OPTIMAL POINT TARGET DETECTION USING DIGITAL RADARS

NIRMALENDU BIKAS SINHA[1] AND M.MITRA[2]

[1]College of Engineering & Management, Kolaghat, K.T.P.P Township, Purba Medinipur, 721171, W.B, India.

[2] Bengal Engineering and Science University, Shibpur, Howrah, W.B, India.

ABSTRACT

This paper presents an overview of recent progress of radar for the image detection and characterization of targets. MIMO radar can improve on conventional target detection, parameter identification, and target classification performance via diversity of, among other things, its simultaneously transmitted waveforms. However, the mutual interference among the waveforms may lead to considerable performance degradation in suppressing clutter near targets. The performance of the conventional radar for moving target detection have been evaluated analytically mainly focusing on the Swerling model II, IV and V and their integration loss during the signal processing related with the threshold voltage level of matched filter . Finally this paper extended toward MIMO radar detection performance for moving target under the condition of unknown parameters or other fluctuating model.

Keywords: *MIMO, SWERLING, CORRELATOR, and SNR.*

1. INTRODUCTION

RADAR theory has been a vibrant scientific field for the last 50 years or so [1]–[3]. Radar theory deals with many different and diverse problems. However, the two most important problems are the detection and range estimation problems. The importance of these two problems is not limited to radars, and other engineering disciplines like sonar and communication deal with very similar problems [4]. Over the years, radar systems have developed considerably. These developments can be attributed to the increase in computation power and advances in hardware design. While early radar systems utilized a directional antenna, today's MIMO radar systems have gained popularity and attracted attention of late for their ability to enhance all areas of system performance. Inspired by the success of MIMO systems in communications [5]-[11], several publications have advocated the concept of MIMO Radar [12][13] from the system implementation point of view [14], as well as for processing techniques for target detection and parameter estimation. Target parameters of interest in radar include target strength, location, and Doppler characteristics. In this paper we derived the formula of integration loss with the threshold voltage dependency over receiver SNR which is the primary parameter about the detection performance for both coherent and non coherent integration factors. In the first part we assumed that retectangular shape scatter comprised of finite no of same scatters. Gain of all scatter is follow the same distribution. But for fluctuating target where scatters are not fixed, so there is a prospective change of amplitude and phase of echo signal. According to this basic assumption we develop the swerling model idea all model we are not discussing, we mainly focus on swerling II, IV and V target .And we derive the formula of probability of detection of these type of scatter by taking some assumption and also dependence of some controlling factors.Finally, the paper addresses the current questions regarding the integration of conventional radar to MIMO radar in practical remote sensing systems for distant targets and standards

2. PULSE INTEGRATION

In this section a more comprehensive analysis of this topic is introduced in the context of radar detection .Coherent integration preserves the phase relationship between the received pulses, thus achieving a build up in the signal amplitude. Alternatively, pulse integration performed after the envelope detector (where the phase relation is destroyed) is called non-coherent or post detection, if a perfect integration. And this pulse integration mainly in practical circuit occurs in a correlator that acts as a matched filter.

2.1. *Coherent Integration*

In coherent integration integrator is used (100% efficiency), then integrating pulses would improve the SNR by the same factor. Otherwise, integration loss occurs which is always the case for non-coherent integration. In order to demonstrate this signal buildup, consider the case where the radar return signal contains both signal plus additive noise. The m^{th} pulse is

$$y_m(t) = s(t) + n_m(t) \;\ldots\ldots\ldots\ldots(1a)$$

Where s(t) is the radar return of interest and $n_m(t)$ is white uncorrelated additive noise signal. Coherent integration of n_p pulse yields

$$z(t) = \frac{1}{n_p}\sum_{m=1}^{n_p} y_m(t) \ldots\ldots\ldots 1(b)$$

$$= \sum_{m=1}^{n_p}\frac{1}{n_p}[\, s(t) + n_m(t)$$

$$= s(t) + \sum_{m=1}^{n_p}\frac{1}{n_p} n_m(t) \;\ldots\ldots\ldots 1(c)$$

The total noise power in z (t) is equal to variance. More precisely

$$\varphi_{nz}^2 = E[(\sum_{m=1}^{n_p}\frac{1}{n_p} n_m(t))\,(\sum_{l=1}^{n_p}\frac{1}{n_p} n_l(t))]$$

