed with its simple required computation, the WVD can be a competitive candidate for FMCW signal analysis.**

I. INTRODUCTION

The radar systems use modulated waveforms and directive antennas to transmit electromagnetic energy into a specific volume in space to search targets. Targets within a special search volume will reflect back to the radar portion of this energy (radar returns or echoes) [1]. These echoes are processed by the radar receiver to extract target information such as range, velocity, angular position and other target characteristics.

Nowadays in modern warfare, most of the radar systems have been low probability of intercept to achieve the principle of "to see and not to be seen" [2].

A. LPI radars

A low probability of intercept radar is defined as radar that uses a special emitted waveform intended to prevent an intercept receiver from intercepting and detecting its emission. In other words, the main goal of LPI radars is not detected by the enemy. To achieve this objective [2], this system use power management, high bandwidth, frequency hopping, reducing antenna sidelobe levels and advanced scanning patterns. EW and RWR use two levels of LPI defined to reduce the probability of detection and identification in receivers:

•LPID radar is defined as radar that uses a special emitted waveform intended to prevent an intercept receiver from intercepting and detecting its emission but if intercepted, makes the identification of the emitted waveform modulation and its parameters difficult.

•LPI radar is defined as radar that uses a special emitted waveform intended to prevent an intercept receiver from intercepting and detecting its emission.

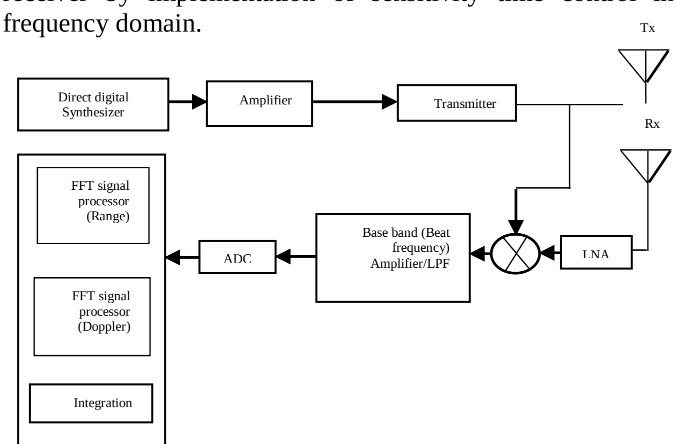
According to the two definitions above, an LPID radar is an LPI radar but an LPI radar is not necessarily an LPID radar although there are some references define LPID radar more comprehensive than LPI radar.

The available LPI radar techniques depending on reducing the radar's effective radiated power (ERP) by using some form of pulse compression technique. The objective is to spread the radar's signal over a wide bandwidth using frequency modulation, phase shift keying and frequency shift keying techniques.

B. Frequency Modulation Continuous Wave (FMCW) radars

One of the important issues in LPI radar is to choose suitable signals that can bring good performance for these systems. FMCW radar is kind of LPI family [3]. FMCW which is a frequency modulation, pulse compression technique used in most of LPI radars, resist interception by electronic support (ES) systems because of high time bandwidth product. The nature of this waveform provides practical advantages over other modulated continuous wave (CW) waveforms because the form of the return signal can be predicted. This technique provides:

• Radar jamming resistance.
• Finding range information by fast Fourier transform (FFT)
• Preventing saturation and controlling dynamic range in the receiver by implementation of sensitivity time control in frequency domain.



The most popular linear frequency modulation is triangular modulation. This consists of two linear frequency modulation sections with positive and negative slopes. By taking the sum and difference of the two beat frequencies target range and Doppler information can be measured unambiguously. This technique is the most used in LPI radars because of its simplicity and ease of implementation as it uses FFT

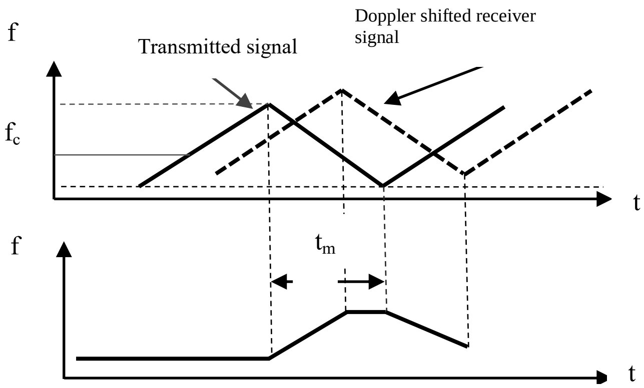


Figure 2.Generation of linear frequency modulation

The frequency of the transmitted signal for the first section is

$$f_1 = f_c - \frac{\Delta f}{2} + \frac{\Delta f}{t_m} t_d$$

Where f_c is the RF carrier, ΔF is the transmitted modulation bandwidth, t_d is the round-trip delay time and t_m is the modulation period .

