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Performance Characteristics: The Phase Mimo Radar Technique

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Abstract: The phased-MIMO radar technology is the combination of the phased array and the MIMO (Multiple Input Multiple Output) radar technique. This proposed new technique gives the benefits of MIMO radar without sacrificing the main benefits of phased-array radar, which is the gain in coherent processing on the emission side. The intention of the proposed technique is to divide the transmission network into a number of overlapping subnets. This means that each subnet is used to consistently transmit a waveform that is orthogonal to the waveforms transmitted by the other subnets. The MIMO technique applied to traditional phased array radar has been investigated and has yielded many advantages over the phased array radar system and the MIMO radar. A Coherent processing gain can be obtained by designing a weight vector for each subnet to form a beam in a particular direction in space.

The proposed technique compared to the previous techniques, which was a phased array and a MIMO radar, is analytically demonstrated and simulated by MATLAB analysis of the corresponding beam patterns and of the overall beam patterns.

Keywords: Multiple input multiple output radar, phased-array radar, coherent processing gain, transmit/receive beamforming.

I. INTRODUCTION

Phased-controlled antennas are widely used in different radars to provide the direction of the beam of radiated or received electromagnetic signals operating at the same frequency. The beam can be directed in the desired direction by controlling the phase shifts between the elements. It offers a directional gain useful for detecting/tracking weak targets and suppressing interferences from the side-lobe from other directions. If we want to focus the antenna beams in different directions, multiple antennas or a multibeam antenna are needed. The desire for new, more advanced antenna matrix technologies is driven by the demands of many new applications. Another strategy is the use of multiple-input multiple-output (MIMO), which has received much attention in recent years, particularly in radar society. The essence of the MIMO antenna array used in radars is the use of multiple antennas to transmit orthogonal waveforms or non-coherent waveforms and multiple antennas to receive echoes reflected by the target. The MIMO array has two advantages: an increase in spatial diversity and an increased degree of freedom (DOF) due to the fact that a MIMO array achieves a larger virtual opening than the physical array of its phased-array counterpart. Although the MIMO array has many advantages over conventional phased-arrays, the first mentioned directional gain is missing. The intermediaries between the two extremes were considered by jointly exploiting the benefits of the phased-array and MIMO array. An idea by splitting the transmission network into different incoherent sub-openings has been introduced. Near-form expressions have been developed to obtain a broad transmission beam-diagram. Based on this work, a phased-MIMO technique was investigated, which benefits from the advantages of the MIMO array without sacrificing the main benefits of the phased array in obtaining coherent processing gain.

In this article, we propose a MIMO antenna radar in phase with frequency diversity. We also divide the antenna array into numerous subnets. However, unlike previous publications in which an equal carrier frequency is used in each subnetwork, a separate carrier frequency is used in each subnetwork. That is, a small frequency increase is used in every subnet. This offers additional options for removing lobes from the network. This is especially useful when the subnets are scarce (although the random positioning of the antennas can break the lobes of the array, this will result in higher side lobes). The most important thing is that by optimally designing the frequency increases over the subnets, we can realize a range-dependent beam-pattern that is of great importance because it offers many new applications. The originality of this article lies in the study of the compromise between the gain in spatial diversity, the gain in spatial multiplexing, and the effect depending on the range of the phased MIMO radar.

MIMO (Multiple Input and Multiple Output Radar) has been developed based on the idea of using multiple antennas to send multiple waveforms and multiple antennas to receive echoes reflected by the target. Although the MIMO radar has a number of advantages, including the energy integration capacity of different waveforms, it suffers from a significant disadvantage, namely the lack of profit in consistent send/receive processing gain. The integration of the MIMO concept into the radar design to ensure independence between the transmitted signals, with each transmitting antenna transmitting an orthogonal signal, offers clear advantages compared to the phased array system compared to the maximum number of targets. Phased array transfer was

first shown in 1905 by Nobel Prize winner Karl Ferdinand Braun,

who demonstrated improved transmission of radio waves in one direction. During the Second World War, Nobel Prize winner Luis Alvarez used phased array transmission in a fast direction radar system for a "controlled approach to the ground", a system to facilitate

aircraft landing.