Where E [ ] is the expected value operator. It follows that

$$\varphi_{nz}^2 = \frac{1}{n_p^2}\sum_{m,l=1}^{n_p}\varphi_{ny}^2\,\delta_{ml}$$

$$= \frac{1}{n_p}\varphi_{ny}^2 \ldots\ldots\ldots\ldots\ldots\ldots(1d)$$

Where φ_{ny}^2 is the single pulse noise power and δ_{ml} is equal to zero for m≠ l and unity for m=l. Observation of equation (1c) and (1d) shows that desired signal power after coherent integration is unchanged, while the noise power is reduced by the factor $1/n_p$ .Thus SNR after coherent integration is improved by n_p. Denote the single pulse SNR required to produce a given probability of detection as $(SNR)_1$. Also, denote $(SNR)_{n_p}$ as the SNR required producing the same probability of detection when n_p pulse is integrated. It follows that

$$(SNR)_{n_p} = \frac{1}{n_p}(SNR)_1 \ldots\ldots(1e)$$

The requirements of knowing the exact phase of each transmitted pulse as well as maintaining coherency during propagation is very costly and challenging to achieve. Thus, radar systems would not utilize coherent integration during search mode, since target micro-dynamics may not be available

2.2. *Non-Coherent Integration*

Non-coherent integration is often implemented after the envelope detector, also known as the quadratic detector. A block diagram of radar receiver utilizing a square law detector and non-coherent integration is illustrated in Fig.1. In practice, the square law detector is normally used as an approximation to the optimum receiver.

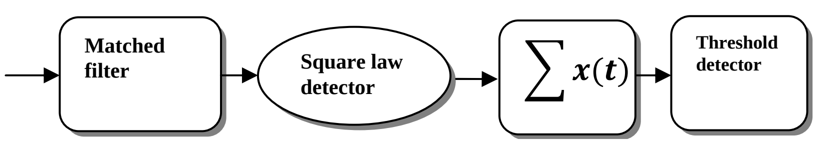

Fig .1 Simplified block diagram of a square law detector and non-coherent integration

3. IMPROVEMENT FACTOR AND INTEGRATION LOSS:

Denote the SNR that is required to achieve a specific probability of detection P_D given a particular probability of false alarm P_{fa} when n pulses are integrated non-coherently by $(SNR)_{NCI}$. And thus, the single pulse SNR, $(SNR)_I$, is less than $(SNR)_{NCI}$.
More precisely

$$(\mathrm{SNR})_{\mathrm{NCI}} = (\mathrm{SNR})\mathrm{I} \times \mathrm{I}(n_{\mathrm{P}}) \ldots\ldots (3a)$$

Where $I(n_p)$ is the integration improvement factor. An empirically derived expression for the improvement factor that is accurate within 0.8 db is reported in Peebles as

$$I(n_p) = 6.79(1 + .235\mathrm{P_D}) \times \left(1 + \frac{\log {}^{1}/_{Pfa}}{46.6}\right) \log(n_p)(1 - .140\, log(n_p) + .018310\, (log\, n_p)^2 \ldots\ldots 3b)$$

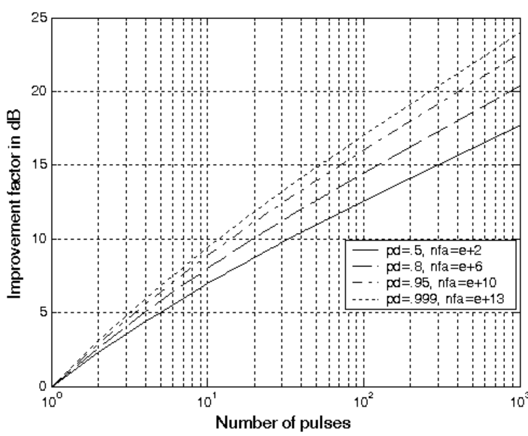

Fig. 2(a) shows plots of the integration improvement factor as a function of the number of integrated pulses with P_D and P_{fa} as parameters
The integration loss is defined as

