Simulation and Performance Prediction of an UWB Radar for Active Protection System Applications

Vivek.R, S.Piramasubramanian, M.Ganesh Madhan and J.Roopchand

***Abstract*—System modeling and simulation of an UWB Radar for Active Protection System Applications is reported. Multi band OFDM type UWB system operating at 10 GHz is considered for the study. The system comprises of a MBOFDM transceiver, Phased array antenna and beam forming processor. Numerical simulation is carried out in MATLAB tool, to evaluate the received signals, position, and velocity of the targets. The performance of the Radar for RPG type projectile detection is evaluated by comparing the actual and estimated target parameters.**

***Index Terms*—Ultra Wide Band Radar, MB OFDM, Active Protection System, Radar Cross-section, Rocket Propelled Grenade.**

I. INTRODUCTION

ACTIVE Protection System (APS) is a close range active defense system mounted on an armored vehicle, required to destroy the target projectile physically by launching counter ammunition. This system is intended to counter all types Anti Tank Missiles and Rocket Propelled Grenades (RPGs). Radar designs include continuous wave (CW) radar and Pulse-Doppler radar [1]. Conventionally, narrow band pulse-doppler type radar is used in APS. However, this type of Radar suffers from ambiguities in range and Doppler measurements and they can also be jammed easily by narrowband interference signals. This reduces the probability of countering the threat missiles. To overcome these limitations, Ultra-wide Band (UWB) Pulse-doppler radar system has been investigated. Ultra-wideband is a radio communication characterized by a very low energy level for short-range and high-bandwidth communications [2]. UWB has traditional applications in non-cooperative radar imaging. The low power spectral density limits the interference potential with conventional radio systems, and the high bandwidth facilitates very high precision for detection and tracking without ambiguities. The transmitted power is also very less which makes it suitable for

R.Vivek, M.Ganesh Madhan and S.Piramasubramanian are with the Madras Institute of Technology campus of Anna University, Chennai, 600 044, India. (email;r.vivekroopchand@gmail.com,mganesh@annauniv.edu,spsnanthan@gmail.com)

J.Roopchand, is now with the Combat Vehicles Research Establishment, CVRDE, DRDO, Avadi, Chennai 600 054 (email.roopchand.j@cvrde.drdo.in)

APS used in mobile vehicle platforms. Conventionally, UWB radars were based on generation and reception of ultra-short pulses, e.g., Gaussian pulses. This approach does, indeed, provide high-range resolution if pulse duration is small enough. However, it also has certain disadvantages, such as low spectral efficiency and ease of signal repeatability (once the signal has been intercepted by an adversary), which can make these imaging systems susceptible to certain types of electronic counter-measures (ECM). Alternatively, multicarrier radar systems (using OFDM), employing a collection of sinusoids at various center frequencies can be utilized. These independent carriers are advantageous in terms of pulse diversity and also in terms of exploiting frequency-dependent characteristics of the channel and signal returns [3,4].Due to recent advances in digital signal processing particularly in sampling technology it is becoming possible to extend multicarrier signal bandwidth to make them truly UWB waveforms. With these features, it is envisaged that, MBOFDM based UWB radar can be a potential candidate for APS applications. Earlier, UWB radar has been reported for detection of buried mines [5,6]. Sakkila et al [7] have evaluated obstacle detection using UWB radar. They have used UWB pulses for their analysis. Short range Radar based on UWB have also been investigated [8]. Modeling and simulation has become a prime tool for Radar development, as it provides performance prediction in the design phase. Further new techniques can be studied prior to practical implementation. It also provides an inexpensive approach to prove new designs. A system simulation of multifunction phased array radar was reported by Zhang Wei et al [9]. Simulation methods of prioritizing the tasks for a phased array radar was reported by Miranda et al [10]. Recently Matlab® and Simulink based system modeling has received widespread acceptance. Garmatyuk has developed a high resolution Radar system model with Matlab / Simulink for UWB synthetic aperture radar [11]. In the case of UWB radar, majority of the citation focus on ground penetrating application [6]. To our understanding, Multicarrier UWB systems for short range, high speed missile detection have not been investigated previously. In this paper, we model a MB OFDM type UWB based short range Radar and simulate to evaluate its performance for detection of Rocket Propelled Grenade (RPG) type anti tank missiles. The Radar cross section for a typical

978-1-5090-0396-9/16/$31.00 ©2016 IEEE

RPG missile is first estimated and subsequently other Radar parameters are determined at 10 GHz. The target detection is simulated and the performance is verified by comparing the actual values and the predicted target parameters. The entire simulation is carried out using MATLAB tool.