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II. BACKGROUND AND MOTIVATION

To facilitate the following comparison between our approach and phased array radars and MIMO radar, this section provides a brief overview of phased array radars and MIMO radar.

III. METHODOLOGY: PHASED-MIMO RADAR

The general phased MIMO radar, we divide the transmission network into different subnetworks (K) that can be separated or superimposed, as shown in Figure 1. Each transmission subnetwork can consist of any number of items ranging from 1 to M. Unlike the generally phased MIMO network discussed in the literature, in this article all elements of each subnetwork are used to coherently transmit the signal S_k (t) at a clear carrier frequency. That is, small frequency increase is used between the subnets. A beam can be formed by any subnetwork in a certain direction. The beamforming weight vector can be properly designed to maximize the profit of consistent processing. At the same time, different waveforms are broadcast by different subnets.

Suppose the kth subnetwork consists of $N_k < M$ transmission elements, the equivalent baseband signal model can be modeled as

$$S_k(t) = \sqrt{\frac{M}{K}}\ \phi_K(t) w^*_k,\ k = 1, 2, \ldots K \quad \text{(i)}$$

with

$$\int_{T_p} \phi_k(t)\phi_{k'}{}^H(t)\, dt = \delta\,(k - k') \quad \text{(ii)}$$

Here K is the number of subnetworks, w_k is the complex vector M x 1 unit standard consisting of N_k beamforming weights corresponding to the active antennas of the kth subnetwork, i.e. number of non-zeros in w_k is equals to N_k and the number of zeros is equal to M - N_k . Note that $\sqrt{\frac{M}{K}}$ is used to obtain an identical transmit power constraint for later comparison, meaning that the transmit energy in a pulse repetition interval (PRI) is given by

$$\int_{T_p} S_k{}^H(t)\, S_k(t)\, dt = \frac{M}{K} \quad \text{(iii)}$$

Either the carrier frequency is in each subnetwork

$$f_k = f_0 + (k\text{-}1)\ \Delta f \quad \text{(iv)}$$

Where Δf is the frequency offset. The signal reflected by a target in the direction θ can be modeled as

$$s_r\,(t,\theta) = \sqrt{\frac{M}{K}}\,\sigma\,(\theta)\,\sum_{k=1}^{K} w^H{}_k\, a_k\,(\theta)\, e^{-j2\pi f_k \tau_k}\, \phi_k\,(t) \quad \text{(v)}$$

Where σ (θ) is the target reflection coefficient, the beamforming vector N_k x 1 are the W_k and a_k (θ) that only contain the elements that corresponding to the active elements of the kth subnetwork are steering vector, and the slant range (r) depending on $\tau_k(\theta)$ is the signal propagation time required for the kth subnetwork. After proper filtering of the signal received by each of the waveform ϕ_K (t), we can obtain a data vector KN x 1

$$s_r\,(t,\theta) = \sqrt{\frac{M}{K}}\,\sigma\,(\theta)\,[c(\theta) \odot d\,(\theta,r)] \otimes b\,(\theta) \quad \text{(vi)}$$

here ⊙ is the Hadamard (element-wise) product, ⊗ is the Kronker product. The c (θ) and d (θ) are K x 1 vectors defined as

$$c\,(\theta) \doteq [W_1{}^H\, a_{\theta_1}\,(\theta),\ W_2{}^H\, a_{\theta_2}\,(\theta), \ldots, W_K{}^H\, a_{\theta_K}\,(\theta),]^T \quad \text{(vii)}$$

$$d\,(\theta,r) \doteq [e^{-j2\pi f1\tau1\,(\theta)},\ e^{-j2\pi f2\tau2\,(\theta)}, \ldots, e^{-j2\pi fK\tau K\,(\theta)}]^T \quad \text{(viii)}$$

$$\phi_K\,(t) \doteq [\phi_1\,(t),\ \phi_2\,(t), \ldots\ \phi_K\,(t)]^T \quad \text{(ix)}$$

Transmission beam formation can be used for different subnets so that certain requirements for beam configuration and/or transmission power are fulfilled. In this article we use the conventional non-adaptive beam reception technology for transmission reception that is widely used in antenna arrays.