$$L_{NCI} = {}^{\mathrm{n_p}}/_{\mathrm{I(n_p)}} \ldots\ldots (3c)$$

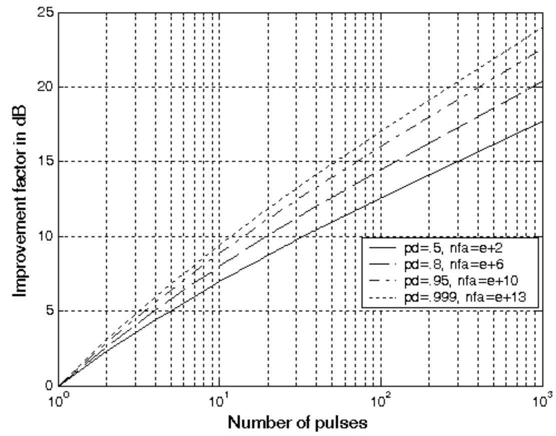

Fig. 2(b) shows a plot of the integration loss versus n_p

4 . DETECTION OF FLUCTUATING TARGETS:

So far the probability of detection calculations assumed a constant target cross section (non-fluctuating target). This work was first analyzed by Marcum.1 Swerling 2 extended Marcum.s work to four distinct cases that account for variations in the target cross section. These cases have come to be known as Swerling models. They are: Swerling I, Swerling II, Swerling III, and Swerling IV. The constant RCS case analyzed by Marcum is widely known as Swerling 0 or equivalently Swerling V. Target fluctuation lowers the probability of detection, or equivalently reduces the SNR. Swerling I targets have constant amplitude over one antenna scan; however, a Swerling I target amplitude varies independently from scan to scan according to a Chi-square probability density function with two degrees of freedom. The amplitude of Swerling II targets fluctuates independently from pulse to pulse according to a Chi-square probability density function with two degrees of freedom. Target fluctuation associated with a Swerling III model is similar to Swerling I, except in this case the target power fluctuates independently from pulse to pulse according to a Chi-square probability density function with four degrees of freedom. Finally, the fluctuation of Swerling IV targets is from pulse to pulse according to a Chi-square probability density function with four degrees of freedom. Swerling showed that the statistics associated with Swerling I and II models apply to targets consisting of many small scatterers of comparable RCS values, while the statistics associated with Swerling III and IV models apply to targets consisting of one large RCS scatterer and many small equal RCS scatterers.

Non-coherent integration can be applied to all four integration cannot be used when the target fluctuation is either Swerling II or Swerling IV. This is because the target amplitude decorrelates from pulse to pulse (fast fluctuation) for Swerling II and IV models, and thus phase coherency cannot be maintained.

5 RCS MEASUREMENT FOR MOVING TARGETS USING SWERLING MODELS

This section analyzes the probability detection of radar for moving targets using Swerling I, II, III, and IV models. This work was first analyzed by Marcum [7]. Swerling [8] extended Marcum's work to five distinct cases that account for variations in the target cross section. The static RCS case is known as Swerling 0 or Swerling V case and the other cases involving moving objects are known as Swerling I, Swerling II, Swerling III, and Swerling IV models. The main problem involving moving objects is its detection, which in turn lowers the SNR. Swerling I targets have constant amplitude over one antenna scan. In case of Swerling I target, the amplitude varies independently from scan to scan whereas in case of Swerling II model, the target fluctuates from pulse to pulse in an independent manner according to a Chi-square probability density function with two degrees of freedom. For Swerling III target, the amplitude varies independently from scan to scan whereas in case of Swerling IV model, the target fluctuates from pulse to pulse in an independent manner according to a Chi-square probability density function with four degrees of freedom. Non-coherent integration can be applied to all four Swerling models but the coherent integration method cannot be used for a moving target is either a Swerling II or a Swerling IV model 0.
For Swerling I and II models Rayleigh probability distribution function

$$f(\sigma) = \frac{1}{\sigma} exp\left(-\frac{\sigma}{\bar{\sigma}}\right); \quad \sigma \geq 0 \ldots\ldots (4)$$

