# SNR Detector for Phased-Multiple-Input-Multiple-Output Radar Applications

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**Abstract.** SNR detection should be on the radar depending heavily on noise and RCS. It is known that PMIMO radar uses overlapping subarrays on the transmit (Tx) side with high SNR performance, especially in the presence of interference effects. This performance combined with various subarrays on the PMIMO radar is applied for SNR detection to overcome disturbances such as noise, interference and low RCS. In this paper, the SNR detection for radar is constructed and evaluated based on the influence of SNR variation and noise, the number of Tx subarrays, and the number of Tx-Rx antenna elements. Its performance is compared with existing radars such as phased array (PhA) and MIMO radars. With 10 dB SNR and number of Tx-Rx antenna elements of 8, the SNR detection result of this radar is close to the PhA 1.999 radar because it has high coherence gain and is superior to MIMO radar.

**Keywords:** Noise radar, Phased-MIMO, SNR detector, Subarray transmit.

## 1 Introduction

The development of radar system technology is very rapid, especially radar systems with antenna arrays in both transmit (Tx) and receive (Rx). This is driven by the demand for the radar system to meet various applications other than the military and defense fields, especially the civilian field, such as the health sector to detect biological tissue as an indication of tumors [1] and breast cancer [2], the automotive industry as a tool for controlling autonomous vehicles [3] [4], etc. The expected radar capabilities include being able to detect targets with low SNR by adjusting to the type of radar cross section (RCS) [5], increasing detection performance capabilities for the probabilities of detection and false alarms [6], resistance to interference and jamming with pulse compression [7], spectrum sharing between radar and cellular systems [8], virtual array enhancement, Tx-Rx gain, maximum number of detections, angle resolution, [9] etc.

The latest development of a radar system with an antenna array is the use of a subarray (SAr) with the same number of antenna elements both on the Tx side as in studies [5], [8], [10], the SAr in Tx has variations [11], [13], and on the transmit-receive (Tx-Rx) side by study [9]. The use of SAr is known to have simultaneous advantages, i.e. the radar on the one hand is able to have high coherent gain for target detection with weak signal to noise ratio (SNR) and small radar cross section (RCS) [5] and on the other hand it is able to increase detection of multiple targets due to the ability to waveform diversity [9]. Other positive impacts of the SAr method

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for radar include an increase in the Tx-Rx beampattern gain, the ability to minimize the influence of interference with high signal to interference plus noise ratio (SINR), the maximum number of detected targets, large virtual array size, detection performance, the ambiguity function, and configuration flexibility from radar to special conditions such as a radar with one SAr acting as the phased-array (PhA) radar and a radar with a single element SAr acting as the MIMO radar [9].

One of the most important performance of radar with SAr is SNR detection especially for targets whose RCS fluctuates resulting in low SNR gain which has an impact on detection performance. SNR detection determines the probability of detection of a target. SNR detection has been investigated by [12] especially for the MIMO radar which are widely separated between Tx and Rx arrays. In this paper, we have formulated and evaluated SNR detection for radars with SAr with the same number of elements on the Tx side, which is called the overlapped equal subarray transmit (OEST) or the phased-MIMO (PMIMO) radars. In this radar setting the right number and size of the SAr can increase the flexibility of the radar in detecting targets, especially for targets with low SNR. Based on the expansion of the formulation of SNR detection by [12] carried out on PMIMO radar by taking into account the type of radar, variations in the number of SAr in Tx, as well as the Tx-Rx configuration of the radar. As a comparison for this paper as well, the results of a study by [13] have investigated the detection performance expressed by the probability of detection and the probability of false alarm without the SNR detection formulation.

