PERFORMANCE OF MIMO RADAR AND PHASED ARRAY RADAR

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ABSTRACT

Radar typically consists of transmitting a narrow beam of electromagnetic energy through an antenna and then receiving the echoes returned by the targets. Only one antenna is often used on a timeshare basis for transmission wave and reception the echoes. At the receiver, it is necessary to determine whether the received signal is a signal reflected by the target or is just noise. To increase the signal to noise ratio and all parameters of the radar, the fame radar used currently, is Multiple Input Multiple Output (MIMO) radar, based on multiple transmitters and receivers. Another radar system, such as phased array radar can also improves the signal to noise ratio. MIMO radar outperforms the conventional radar systems. This paper, research is about the performance of MIMO radar and phased array radar.

Keyword: *antenna, range, coherent, MIMO, array, radar*

1. INTRODUCTION

Radar or radio detection and ranging is a detection system that uses radio waves to determine the distance, angle, and the speed of target. There are more several radar technique based on the specific radar characteristics, such as frequency band, antenna type, the relative positioning of the transmitter and the receiver, and waveforms utilized. Radar system must be able to extracts the desired echoes from the noise. For MIMO radar, in which multiple transmitters and receivers are used, each transmit antenna radiates an arbitrary waveform independently of the other transmitting antennas. Each receiving antenna can receive these signals. MIMO radar systems can be used to improve signal-to-noise ratio. Thus, the probability of detection of the targets is also increased [1].

2. MIMO RADAR

For MIMO radar with M transmitter elements and N receiver elements, M orthogonal waveforms are used. MIMO radar provides additional virtual spatial antenna. The spatial resolution for the clutter is the same as receiving array with MN physical antenna array elements [2].

2.1 MIMO radar classification

MIMO radar can be categories as statistical MIMO and coherent MIMO radar [2].

Statistical or distributed MIMO radars is a radar with widely separated antennas. All antennas are far enough from each other so that they obtain echoes from different angles of target. This MIMO radar provide independent scattering responses for each antenna; give a diversified view of the target, thus improving detection.

For coherent or co-located MIMO radars, all the elements are closely spaced in a subarray such that direction finding is possible. Thus, the radar cross section of the target observed by any transmit/receive propagation paths are identical. MIMO coherent radar improve angular resolution by transmit orthogonal waveforms at each transmit element, thus location [3].

2.2 MIMO radar parameters

To improve performance of MIMO radar, parameters are probability of detection and target number detecting.

- **Statistical MIMO radar**

For statistical MIMO radar, detection probability of target is defined by [2]:

$$P_d = 1 - Q_{\chi^2_{2N_TN_R}}\left(\frac{1}{\left(\frac{\gamma}{N_T}+1\right)} Q^{-1}_{\chi^2_{2N_TN_R}}\left(1-p_{fa}\right)\right) \qquad (01)$$

Where, $Q_{\chi^2_{2N_TN_R}}$, $Q^{-1}_{\chi^2_{2N_TN_R}}$ and p_{fa} are chi-square cumulative distribution function with $2N_RN_T$ degrees of freedom, and chi-square inverse cumulative distribution function and false alarm probability.
Target number detectable is expressed by [4]:

$$K \in \left[\frac{2(N_T+N_R-1)}{3}, \frac{2N_TN_R}{3}\right] \qquad (02)$$

- **Coherent MIMO radar**

For coherent MIMO radar, detection probability of target is defined by [2]:

$$P_d = exp\left(\frac{ln(p_{fa})}{(\gamma N_R + 1)}\right) \qquad (03)$$

3. PHASE ARRAY RADAR

For a phased array radar, for which all the parameters are same as the MIMO radar with M transmitter elements and N receiver elements except that the same phase-shifted waveform, is transmitting by beamforming. Each antenna is equipped with a phase shifter to create constructive and destructive interference to steer the beam in the required [5].

3.1 Phased array antenna parameters

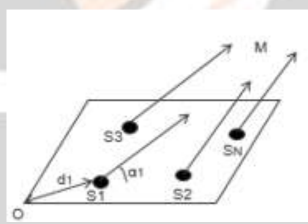

Fig -1: Antenna array

With N antenna array, the field radiated by each element is [5]:

$$E_k(M) = e^{j\omega t} e^{-j\beta r_k}\left[f_k(\theta_k)\frac{A_k}{r} e^{j\Phi_k}\right] \qquad (04)$$

Where:

- A_k is the excitation amplitude of individual elements
- Φ_k is the excitation phase of individual elements
- $f_k(\theta_k)$ is the relative pattern of individual elements
- r_k is distance between reference point and individual elements
- r is the distance between the reference point and M
- $\beta - \frac{2\pi}{\lambda}$