Where, $\bar{\sigma}$ is the average cross-section value. For Swerling III and IV types of targets Rayleigh probability distribution function

$$f(\sigma) = \frac{4\sigma}{\sigma^2} exp\left(-\frac{2\sigma}{\bar{\sigma}}\right); \quad \sigma \geq 0 \ldots\ldots (5)$$

We assume probability detection (p_d) of a radar signal which is a sine waveform having amplitude A, V_T is the threshold voltage when noise alone is present in the radar, n_p is the number of pulses and Swerling models; however, coherent variance φ^2. When probability of false alarm (P_{fa}) is small and p_d is relatively large so that the threshold is large. According to Marcum, probability of false alarm $(P_{fa}) = \ln(2)\left(\frac{n_p}{n_{fa}}\right)$; for $n_p > 1$, Where n_{fa} is the false alarm number

$$p_d \approx F\left(\frac{A}{\varphi} - \sqrt{2ln\left(\frac{1}{P_{fa}}\right)}\right) \ldots\ldots (6);$$

Where $ln\left(1/p_{fa}\right) = V_T^2/2\varphi^2$

Case 1: Detection of Swerling I Targets

According to Swerling P_d for Swerling I type targets can be defined as $P_d = e^{-V_T/(1+SNR)}$; $n_P = 1$

$$P_D = 1 - \Gamma_I(V_T, n_P - 1) + \left(1 + \frac{1}{n_P SNR}\right)^{n_P-1} \Gamma_I\left(\frac{V_T}{1 + \frac{1}{n_P SNR}}, n_P - 1\right) \times e^{-V_T/(1+n_P SNR)} \ldots (7)$$

For $n_P > 1$

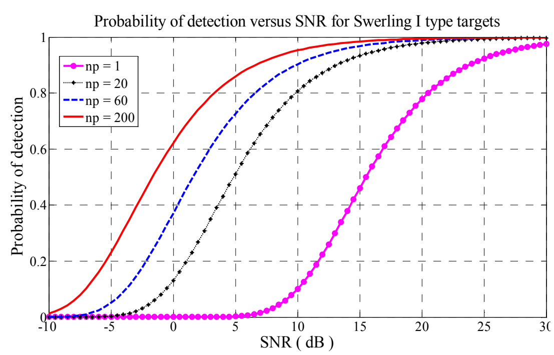

Fig. 3 p_d in Swerling model for different n_p with p_{fa} rate set to 10^{-9}

Fig.3 shows the p_d versus the single pulse SNR, with the P_{fa} as a parameter for different no of pulses in Swerling model I. Fig.3 clearly shows that when no of pulses increases, system performance in terms of probability of miss detection reduces

Case 2: Detection of Swerling II Targets

By using the Gram-Charier series, the probability of detection can be computed as

$$p_d = \frac{erfc\left(V/\sqrt{2}\right)}{2} - \frac{e^{-v^2/2}}{\sqrt{2}} \times$$
$$[c_1(v^2-1) + c_2 v(3-v^2) - c_3 v(v^4 - 10v^2 + 15)] \quad ..(8)$$

Where the constant c_1 , c_2, c_3 are Gram-Charier series coefficients and $v = \frac{V_T - n_p(1+SNR)}{\omega}$. The above coefficients and ω depend upon target fluctuation type. For $n_p > 50$, the above three coefficients can be substituted as

$$c_1 = -\frac{1}{\sqrt[3]{n_p}},\ c_2 = \frac{1}{4n_p},$$
$$c_3 = \frac{c_3^2}{2} \text{ and } \omega = \sqrt{n_p}(1+SNR).$$

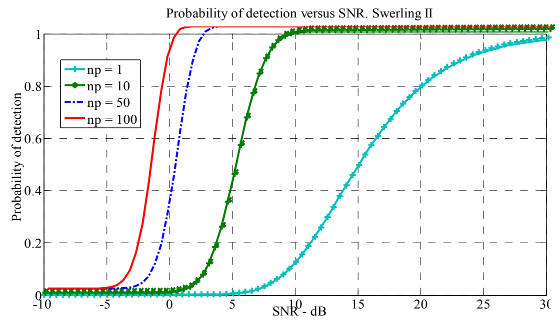

Fig.4 shows the probability of detection as a function of SNR for different n_p , where P_{fa} is set at 10^{-10} .