## 2 Method

### 2.1 Signal Model of the PMIMO Radar

Signal modeling from the PMIMO radar in this paper is adapted from [13] with several modifications. It is assumed that if there are total antennas in Tx and Rx that are located or far apart, respectively, namely $U$ and $V$ antennas, the range of the number of SAr in Tx is $1 \le W \le U$ where the SAr in Tx is $W$. The spacing between antenna elements at Tx and Rx is $d_{Tx}$ and $d_{Rx}$, respectively, which are half a wavelength from the working frequency of the radar. The number of SAr elements in $W$ is determined by $U_W = U - W + 1$. The signal transmitted by the radar to the target and back received by the radar is non-dispersive and has a narrow frequency field, so the received $V$×1 vector signal is expressed by

$$\mathbf{y}(t) = \gamma \sum_{i=1}^{I} \sigma_i(\theta_i)\mathbf{b}(\theta_i)[\mathbf{j}(\theta_i) \circ \mathbf{k}(\theta_i)]^T \mathbf{\Phi}(t) + \mathbf{n}(t) \tag{1}$$

with

$$\mathbf{j}(\theta) = [\mathbf{a}_1^H \mathbf{c}_1(\theta) \;\; \mathbf{a}_2^H \mathbf{c}_2(\theta) \;\; .... \;\; \mathbf{a}_W^H \mathbf{c}_W(\theta)]^T \tag{2}$$

$$\mathbf{c}(\theta) = [1 \;\; e^{-j2\pi(d_{Tx}\sin(\theta)/\lambda} \;\; .... \;\; e^{-j2\pi(U-1)d_{Tx}\sin(\theta)/\lambda}]^T \tag{3}$$

$$\mathbf{k}(\theta) = [e^{-j2\pi f \mu_1(\theta)} \;\; e^{-j2\pi f \mu_2(\theta)} \;\; .... \;\; e^{-j2\pi f \mu_W(\theta)}]^T \tag{4}$$

where $\gamma$ is $(U/W)^{0.5}$, the number of targets i = 1, 2, ..., I, $\sigma(\theta)$ as the reflection coefficient on the target received by the radar $\theta$ which is proportional to the RCS, coherent vector and radar directivity respectively expressed by $\mathbf{j}(\theta)$ and $\mathbf{k}(\theta)$ with dimension $W\times1$ on the antenna Tx, $\mathbf{c}(\theta)$ is the steering vector on Tx. For the SAr weight vector in Tx it is expressed by **a**. The Hermitian transpose, Hadamard multiplication, and transpose operators are represented by $(\bullet)^H$, "$\circ$", and $(\bullet)^T$, respectively. If the working frequency of the radar is $f$, then its wavelength is expressed by $\lambda$. While $\mathbf{\Phi}(t)$ is the waveform for the transmitted SAr where $\mathbf{\Phi}(t) = [\phi_1(t)\ \phi_2(t)\ \ldots\ \phi_W(t)]^T$ and $\mathbf{n}(t)$ is a white Gaussian noise vector with dimension $V\times1$.

If (1) is fed to a match filter for the $W$ waveform, then the signal (1) changes to a signal data vector with dimension $WU\times1$ which is expressed by

$$\mathbf{y} = \gamma\sigma\, kron\{[\,\mathbf{j}(\theta)\circ\mathbf{k}(\theta)]\mathbf{b}(\theta) + \mathbf{n} \tag{5}$$

where $kron(\cdot)$ is the Kronecker multiplication operator.

It can be seen from the received vector signal (5) that there is a coherent vector Tx and a vector of diversity Tx which has the potential to increase the degree of freedom (DoF) in the flexibility of the number of SAr. This is what will be studied comprehensively in the formulation and evaluation of the PMIMO radar detection performance.

## 2.2 SNR Detector

The best performance measure of various detectors is the probability of detection ($P_d$). So the $P_d$ comparison of various radar systems must be determined to determine which one is the best. The comparison is a numerical calculation of a single scalar performance measure such as a function of the detector's SNR performance [12]. The range of a target is determined by the SNR and $P_d$ detectors.