When the conventional non-adaptive beam former is used, the transmission beam former can be written as

$$W_k = \frac{a_{k(\theta_0)}}{\|a_{k(\theta_0)}\|} \quad \text{(x)}$$

Similarly, the weight vector of the received beam former is

$$W_R \triangleq u\,(\theta^0, r^0) \quad \text{(xi)}$$

The corresponding standard send-receive beam pattern is expressed in

$$G\,(\theta) \doteq \frac{|W_R{}^H\, u\,(\theta,r)|^2}{|W_R{}^H\, u\,(\theta_0,r_0)|^2} \quad \text{(xii)}$$

IV SIMULATION RESULTS AND DISCUSSION

Table- I: Network Parameters

Sender array equipped with M collocated antennas	10
Receiving array (N)	10
the inter-element spacing (d_T)	0.5
Subnets (K) (1 ≤ K ≤ M)	4
Interfering targets located at directions	−30◦ and −10◦
Interference Power (INR)	50dB
Target Power	0dB
Frequency (f_0)	10GHz
Frequency offset (Δf) varies	0(initial)

Assumed Δf = 0 it means that the array is simple phased-MIMO array. Assumed the following simulation parameters: M = N = 10, f_0 = 10 GHz, d_T = 0.5 and K = 4. In this case, the beam-patterns are range independent. From Figure 1, we can see that the phased-array has a directional gain while the MIMO array has no directional gain. From Figure 2, we can see that the phased-array has no diversity gain while the MIMO array has a diversity gain. From Figure 3, we can observed that the cases phased-array and MIMO array have nearly the same overall transmit-receive beam-pattern; however,

the phased-MIMO array has a better overall transmit-receive beam-pattern. Since the aperture of the whole array is always greater than the aperture of the subarrays, the transmit beam-pattern of the phased MIMO radar represents a compromise between MIMO beam-patterns and phased-array radars. From Figure 1, we can see, the reduction of the aperture of the subnetwork results in the beam-pattern of the phased-MIMO radar beam with a wider main beam and slightly higher lateral-lobe levels compared to the beam-pattern of the matrix radar phase beam. This small loss in the form of the beam-pattern is repaid to a larger gain in the waveform diversity beam-pattern

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as shown in Figure 2. We can see from Figure 2 that the phased-array radar does not obtain waveform diversity gain (0 dB flat pattern), while the waveform diversity beam-patterns of the MIMO and phased MIMO radars are equivalent to conventional beam-patterns offered by the virtual networks of elements M and K, respectively. In Figure 1, we can see that the phased-array radar has the typical conventional beam-pattern with the Main-lobe (with width π /M) centered on θ_s while the MIMO radar has a flat transmission gain (0 dB).

On the other hand, the phased MIMO transfer beam-pattern is characterized by the aperture (actual size) of the individual subnets. Because K $\leq$ M, the waveform diversity beam-pattern of the phased MIMO radar has a wider main-lobe and a higher side-lobe levels, relative to the waveform diversity beam-pattern of the MIMO radar.