The above Fig.4 shows that as the no of pulses increases then there is a sharp increase in the probability of detection. So, performance improves as the number of pulses increases

Case 3: Detection of Swerling III Targets

For n_p = 1 and 2, the p_d for Swerling III type targets can be expressed as

$$\left.\begin{aligned} P_d &= exp\left(\frac{-V_T}{1+n_pSNR/2}\right)\left(1+\frac{2}{n_pSNR}\right)^{n_p-2} \times K_0\ ;\ n_p = 1,2 \\ K_0 &= 1 + \frac{V_T}{1+n_pSNR/2} - \frac{2}{n_pSNR}(n_p-2) \\ P_d &= \frac{{V_T}^{n_p-1}e^{-V_T}}{(1+n_pSNR/2)(n_p-2)!} + 1 - \Gamma_I(V_T, n_p-1) + K_0 \times \Gamma_I\left(\frac{V_T}{1+2/n_pSNR}, n_p-1\right);\ \text{For } n_p > 2 \end{aligned}\right\} \ldots\ldots(9)$$

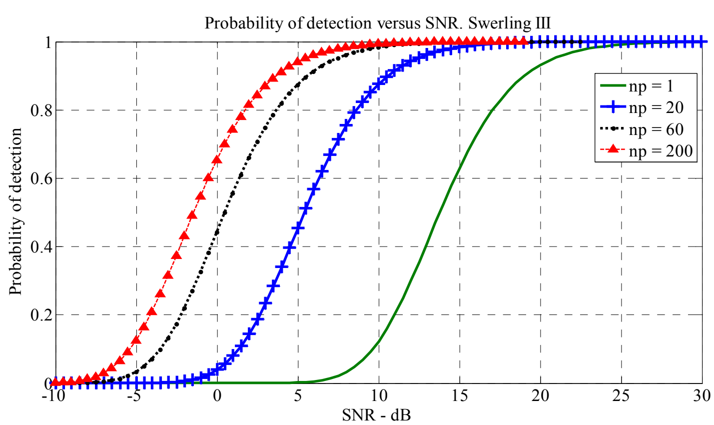

Fig.5 shows the probability of detection as a function of SNR for different number of pulses where P_{fa} is set at 10^{-9} .

Case 4: Detection of Swerling IV Targets

From Eqn.8.13, for $n_p \geq 50$, the Gram-Charier series coefficients is modified to

$$c_1 = \frac{1}{\sqrt[3]{n_p}} \frac{2\beta^3 - 1}{(2\beta^2 - 1)^{1.5}},$$

$$c_2 = \frac{1}{n_p} \frac{2\beta^4 - 1}{(2\beta^2 - 1)^2}, \quad c_3 = \frac{c_3^2}{2},$$

$$\omega = \sqrt{n_p} \times \left(\sqrt{2\left(1 + \frac{SNR}{2}\right)^2 - 1} \right)$$

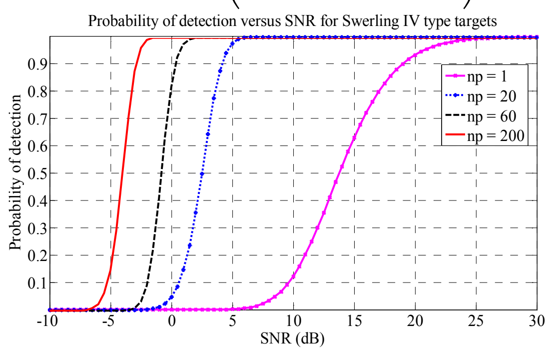

Fig. 6 shows p_d as a function of SNR for different n_p set at $P_{fa} = 10^{-9}$.