The steps in the formulation of SNR detection from PMIMO radar are based on the Neyman-Pearson (NP) criteria with a signal and noise distribution approach in the form of a chi-square distribution where signal and noise are expressed by (5). Based on the NP criteria, the binary hypothesis test of this radar can be formulated with

$$T_d \approx \|\mathbf{y}\|^2 = \begin{cases} \dfrac{U_W W V\sigma_n^2}{2}\chi^2_{(2WV)} & H_0 \\ \dfrac{\gamma^2 U_W^2 W^2 V^2\sigma_i^2}{2}\chi^2_{(2WV)} + \dfrac{U_W W V\sigma_n^2}{2}\chi^2_{(2WV)} & H_1 \end{cases} \tag{6}$$

If $T_d$ is a test statistic (detector) on the radar system, the detector's SNR is expressed by [12]

$$\rho = \frac{2\left|E(T_d \| H_0) - E(T_d | H_1)\right|^2}{\left|Var(T_d \| H_0) + Var(T_d | H_1)\right|} \tag{7}$$

If $T_d|H_i$, $i = 0, 1$ is normally distributed, then $\rho^{0.5}$ is the normalized distance between the mean distribution of the detector test statistic and the null hypothesis and its alternatives. This provides the ability to distinguish between the two hypotheses.

Based on the study [9] for PMIMO radar has been obtained

$$E(T_d|H_0) = U_W WV\sigma_n^2 \quad (8)$$

$$E(T_d|H_1) = \gamma U_W^2 W^2 V^2 \sigma_i^2 + U_W WV\sigma_n^2 \quad (9)$$

$$Var(T_d|H_0) = U_W^2 W^2 V^2 \sigma_n^4 \quad (10)$$

$$Var(T_d|H_1) = \gamma^2 U_W^4 W^4 V^4 \sigma_i^4 + 2\gamma U_W^3 W^3 V^3 \sigma_i^2 \sigma_n^2 + U_W^2 W^2 V^2 \sigma_n^4 \quad (11)$$

Substitute (8)-(11) into (7) so that the SNR detector for PMIMO radar is expressed as

$$\rho = \frac{2\gamma U_W^2 W^2 V^2 \sigma_i^4}{\gamma^2 U_W^2 W^2 V^2 \sigma_i^4 + 2\gamma U_W WV\sigma_i^2 \sigma_n^2 + 2\sigma_n^4} \quad (12)$$

If it is known that the SNR is

$$SNR = \frac{\sigma_i^2}{\sigma_n^2} \quad (13)$$

then in (12) can be simplified to

$$\rho = \frac{2\gamma U_W^2 W^2 V^2 (SNR)^2}{\gamma^2 U_W^2 W^2 V^2 (SNR)^2 + 2\gamma U_W WV(SNR) + 2} \quad (14)$$

Seen in (14) which is the contribution of this paper. As validation that the PMIMO radar is a general form of other radars such as the PhA and the MIMO radars, the following analysis of the SNR detection is given for these radars following the SAr conditions implemented to (14). For a MIMO radar having a SAr at Tx i.e. $W = U$ then the SNR detection at (14) will be

$$\rho_{\mathrm{PhA}} = \frac{2\gamma U^2 V^2 (SNR)^2}{\gamma^2 U^2 V^2 (SNR)^2 + 2\gamma UV(SNR) + 2} \quad (15)$$

Meanwhile for the PhA radar, which has a SAr at Tx, which is $W = 1$, the SNR detection performance becomes

$$\rho_{\mathrm{MIMO}} = \frac{2\gamma U^2 V^2 (SNR)^2}{\gamma^2 W^2 V^2 (SNR)^2 + 2\gamma U_W WV(SNR) + 2} \quad (16)$$

It appears that the expressions for SNR detection on the PhA and the MIMO radars at (15) and (16) respectively are in line with those of study [12] with slight modification of the variables.

## 3 Results and Discussion

After formulating the SNR detection from the PMIMO radar as in (14), the next step is to evaluate it against several factors, including: the type of radar, variations in the number of SAr in Tx, and the Tx-Rx configuration of the radar. To test its effectiveness, it is compared with the detection performance of existing radars such as the PhA radar with (15) and the MIMO radar with (16). If it is assumed that the PMIMO radar has $U = V = 8$ antenna elements with a space between the elements half a wavelength of the working frequency, it will produce a range of the number of SAr in Tx which is $1 \leq W \leq 8$. The number of SAr conditions for the PhA radar is $W = 1$ and the MIMO radar is $W = 8$.