This paper is formed as follows Section II presents the Design Consideration, Section III and simulation results and they are discussed, finally the paper is concluded with Section IV.

II. Design Considerations

The important design parameters for the APS radar are missile RCS, Pulse characteristics and the beam steering. The details of these parameters are discussed in the subsequent sections.

A. RCS of Rocket Propelled Grenade

Rocket Propelled Grenade is one of the dangerous Anti Tank Projectile, which is used extensively in the combat. The penetrative power of the projectile exceeds the passive steel Armor system. The important dimensions of the RPG is shown in Fig. 1.

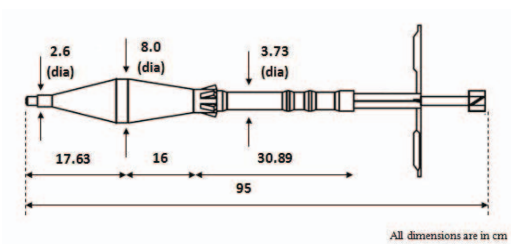


Fig. 1. Structure and dimensions of a typical RPG

The RPG missile was modeled as a perfect electrical conductor at its actual dimensions, using CST Microwave Studio, a 3D Electromagnetic simulation tool. The model is shown in Fig. 2.

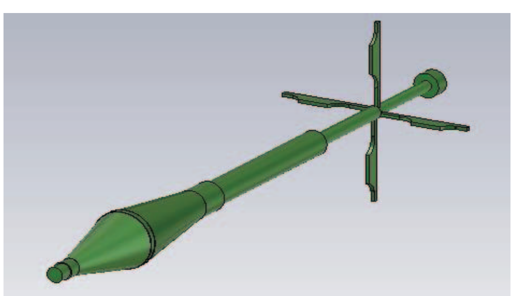


Fig. 2. CST microwave studio model of RPG

In this simulation, plane wave at 10 GHz frequency, is made to incident at the nose cone of the missile RPG −7. An azimuth scan is carried out and we observe a large value of RCS in the rear side compared to the front. The far field polar plot of the RCS is depicted in Fig.3. A RCS value of -11.3 dBm is found for the front (0 deg). This value is considered for the Radar, as these missiles are launched straight towards the armored vehicles.

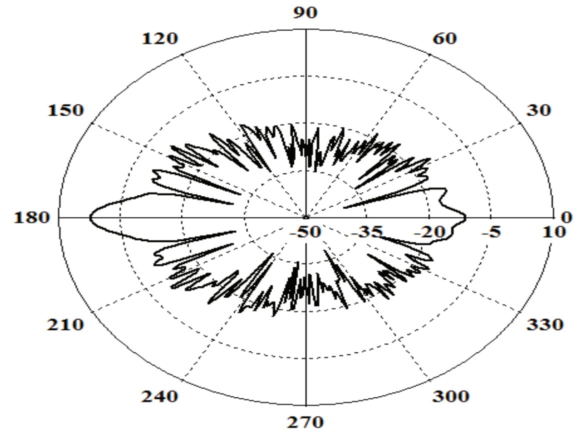


Fig. 3. Polar plot of RCS

B. Radar parameters

As per the FCC regulation, the bandwidth of UWB surveillance radar is chosen as 2 GHz and a center frequency as 10 GHz. For deriving the various radar parameters, the specifications for the UWB radar are provided in TABLE I. Based on these requirements, the pulse repetition frequency and pulse width are arrived as 2 MHz and 0.5 ns respectively. The calculations are carried out using standard radar equations [1].Further, the peak and average transmit powers are evaluated as 6.5 dBm and -23 dBm.

TABLE I
UWB PULSE-DOPPLER RADAR SPECIFICATIONS

Parameters	Values
Minimum Range resolution	0.075 meters
Maximum unambiguous range	75 meters
Probability of Detection	0.9
Probability of False Alarm	10^{-6}

C. OFDM signal generation

The block diagram of OFDM signal generation is given in Fig. 4.