Fig.6 and Fig.4 have been designed for same P_{fa}, but Swerling IV model increases the performance as it has four degrees of freedom.

Case 5: Detection of Swerling V Targets

For Swerling V case involving moving targets, p_d can be calculated using Eqn.8 mentioned above. In this case, the Gram-Charier series coefficients are modified as

$$c_1 = -\frac{SNR + {}^1/_3}{\sqrt{n_p}(2SNR + 1)^{1.5}},$$

$$c_2 = \frac{SNR + {}^1/_4}{n_p(2SNR + 1)^2}$$

$$c_3 = {}^{c_3^2}/_2$$

$$and \quad \omega = \sqrt{n_p(2SNR + 1)}.$$

Fig. 7 shows the p_d versus SNR plot in Swerling model V. As the degree of freedom is increased to 4, hence the P_d improves drastically.

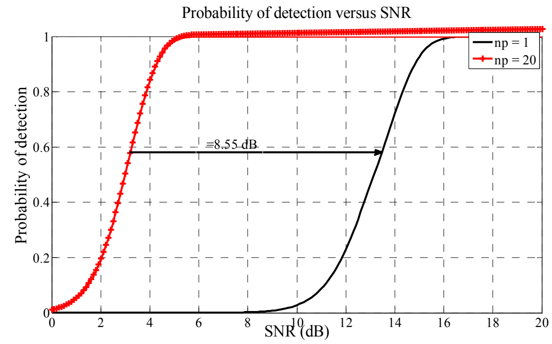

Fig. 7 shows p_d as a function of SNR for different number of pulses where P_{fa} is set at 10^{-9}.

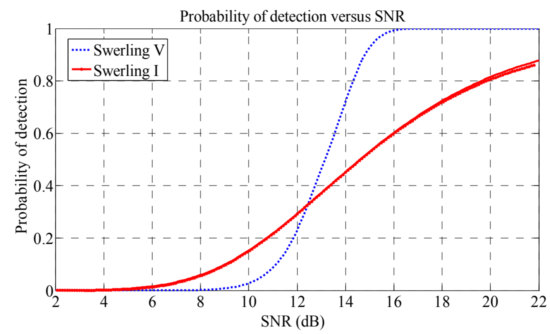

Fig .8 shows the comparison of Swerling model I and V

The only parameter which can be used to describe a complex target is the median RCS. Detection statistics is then calculated using Swerling I and II models having same median value. Doppler spectrum width of the echoes determines whether amplitude should vary from pulse to pulse or scan to scan. If the target is approaching the radar nose on region standard detection statistics should be used otherwise cumulative detection statistics should be used for high detection probability case. As the degree of freedom increases, fluctuations about the mean become more constrained. Hence, the steady state component becomes stronger. However traditional radar system does not have security. Owing to these limitations next DSSS Radar has been developed.

6. PERFORMANCE OF MIMO RADAR IN CASE OF MOVING TARGETS:

The detection performance of special diversity MIMO radar for Swerling I and Swerling II target model is analyzed based on coherent pulses. The detection method provides a unified frame for conventional radar and the MIMO radar.

Simulation results indicate that MIMO radar can provide much better detection performance when more coherent pulses are used. In contrast with conventional radar, the detection performance of MIMO radar in Swerling I target model outperforms Swerling II target model.

The detection performance of traditional radar and MIMO radar is shown in Fig. 9 and Fig. 10 respectively.