II. WIGNER-VILLE DISTRIBUTION

WVD was used to solve the relation between the mass and the momentum of the electron, but using the duality between the Time-Frequency and Mass-Momentum we can easily use it to extract signal parameters [4].
Detection and analysis of FMCW waveforms in the presence of noise and multi-path time-frequency (T-F) analysis is an efficient tool to analyze these waveforms. By using this analysis, it is possible to see which frequencies exist at a given time instant.
In FMCW waveforms, the instantaneous frequency (IF) is modulated as a linear component with time, WVD satisfies marginal properties, gives the highest energy concentration in T-F plane and exhibits non-stationarities of the signal [4],[7].
We use WVD to extract FMCW signal parameters, to obtain the WVD at a given time, previous and present samples of the signals are multiplied, by Fourier transforms of these multiplications they are calculated and stacked in a WVD matrix.
The WVD of a signal x(t) is defined by the following equation:

$$W_x(t,f) = \int^{\infty} x\left(t+\frac{\tau}{2}\right) x^*\left(t-\frac{\tau}{2}\right) e^{-j2\pi f\tau}$$

Figure 1.Structure of FMCW radar system

Where t is the time variable and f is the frequency variable.

WVD is a 2-dimensional function describing the amplitude of the signal as a function of time and frequency. These types of T-F distributions give a higher probability of detecting the modulation parameters.
Discrete WVD is defined as:

$$W(l,w) = 2\sum_{-\infty}^{\infty} x(l+n)\, x^*(l-n) e^{-j2wn}$$

Given that $x(l)$ is a digital signal with l is discrete time index between [-∞, ∞]
Pseudo WVD (PWVD) is derived by windowing the signal samples and defined as:

$$W(l,w) = 2\sum_{-\infty}^{\infty} x(l+n)\, x^*(l-n) w(n) w(-n) e^{-j2wn}$$

Where $w(n)$ is a real valued window with length $2N$-1 and $w(0)$ =1
Frequency resolution is equal to $\Delta t_W = 1/f_s$.

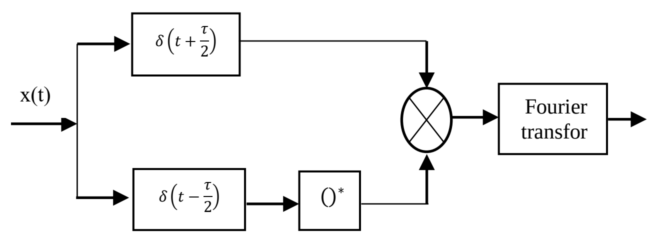


Figure 3. Block diagram of WVD method

III. SIMULATION

To illustrate the parameter extraction algorithm proposed in this study (WVD),For FMCW chirp signal: $x(t) = e^{(j2\pi kt^2)}$,we simulate WVD method and obtain output results for two different cases.
The first case is one signal with characteristics of $\Delta f =$ 500Hz, period t_m =1ms and center frequency f_c =1kHz and we show the results in 3 different conditions.
(1) We obtain the result of simulation without noise as shown in figure 4, We detect the signal without losses in signal and the signal occupied all the range of time.

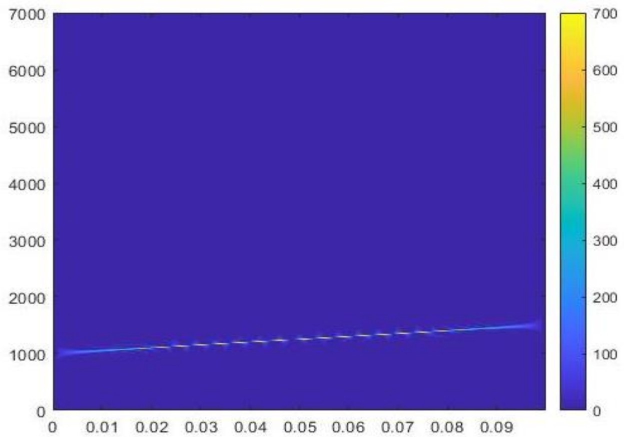


Figure 4. Output of WVD method (T-F) without noise

(2) We obtain the result of simulation with the same characteristics of the signal but we apply noise and study it at different SNR values. As SNR value decreased the noise considered to be part of the signal and we can't detect it, and we apply threshold (μ=20) to decrease the effect of noise.