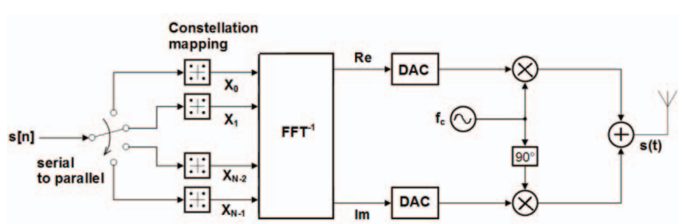


Fig. 4. OFDM signal generation [8]

The OFDM signal is simulated based on the block diagram shown in Fig. 4 in Matlab and the resulting signal is shown in Fig. 5. The data sequence is streamed into several sub-samples and each samples are modulated with a different sub- carriers and been summed up and then up-converted to a frequency level of 10 GHz and transmitted in free space.

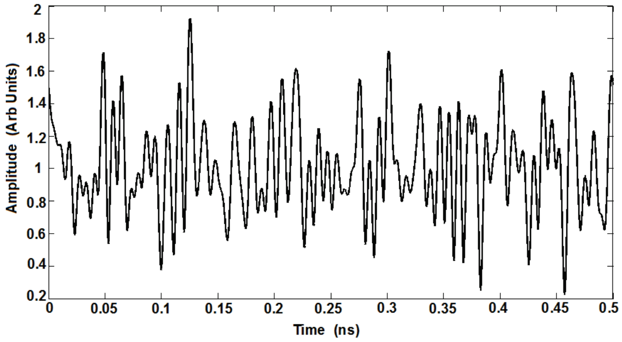


Fig. 5. Simulated OFDM signal at 10 GHz

This signal is transmitted during every ON time period of the Pulse-Doppler radar. The duration of the signal is equivalent to the reciprocal of BW. The ambiguity function of the UWB signal is computed and shown in Fig. 6.

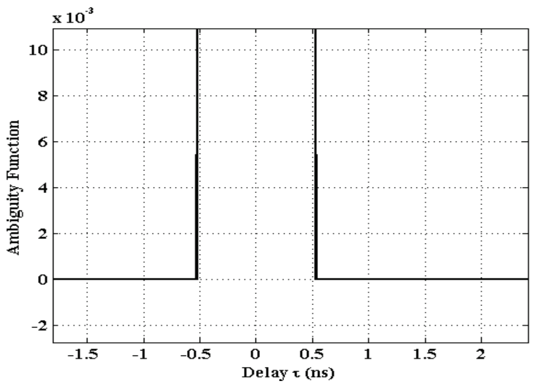


Fig. 6. Ambiguity function Zero Doppler cut.

From the plot, the ambiguity function shows a delay τ of 0.5 ns. The range resolution corresponding to the delay is given by$R = \frac{c\tau}{2}$, where c is the speed of light. This corresponds to a range resolution of 0.075m.

D. Phased array antenna

A 20 x 20 phased array is chosen for the radar in order to achieve small azimuth beam width of the effective radiation pattern. The spacing between adjacent elements along the row and the column of the array is chosen as λ /2. This value is chosen to ensure the main lobe maximum is along the desired direction and also to reduce the side lobe level of the radiation pattern. A planar array is chosen to facilitate scanning in both azimuth and elevation direction.

For a uniformly spaced array, Taylor tapering window is usually applied [12]. The effective radiation pattern of the phased array antenna for antenna spacing of λ /2 is shown Fig. 7, which illustrates low side band level and good directivity.

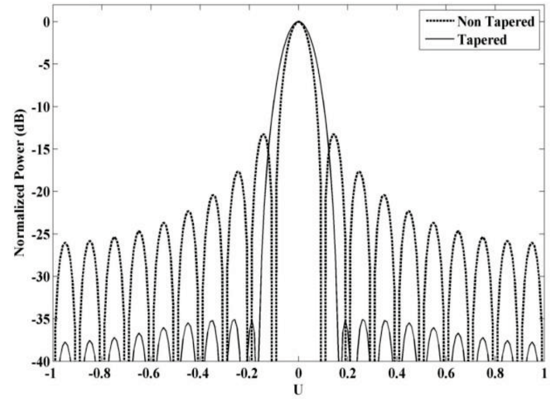


Fig. 7. Radiation pattern with array element spacing of λ /2

The radiation pattern of the phased array has to be steered in both azimuth and elevation direction, to cover a specified scan volume. The radar is designed to scan -45 degree to +45 degree in azimuth and -5 degree to +45 degree in elevation, with a scan step of 10 degrees and a revisit time of 0.225 milli seconds. Using the above values, the dwell time and hits per scan are computed as 0.005 milli seconds and 10 respectively. The phased array antenna continuously radiates pulsed UWB signal at various azimuth and elevation angles contained in the specified scan volume.

E. Radar Receiver

The block diagram of a typical Radar receiver subsystem is shown in Fig. 8.