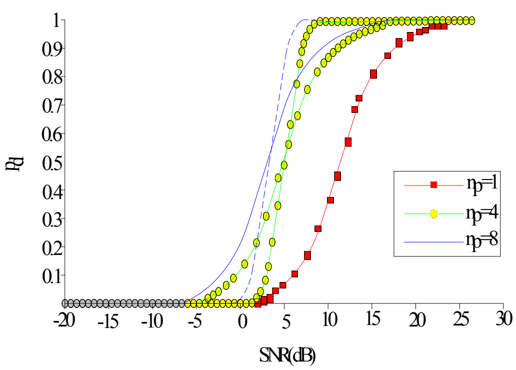

Fig. 9

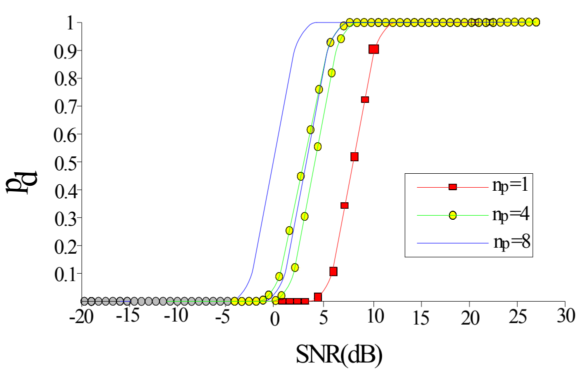

Fig. 10

Fig. 9 and Fig.10 Comparison of detection performance of traditional radar and MIMO radar.

In Fig. 9 and Fig. 10 the solid line (in blue) stands for the detection probability curve of Swerling I target model and the dotted line for Swerling II target model. From Fig. 9 we get the following results.

Case- 1: For single pulse detection (n_p =1), the two detection probability SNR curves of Swerling I and Swerling II overlap which shows that they have the same detection performance.

Case- 2: With the increase in the number of pulses, the detection performance of Swerling I and Swerling II targets are both improved.

Case-3: For multiple pulse detection, when the same P_d (p_d> 0.4) is taken, the SNR is higher for the slow fluctuating target than the faster one. Thus, a Swerling II target model comfortably outperforms Swerling I target.

The reason behind the phenomena is that for any traditional radar, the echo of slow fluctuating target is totally correlated during one scan. The amplitudes of all echoes will not exceed the detection threshold if the first one is under that particular value, thus increasing the SNR is the only way to detect the target. In case of fast fluctuations, the pulses are uncorrelated and the amplitudes of the pulses may vary. So, the pulses have a good opportunity to exceed the detection threshold. Thus, in this case we are able to detect the target successfully. Overall, the detection performance gets averaged. This all leads to the conclusion that the detection performance of Swerling I target is inferior to the Swerling II target. From Fig. 10 we get the following results.

Case 1 and Case 2 remain same for traditional radar as well as for MIMO radar.

Case -3: For MIMO radar, in case of multiple pulse detection, Swerling I target needs lower SNR to get the same probability detection. The spatial diversity MIMO radar has more advantages for Swerling I target than Swerling II target which is contrary in case of traditional radar. MIMO radar can carry out energy accumulation in time domain (pulse interval coherent) and also in the spatial domain (scan interval incoherent). Due to the spatial diversity, the echo complex amplitudes of different transmitter - receiver path are mutually independent. Thus, the spatial diversity MIMO radar has the some superiority over fast and slow fluctuating targets.

Hence, from the analysis and simulation we can derive the conclusion that spatial diversity MIMO radar has a better detection performance for Swerling I target as compared to Swerling II target model.

7. CONCLUSION

A lot of ambiguity occur in the recoznigation analysis of traditional RADAR system during pulse integration from the plot it is also clear shows that as no of pulse is increases the integration losses reduces and also improvement factor increase .And for also for flucting target we established condition that swerling I outperforms the swerling II as in conventional radar system SNR is an controlling factor, and in swerling I as the SNR reduces so its performance degrades than swerling II. The target detection parameter mainly depends on received SNR which in terms as function of no pulses, actually a process of increase this no of pulse is multiple input and output antenna. But there are still lots of problems to be further studied: during the derivation in this paper, we suppose we have got the target parameters and noise variance, we may study the detection performance under the condition of unknown parameters or other fluctuating model; they are two extreme cases to the scan interval and pulse interval independence, the actual target fluctuates between the two and the detection performance here is worth to be researched.The experimental results during the performance of MIMO radar in comparison to any conventional radar for moving targets suggest that spatial diversity MIMO radar has better detection performance for Swerling II model than Swerling I target model .