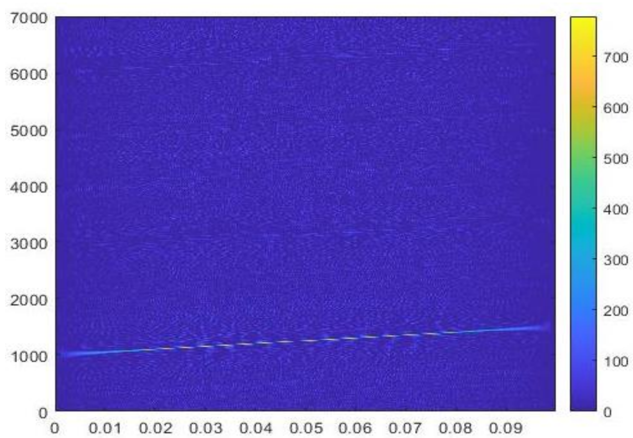


Figure 5. Output of WVD method with SNR 0dB

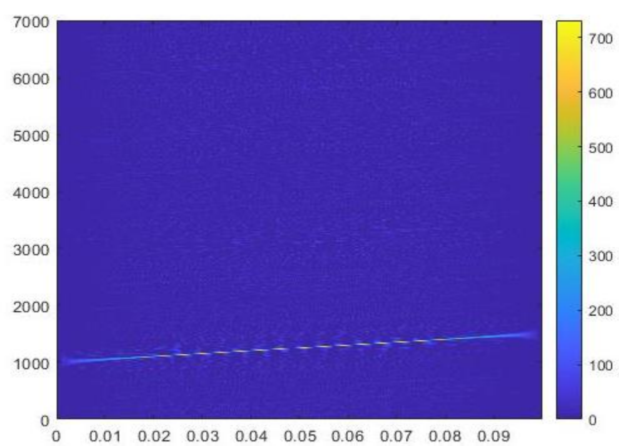


Figure 6. Output of WVD method with SNR 5dB

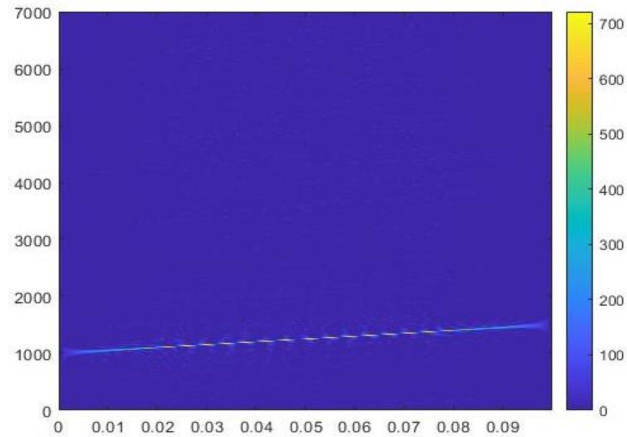


Figure 7. Output of WVD method with SNR 10dB

As shown in figures 5,6 and 7they illustrate the effect of changing in SNR values and the same threshold (μ).

(3) We obtain the result of simulation with the same characteristics of the signal and the same SNR (SNR =10) but at different thresholds. We raise μ trying to remove the effect of noise but we face a problem of losses in signal. These losses represented in frequency and time, the signal doesn't occupy all the range of time with percentage of error in figure 8 equals 1% approximately and in figure 9 equals 2% approximately.