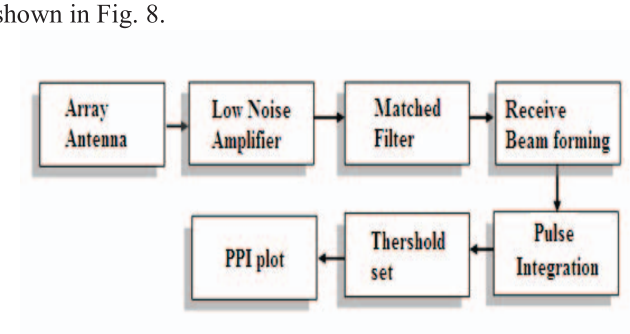


Fig. 8. Radar Receiver Functional Blocks [8]

In this design, a low noise amplifier of gain 50dB is chosen, to enhance the detection capability as the RCS of the target is very low. Matched filter is used to detect the existence of a target from the reflected (echo) signal followed by beam-forming. A sub-band phase shift beam-former which separates the signal into several sub-bands and applies narrowband phase shift beam-forming to the signal in each sub-band is considered in this work. The beam-formed signals in all the sub-bands are regrouped to form the output signal [12].

III. SIMULATION RESULTS

The Simulation flow for the UWB Pulse-Doppler Radar system is given in Fig. 9.

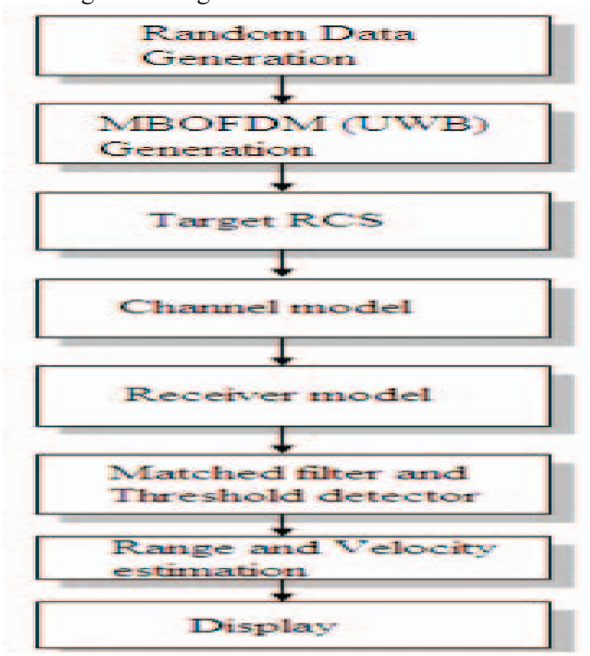
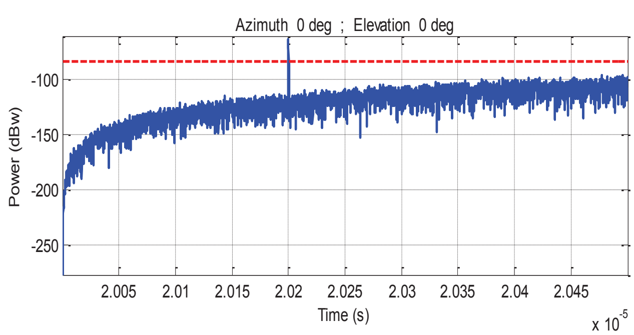


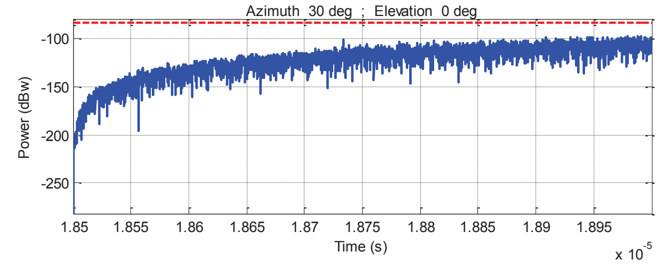
Fig. 9. Simulation Flow

The random data generation is followed by 4 PSK modulation and an IFFT operation provides the MBOFDM signal, which is up converted to 10 GHz. The generated UWB waveform is shown in Fig.6. This waveform is transmitted in the form of pulses in to the area of scan. The radar system simulation is a complex task were each samples in the radar data cube represents a pulse. Each reflected pulse carries the information about the Doppler and range information of the targets are needed for the radar system to detect the targets. The range of the target is determined from the matched filter output which is sampled for each pulse. The velocity of the target is determined by applying periodogram for each of the matched filter output.