### 3.1 SNR Detection Performance Comparison of Different Types of Radar

Comparison of SNR detection performance was carried out based on the SNR detection formulation for the PMIMO, the PhA, and the MIMO radars in (14), (15), and (16) respectively. This detection performance varies for the SNR range from -25dB to +25dB. Testing the performance of the SNR detector on the PMIMO radar is carried out by comparing the results of SNR detection from other radars, namely PhA and MIMO radars where the antenna configuration for each radar is 8 for Tx and 8 for Rx, while for the $W$ subarray configuration, the PMIMO radar is $W = 4$, the PhA radar with $W = 1$ and the MIMO radar with $W = 8$. The results of the obtained SNR detection are presented in **Figure 1**.

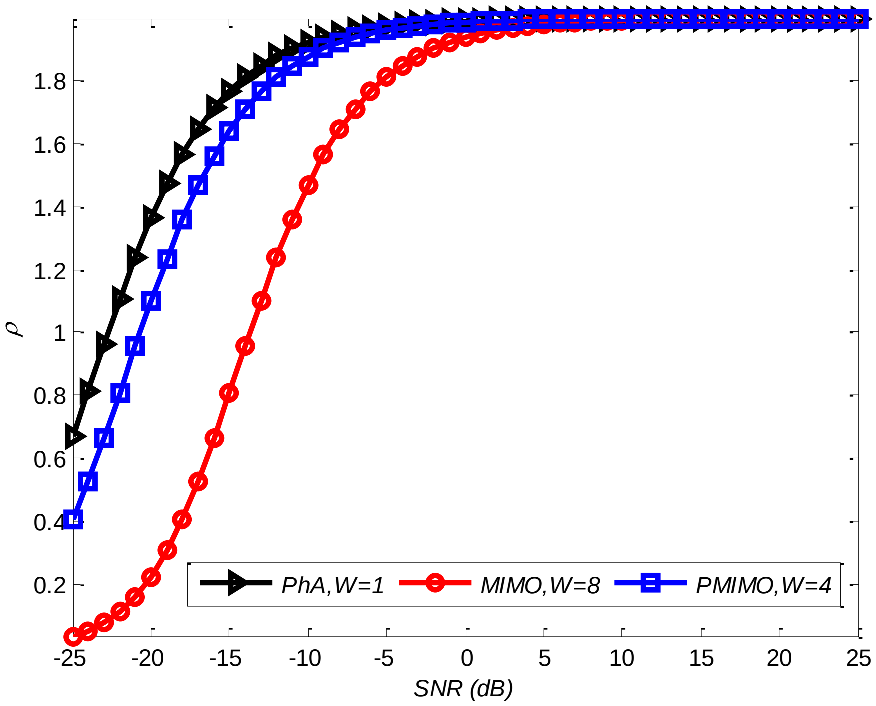


**Fig. 1.** SNR detection performance of various types of radar.

**Figure 1** shows the SNR detector performance of various types of radar starting at low to high SNR levels. The graph shows that when the SNR condition is low around -10 dB, the PhA and the PMIMO radars are able to detect well with the achievement of detection values of 1.923 and 1.879, respectively. Meanwhile, for the MIMO radar the detection results are small, which is only worth 1,469. On the other hand, when the SNR condition is 10 dB, the detection value of the PMIMO radar is equivalent to that of the PhA radar, which is 1.999, while the MIMO radar is still slightly behind, with the detection value of 1.994. So when the SNR condition is low, the PhA radar is superior in terms of detection and is followed by the PMIMO radar, while the MIMO radar is in the last position. This strengthens a study conducted by [12] where the SNR detection performance for low SNR on the PhA radar is better than the MIMO radar.

### 3.2 Impact of Subarray Number on Tx

The PMIMO radar has a special characteristic that is capable of dividing the antenna on its Tx into several SAr. This causes this radar to act like the PhA radar at $W = 1$ and can also act as the MIMO radar at $W = 8$, therefore this radar is also known as a joint radar of two radars, namely PhA and MIMO.