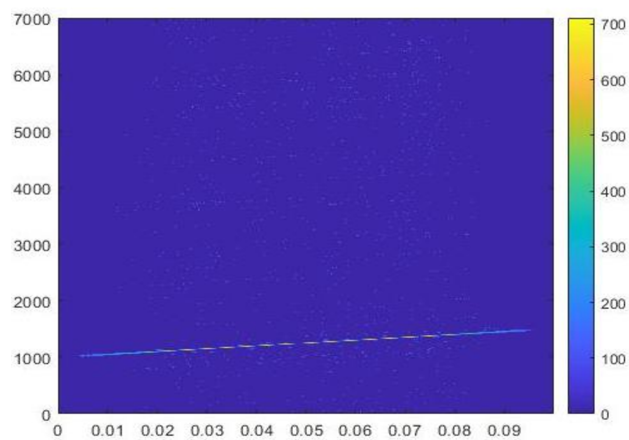


Figure 8. Output of WVD method at μ =100

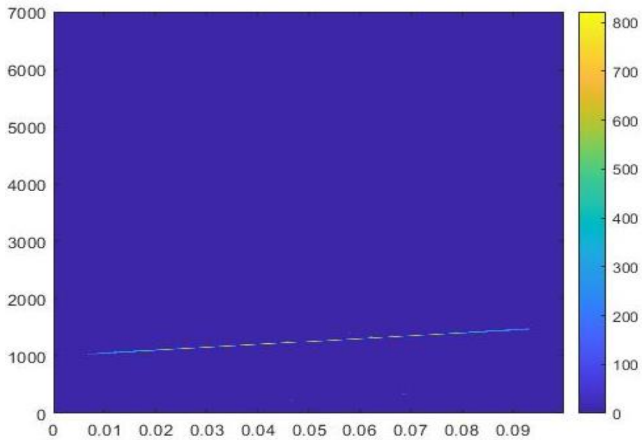


Figure 9. Output of WVD method at μ =170

Raising μ shows the capability of almost removing the noise but with losses in signal with similar percentages of error as in the two figures 8 and 9.

The second case is two signals, one with characteristics of $\Delta f = 500$Hz, period t_m =1ms and center frequency f_c =1kHz and the other with characteristics of $\Delta f = 800$Hz, period t_m =1ms and center frequency f_c =2kHz and we obtain the results in two different conditions.

(1) We obtain the result of simulation without noise as shown in figure 10.

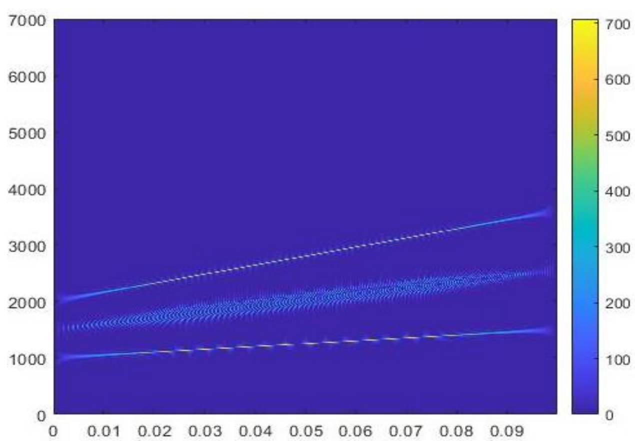


Figure 10. Output of WVD method of 2 signals without noise

The main problem in detecting two signals is the cross-terms between the two signals.

(2) We obtain the result of simulation at the same characteristics of the two signal and the same signal to noise ratio (SNR=10) but at different μ.