REFERENCES:

[1] W. M. Siebert, "A radar detection philosophy," IEEE Trans. Inf. Theory, vol. 2, no. 3, pp. 204–221, Sep. 1956.

[2] M. Skolnik, Introduction to Radar Systems, 3rd ed. New York: Mc-Graw-Hill, 2002.

[3] P. M. Woodward, Probability and Information Theory with Application to Radar. Norwood, MA: Artech House, 1953.

[4] H. L. V. Trees, Detection, Estimation, and Modulation Theory. New York: Wiley, 1968, vol. III.

[5] J. Yang and S. Roy, "On joint transmitter and receiver optimization for multiple-input multiple-output (MIMO) transmission systems", IEEE Trans. Commun., vol. 42,no. 12, pp. 3221–3231, (Dec. 1994).

[6] X. Zhu and R. D. Murch, "Layered space-frequency equalization in a single-carrier MIMO system for frequency-selective channels, IEEE Trans. Wireless Commun., vol. 3, no. 3, pp. 701–708, (May 2004).

[7] H. B¨olcskei,"MIMO-OFDM wireless systems: Basics, perspectives, and challenges", IEEE Journal on Wireless Communications, Vol. 13, No. 4, PP. 31-37 (Aug. 2006).

[8] Y. Li and N. R. Sollenberger, "Adaptive Antenna Arrays for OFDM systems with Co-Channel Interference", IEEE Trans. Communications, vol. 47, no. 2, pp. 217-229, February 1999.

[9] G. J. Foschini and M. J. Gans, "On limits of wireless communications in a fading environment when using multiple antennas", Wireless Personal Communications, Vol. 6, No. 3, March 1998, pp 311-335.

[10] M. Jankiraman, Space time Codes and MIMO systems, published by Artech House, 2004.

[11] B. Vucetic & J. Yuan, 'Space Time Coding', published by John Wiley &Sons Inc., 2003.

[12] E. Fishler, A. Haimovich, R. Blum, D. Chizhik, L. Cimini, and R. Valenzuela, "MIMO Radar: An Idea Whose Time Has Come", proceedings of IEEE radar conference, pp.71-78, (April 2004).

[13] N.H.Lehmann, E.Fishler, A.M.Haimovich, et al. "Evaluation of Transmit Diversity in MIMO-Radar Direction Finding, IEEE Transactions on Signal Processing, vol.55, pp. 2215-2225,(May 2007).

[14] E. Brookner "Phase arrays around the world Progress and future trends," Proc. IEEE Int. Symp. Phased Array Systems and Technology, pp.1-8, (oct.2003)

AUTHOR PROFILES:

Prof. Nirmalendu Bikas Sinha received the B.Sc (Honours in Physics), B. Tech, M. Tech degrees in Radio-Physics and Electronics from Calcutta University, Calcutta,India,in1996,1999 and 2001, respectively. He is currently working towards the Ph.D degree in Electronics and Telecommunication Engineering at BESU. Since 2003, he has been associated with the College of Engineering and Management, Kolaghat. W.B, India where he is currently an Asst. Professor is with the department of Electronics & Communication Engineering & Electronics & Instrumentation Engineering. His current research Interests are in the area of signal processing for high-speed digital communications, signal detection, MIMO, multiuser communications,Microwave /Millimeter wave based Broadband Wireless Mobile Communication ,semiconductor Devices, Remote Sensing, Digital Radar, RCS Imaging, and Wireless 4G communication. He has published more than 50 papers in different international Conference, proceedings and journals.He is presently the Chief-editor, Editor and Reviewers in different international journals including IEEE.

Dr. Monojit Mitra is an Assistant Professor in the Department of ETC of BESU, Shibpur. He obtained his B.Tech, M.Tech & Ph. D .degrees from Calcutta University. His research areas are in the field of Microwave & Microelectronics, especially in the fabrication of high frequency solid state devices like IMPATT. He has published large number of papers in different national and international journals. He has handled sponsored research projects of DOE and DRDO. He is a member of IETE (I) and Institution of Engineers (I).