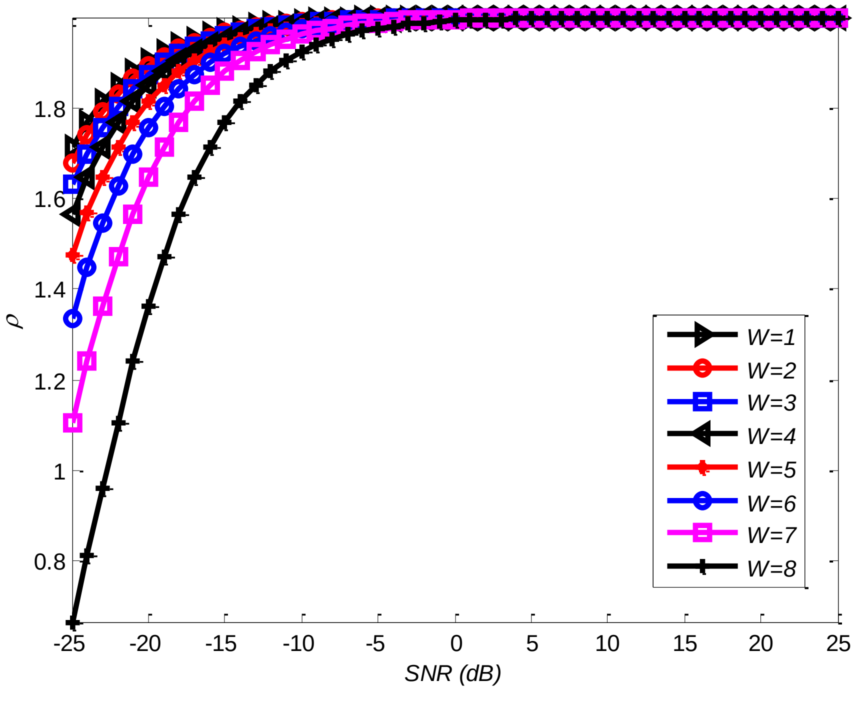


**Fig. 2.** SNR detection performance of the PMIMO radar for SAr variations in Tx.

**Figure 2** shows the performance of the SNR detector on the PMIMO radar with variations in the SAr number of $W$ with a range from 1 to 8. **Figure 2** shows that the more the number of SAr on the Tx side, the lower the detection ability of the radar, especially at low SNR conditions.

For example, when the SNR is -10 dB, for $W$ = 8 the detection value obtained is only 1.469 while for $W$ = 7 it is still able to obtain a detection value of 1.712, for $W$ = 6 it is 1.802, $W$ = 5 is 1.850, $W$ = 4 is 1.879, $W$ = 3 is 1.899, $W$ = 2 is 1.913, and $W$ = 1 is 1.923. From these data, it can be seen that in the condition $W$ = 5, the difference in detection performance from the radar is not too large. Although it is clear that the less SAr the better the detection performance. However, when the condition $W > 5$, the detection performance of the radar will experience a significant decrease compared to the previous condition. However, this only applies to low SNR conditions because when the SNR has reached 10 dB starting from $W$ = 1 to 8 the detection results obtained have reached almost the same value, namely in the range of 1.998 and then will reach a detection value of 2 when the SNR condition of 16 dB and will be consistent throughout. The fewer the number of SArs, the less the distribution of antennas per SAr on Tx, so the stronger the signal emitted because there are several antennas in each SAr.

### 3.3 Effect of Tx and Rx Antenna Configuration

The antenna is the main component of the radar which acts as the Tx and Rx of the signal. The configuration or setting of the number of antennas on the radar will affect the performance of the radar, because the influence of the detected SNR will depend on the condition of the antenna both on Tx and Rx. The results of SNR detection from several antenna configurations on the radar can be seen in **Figure 3**.