Or, $r_k = r - d_k\cos(\alpha_k)$

$$E_k(M) = e^{j\omega t} e^{-j\beta r}\left[f_k(\theta_k)\frac{A_k}{r} e^{j(\Phi_k + \beta d_k\cos(\alpha_k))}\right] \qquad (05)$$

The total field radiated is defined by:

$$E_{TOTAL}(M) = e^{j\omega t}\frac{e^{-j\beta r}}{r}\sum_{k=1}^{N} A_k f_k(\theta_k) e^{j(\Phi_k+\beta d_k \cos(\alpha_k))} \tag{06}$$

If each antenna is identically,

$$E_{TOTAL}(M) = \frac{e^{-j\beta r}}{r} f(\theta)\sum_{k=1}^{N} A_k\, e^{j(\Phi_k+\beta d_k \cos(\alpha_k))} \tag{07}$$

The array factor AF is defined by [5]:

$$E_{TOTAL}(M) = \frac{e^{-j\beta r}}{r} f(\theta)\ \mathrm{AF} \tag{08}$$

$$E_{TOTAL}(M) = E_{One\ elemnt}(M)\mathrm{AF}$$

3.2 Antenna with N elements linear array

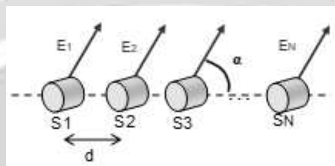

Fig -2: N linear antenna array

With uniform amplitude and equally spaced elements we have:

$$A_k = A_0 \tag{09}$$

$$d_k = kd \tag{10}$$

$$\Phi_k = k\Phi \text{ with } k = [0,\ N-1] \tag{11}$$

Then, the array factor is expressed by:

$$AF(\alpha) = \sum_{k=0}^{N-1} A_0\ e^{j(k\Phi + k\beta d\cos(\alpha))} \tag{12}$$

When, $\Phi + \beta d cos(\alpha) = 0$, AF is maximal.

Then,

$\cos(\alpha) = -\frac{\Phi}{\beta d} = -\frac{\Phi\lambda}{2\pi d}$

When, α =0 then Φ is expressed by:

$$\Phi = -\frac{2\pi d}{\lambda} \tag{13}$$

For phase array radar, target number detectable is expressed by:

$$K < \frac{2N_R}{3} \tag{14}$$

4. SIMULATION

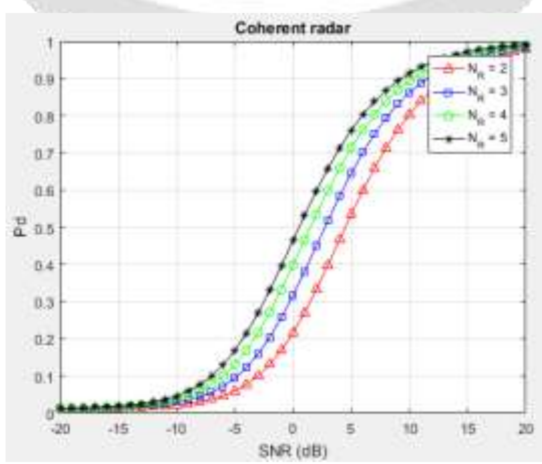

Fig -3: Detection probability of Coherent radar over SNR

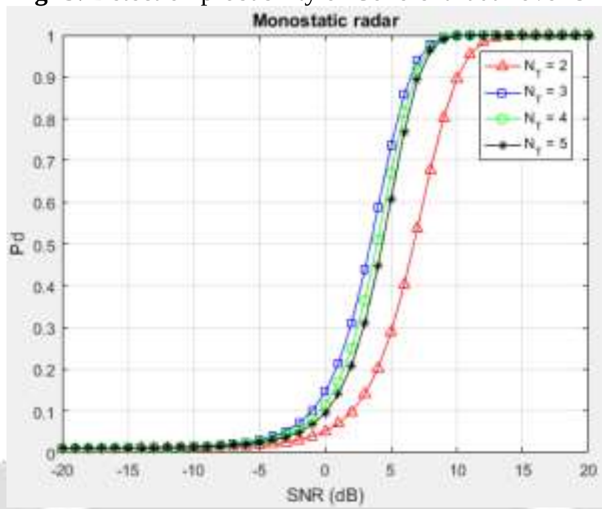

Fig -4: Detection probability of statistical radar over SNR with N_R=5

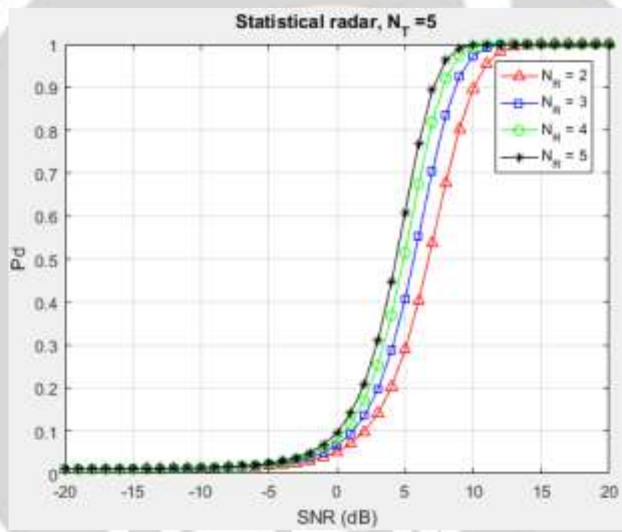

Fig -5: Detection probability of statistical radar over SNR with N_T=5

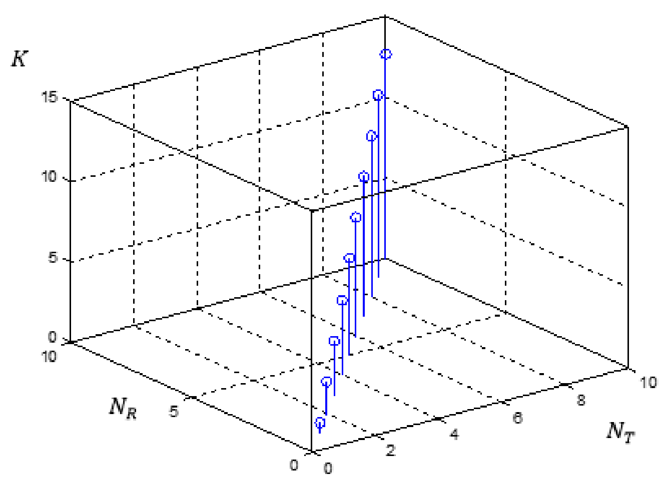

Fig -6: Target number detection of statistical radar

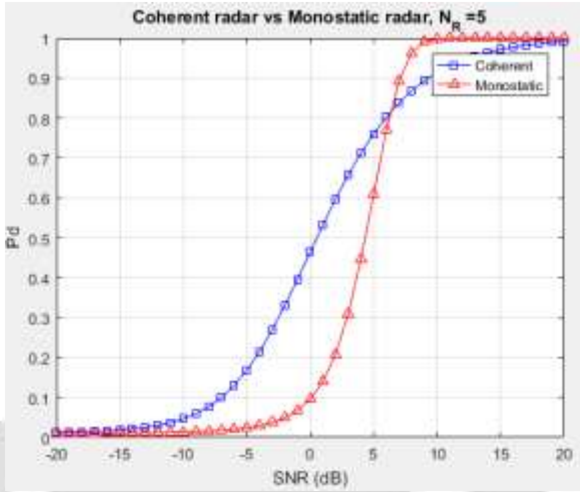

Fig -7: Detection probability of statistical and coherent radar over SNR

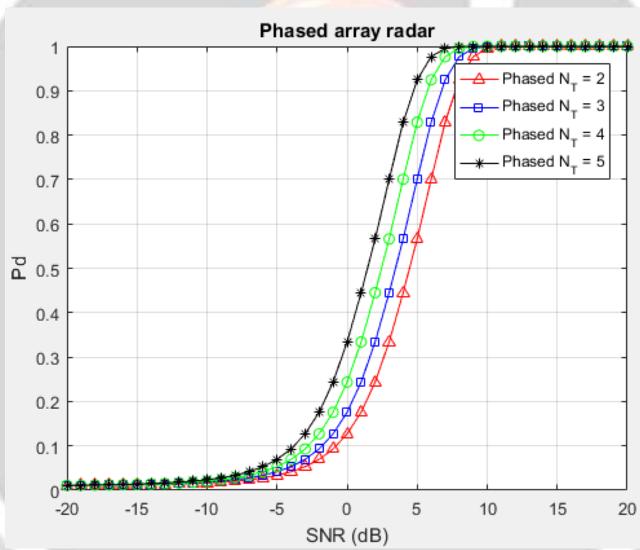

Fig -8: Detection probability of phase array radar over SNR

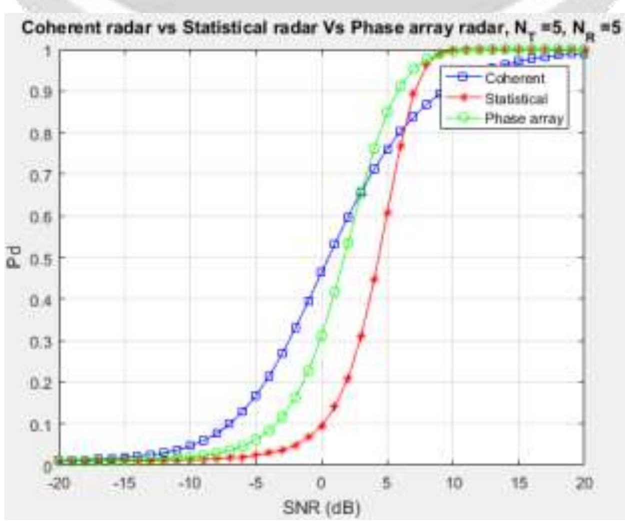

Fig -9: Detection probability of statistical, coherent radar and phased array over SNR