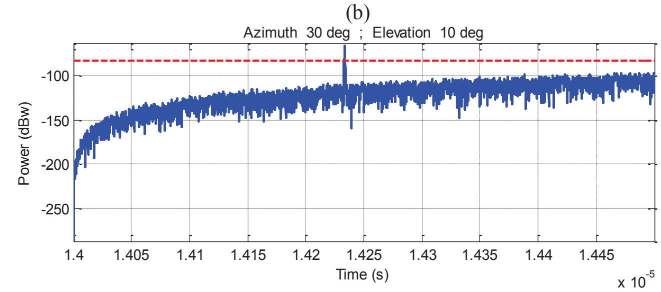
Non-coherent integration is employed since it is simple to construct and cost effective. The number of hits per scan determines the number of pulses to be integrated. The hits per scan is computed as 10 and the same number of pulses are integrated. The matched filter result after integration of 10 pulses, for different scan angles is depicted in Fig. 10.



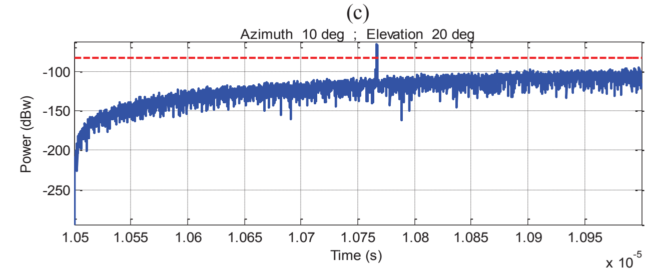
(a)



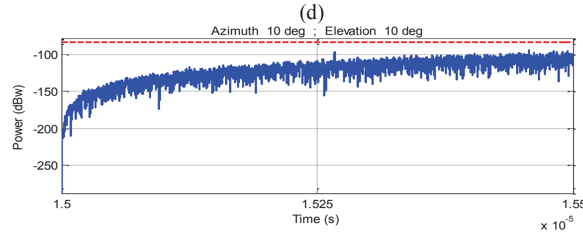
(b)



(c)



(d)



(e)

Fig.10. Response of Pulse Integrator for echo signal at various azimuth and elevation angles. Fig. (a), (c) and (d) Indicate the presence of target, while Fig. (b) and (e) Indicate absence of target at those angles.

For the chosen values of probability of detection and probability of false alarm rate, the value of minimum SNR for detection process, without pulse integration is 13dB. This SNR value reduces to 5 dB after integration of 10 pulses. This enhances the detection capability of the radar system to detect the low RCS threat missiles in a battlefield scenario.The threshold level is determined for the given P_{fa} value using Neyman-Pearson (NP) criterion and the computed threshold value is -85 dBW. All the signals exceeding the threshold level will be considered for calculating range and velocity measurements.

A. Range and Doppler estimation

A range gate is formulated in MATLAB and the range is estimated using the peak signal point in the integrated pulses. The Doppler frequency shift for the detected targets is estimated and the target velocity is determined from the Doppler shift values. Fig. 11 indicates the Doppler spectrum for moving target.

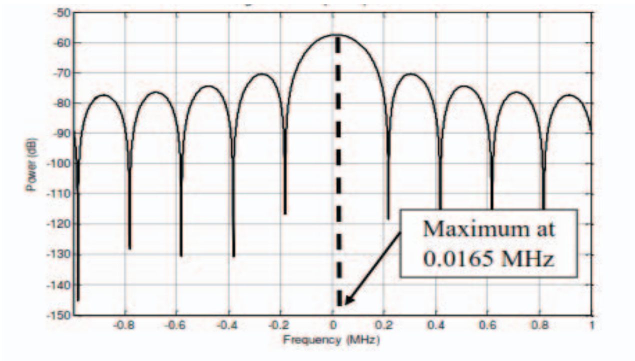


Fig. 11. Doppler spectrum of received signal for moving target.

The simulation is repeated for three targets at different ranges and velocities. Based on the Doppler spectrum of the received signals, the estimated values of range and velocity are determined for all the cases. The values are found to match with the true values and provided in Table II.