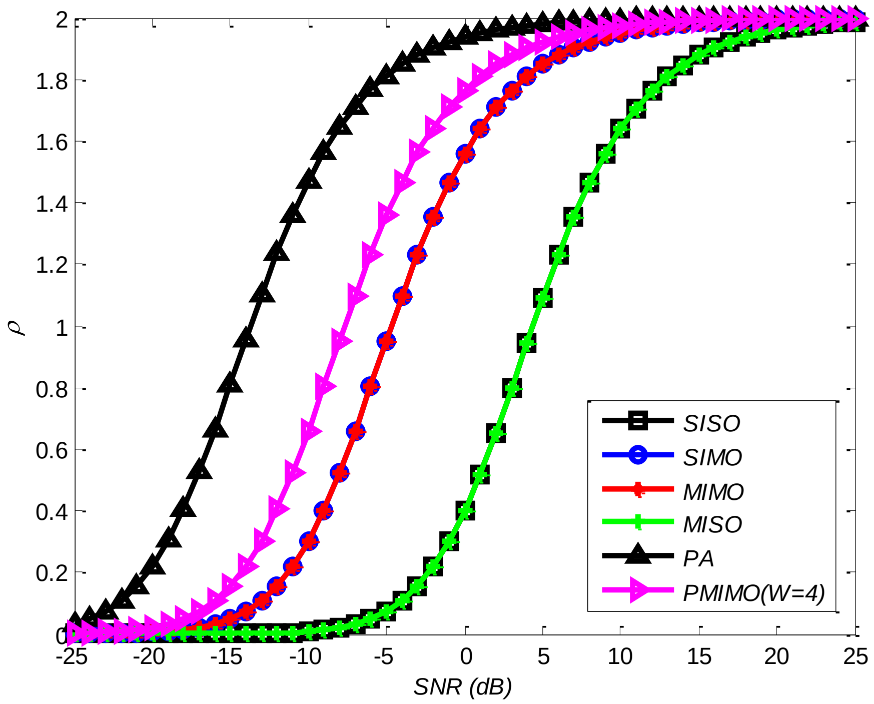


**Fig. 3.** SNR detection performance of various types of radar.

**Figure 3** presents the results of SNR detection on a radar with several antenna configurations at Tx and Rx which shows the effect of the number of antennas on radar detection performance. In the configuration conditions of the single-input-single-output (SISO) and the multiple-input-single-output (MISO) radars where the number of antennas on Rx is single so that the detection performance of the radar is not good, especially when the SNR condition is lower than -10 dB with a detection result of only 0.01, while to achieve a detection value of 1 SISO and MISO radar must be at the SNR level of 5 dB after that the detection value will continue to increase significantly until at 17 dB there is no significant increase and only increases slightly. While in the single-input-multiple-output (SIMO) and the MIMO conditions, the detection performance when the SNR condition is low, namely -10 dB is not much different from the previous one which only obtained a detection value of 0.30 but the increase in the detection value was higher than the previous one because to achieve a detection value of 1 only at -4 dB. alone is capable and so is the SNR condition which has started to be high at 15 dB the detection value has started to be constant or remains at number 2.

## 4 Conclusion

This paper has formulated the SNR detection performance of the PMIMO radar which was evaluated against the type of radar, variations in the amount of SAr in Tx, and the Tx-Rx configuration of the radar. Evaluation and validation of the SNR detection performance has been carried out on other types of radar because the PhA and MIMO radars are special cases of this radar where the SAr for both types of radar is $W = 1$ and $W = U$, respectively. The advantages and flexibility of the PMIMO radar to detect the SNR of the target is determined by the variation in the number of SAr in Tx, namely $W$ where for a small number of $W$ it will provide the highest SNR detection value, especially for low SNR. For the case $1 \leq W \leq 8$ of the proposed radar and in the condition $W \leq 5$, the difference in the detection performance of the radar is not too big. While it is clear that the lower the SAR the better the detection performance. However, in contrast to the condition $W > 5$, the detection performance of the radar will experience a significant decrease. Moreover, this only applies to low SNR conditions because when the SNR has reached 10 dB starting from $W = 1$ to 8 the detection results obtained have reached almost the same value, namely in the range of 1.998 and then will reach a detection value of 2 when the SNR condition is by 16dB. So that the PMIMO radar capability is expected to provide design options for radar designers to be implemented in radar systems with the main purpose of multi-target detection with low SNR.

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