For antenna array simulation, dipole antenna is used and we suppose that:

- $\lambda = 2m$
- $d = \lambda/2$
- $N = 2$

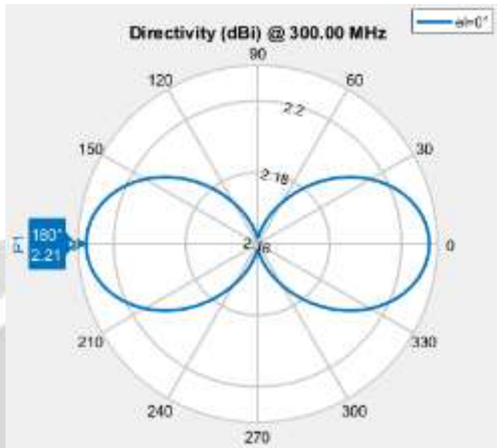

Fig -10: Pattern of one dipole antenna

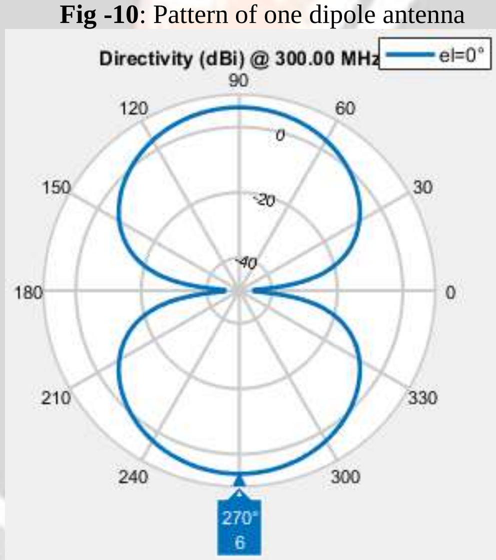

Fig -11: Pattern of two antenna dipole array with $\Phi_k = 0$

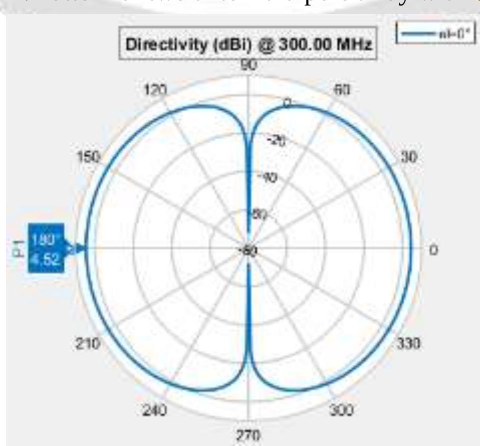

Fig -12: Pattern of two antenna dipole array with $\Phi_k = -2\pi d/\lambda$

5. RESULTS

With Fig -3, Fig -4, Fig -5, detection probability of both statistical MIMO radar and Coherent MIMO radar increases with number antenna and signal to noise ratio. The detection performance of the Statistical MIMO radar decreases as the number of transmit antennas increases. The reason for this is that the power supplied to each transmitting antenna decreases as the number of transmitters increases.
With Fig -7, about detection probability, statistical MIMO radar is more performant than coherent MIMO radar for high values of SNR, but coherent radar is performant for low values of signal to noise ratio.
With Fig -8, phased array radar performance increase with number of transmitter antenna.
With Fig -9, coherent MIMO is performant over Statistical MIMO radar and phased array for low signal to noise ratio. Phase array detection probability is performant over statistical MIMO radar. However the maximum number of targets that can be uniquely identified by a MIMO radar.
With Fig -11, when the phase shift is null, pattern of the antenna array is deflecting 90° from a single dipole antenna.
With Fig -12, pattern of antenna array increase with number of antenna element in all directions. Then, the radar range increase. Peak(antenna array) = 2 Peak(single dipole antenna) ➔ 4,52 ≈ 2x 2,21

6. CONCLUSION

MIMO and Phased Array Radar improves traditional radar performance. For phased array radar, several antennas transmit single waveform scaled versions, and for the MIMO radar system, orthogonal waveforms are transmitted over multiple antennas. Thus, MIMO radar improves the signal-to-noise ratio, the probability of detection of the targets. Phased array radar, improves radar range and the signal-to-noise ratio.

7. REFERENCES

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