TABLE II
RANGE,VELOCITY AND DIRECTION OF ARRIVAL OF TARGETS

Parameters	True Value	Estimated Value
	Target 1	
Range	35 meters	34.95 meters
Velocity	50 m/s (stationary)	44 m/s
Direction (Az,El)	10,20 degrees	10,20 degrees
	Target 2	
Range	30 meters	29.91 meters
Velocity	290 m/s	286 m/s
Direction (Az,El)	30,10 degrees	30,10 degrees
	Target 3	
Range	40 meters	39.97 meters
Velocity	0 m/s	0 m/s
Direction (Az,El)	0,0 degrees	0,0 degrees

These values are plotted in a Radar Plan Position Indicator (PPI) scope in Matlab, as shown in Fig. 12.

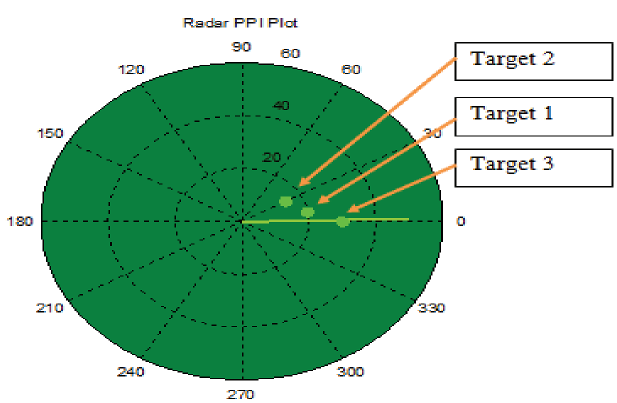


Fig. 12. Radar PPI scope displaying three detected targets

As the velocity of anti-tank threats is in the range of 70m/s to 300m/s, any target with velocity less than 70m/s is considered as a false target. Once a potential target is identified based on the above mentioned criterion, the direction of arrival (DOA) and range information is transferred to the tracking radar.

IV. Conclusion

A system modeling approach for the evaluation of MBOFDM based UWB radar is reported. The Radar operation at 10 GHz is simulated and received pulses are identified. The Radar parameters are determined for indentifying a RPG type missile, which finds application in Active protection systems for armored vehicles. The simulation indicates target identification with range and velocity details and found to match well with the actual data.

References

[1] M.I.Skolnik," Introduction to Radar systems",3rd Ed, Tata McGrawHill, 2001.
[2] J.H. Reed, Introduction to Ultra Wideband Communications Systems. New Jersey: Prentice Hall PTR, 2005.
[3] E.Mozenson and N.Levanon," Multi carrier radar signals with low peak to mean envelope power ratio",IEE Proc. Radar, Sonar and Navigation, Vol.150,No.2, 2003, pp.71 -77.
[4] R.J.Duckworth and K.H.Parikh and W.R.Michalson," Radio design and performance analysis of multi carrier ultra wide band(MC-UWB) positioning system" Proc. 2005 Institute of Navigatin Nat.Tech meeting,Sandiago,California, January 2005.
[5] L.Carin, N.Geng, M.McClure, J.Sichina and L.Nguyen," Ultrawideband Sysnthetic aperture Radar for Mine field detection"*IEEE Antennas and Propagation*, Vol.41,No.1,1999, pp.18-33.
[6] A.J.Dumanian and C.M.Rappaport," Enhanced detection and classification of buried mines with a UWB Multistatic GPR" Proc.*IEEE Antennas and Propagation Soc.Int.Symposium*, Washington, DC, vol.3B, July 2005,pp88-91.
[7] L. Sakkila, C. Tatkeu,Y. El Hillali, A. Rivenq, F. El Bahhar and J-M. Rouvaen," Short Range Radar Based on UWB Technology" Chapter 2, Radar Technology, Ed. . Guy Kouemou, Intech Croatia, Dec 2009.
[8] Nicola Jean Kinzie.,Ultra-Wideband Pulse Doppler Radar for Short-Range Targets",M.S.Thesis, University of Colorado, 2008.
[9] Zhang Wei, Shi Jun and Tian Zhong,," System simulation for a multi-function phased array radar", Proc. IET International conference on Radar systems 2007, Edinburgh,pp.1-4.
[10] S.L.C. Miranda, C.J.Baker, K. Woodbridge and H.D. Griffiths," simulation methods for prioritising tasks and sectors of surveillance in phased array radars" International Journal on Simulation System Science and Technology, Vol.5, No.1-2,pp18 – 25.
[11] High-resolution radar system modeling with MATLAB/SIMULINK by Dmitriy Garmatyuk, Defense Electronics, August 2006 ,pp 12 -19.
[12] Baseem.R.Mahafza,"Radar systems analysis and design using Matlab", 3rd ed, Chapman and Hall /CRC, 2013.