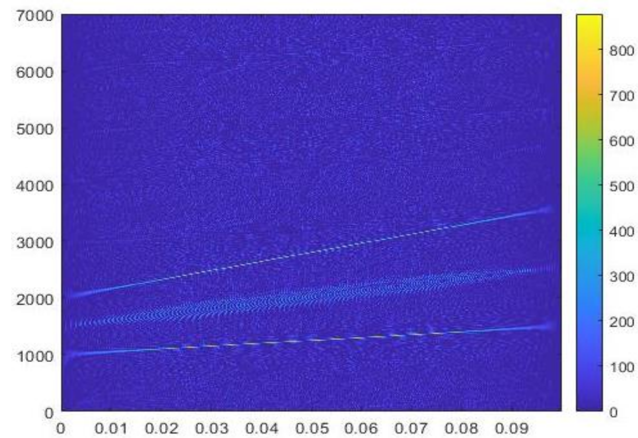


***Figure 11**. Output of WVD method of 2 signals at μ =20*

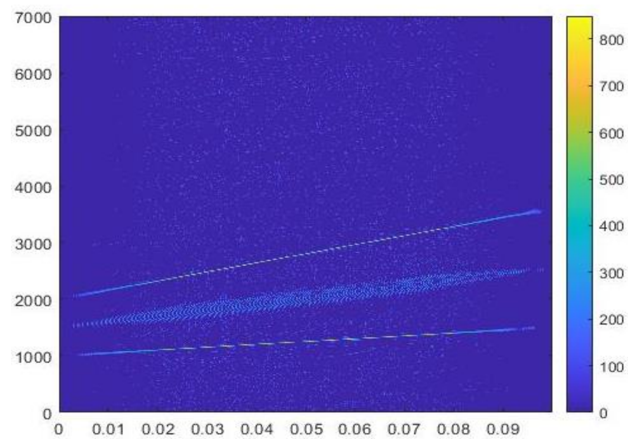


Figure 12. Output of WVD method of 2 signals at μ =100

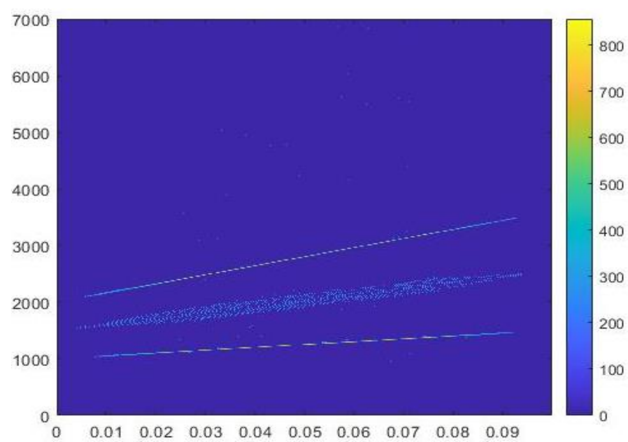


Figure 13. Output of WVD method of 2 signals at μ =200

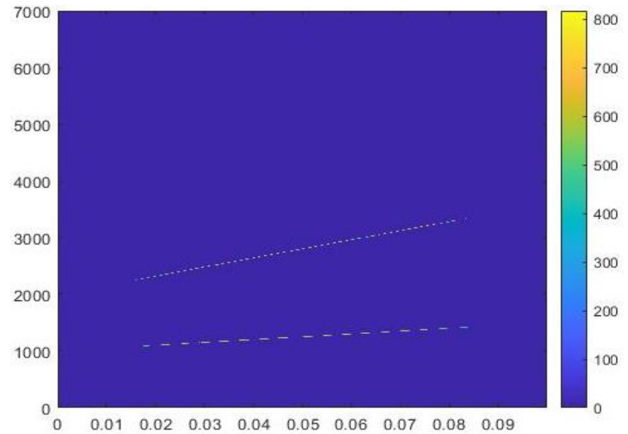


Figure 14. Output of WVD method of 2 signals at μ=450

As shown in the previous 4 figures, as raising μ the effect of cross terms and noise decreased but with notable losses in the signal along time and frequency. At figure 14 we detect 2 clear signals without noise or cross-terms but with a percentage of error equals 3% approximately.

IV. Conclusion

The FMCW signal is one of the most commonly used signals in LPI radars. Because of the many advantages of FMCW radars, the most of valid companies design FMCW radars for military and commercial applications. WVD method is used for detection and estimation of LPI signals. It can be used correctly for detection FMCW signals as SNR increased. But when the noise level increases this technique can't correctly estimate the parameters of the signal. WVD method can't correctly estimate the parameters of two detected signals because of the cross-terms.

References

[1] Merrill .Skolink, "**Introduction to Radar Systems**," McGraw-Hill Education, 2003.

[2] A. Denk, "**DETECTION AND JAMMING LOW PROBABILITY OF INTERCEPT (LPI) RADARS**," THESIS , MONTEREY, CALIFORNIA , 2006.

[3] Y. L. W. H. a. T. L. Jau-Jr Lin, "**Design of an FMCW radar baseband signal processing system for automotive application**," 2016.

[4] S. M. Hosseini, "**Interception FMCW radar using Wigner-Ville-Distribution(WVD)**," Shiraz,Iran, 2013.

[5] D. B. Copeland, "**DETECTION AND ANALYSIS OF FMCW AND P-4 POLYPHASE LPI WAVEFORMS USING QUADRATURE MIRROR FILTER TREES**," Monterey, CA, 2009.

[6] J. Antonio F. Lima, "**ANALYSIS OF LOW PROBABILITY OF INTERCEPT (LPI) RADAR SIGNALS USING CYCLOSTATIONARY PROCESSING**," Phillip E. Pace , Monterey, California , 2002.

[7] T.O.Gulum, "**A Parameter Extraction Technique for FMCW Radar Signals using Wigner-Hough-Radon Transform**," Istanbul,Turkey, 2012.