However, it can be seen in Figure 3 that the overall form of the send/receive beam-pattern shape for the proposed, the Phased-MIMO radar has been considerably improved as compared to the beam-patterns of the phased-array and MIMO radars. In particular, it should be noted that the overall beam-pattern of the proposed phased-MIMO radar technique is relative to the multiplication of the transmit beam-patterns and the waveform diversity beam-patterns (i.e., relative to the summation of the curves of Figures 1 and 2 in dB). We can also see in Figure 3 that the phased array and MIMO radars have precisely the same global send/receive beam-patterns. On the similar time, a phased MIMO radar has minor lateral-lobe levels as compared to a phased array and MIMO radars.

In specific, the Case (d_T = 0.5 wavelength) is selected and the beam-patterns are plotted based on the formation of corresponding non-adaptive beams for the phased-array, MIMO, and phased-MIMO radars. Therefore, the complexity of the system can also be taken into account, or 4 is the most suitable value for K.

Table II: Comparison for different techniques

Techniques	Transmit beam-patterns	Waveform diversity beam-patterns	Overall beam-patterns
Phased Array Radar	has directional gain	has no diversity gain	have nearly the same as MIMO radars overall send/receive beam-patterns
MIMO Radar	has no directional gain	has diversity gain	Nearly same as Phased array radar
Proposed Phased-MIMO radar	has no directional gain	has larger diversity gain compared to both phased-array and MIMO radars	This is considerably enhanced as compared to the beam-patterns of the phased-array and MIMO radars.

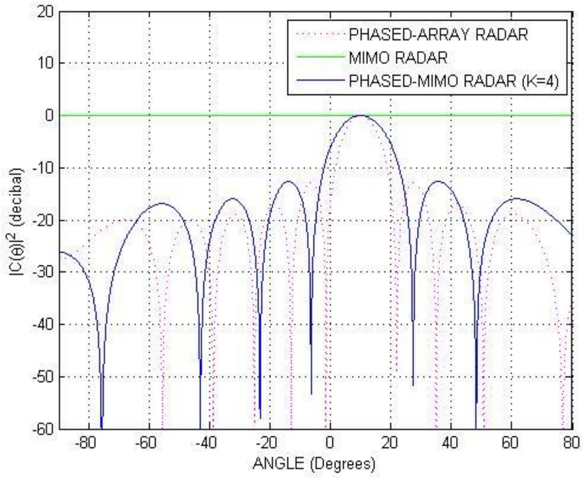

Figure1: Transmit beam-patterns.

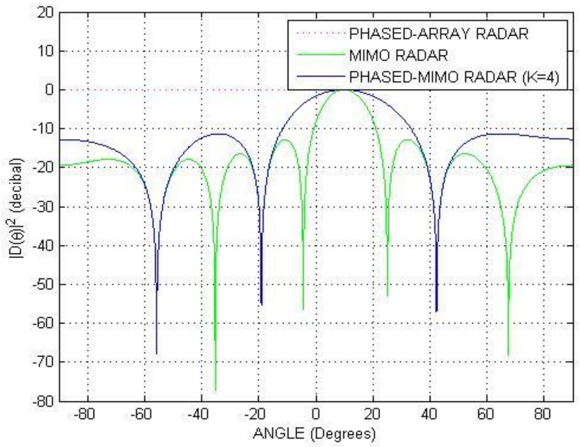

Figure2: Waveform diversity beam-patterns.

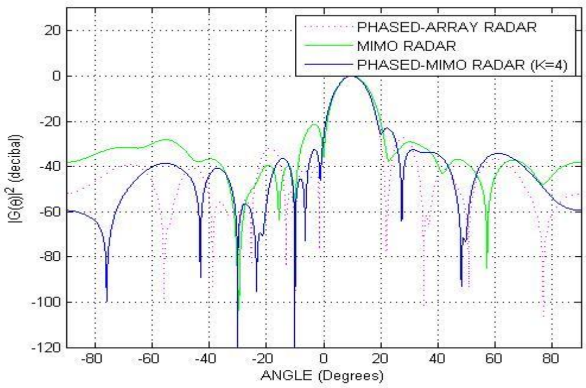

Figure3: Overall beam-patterns.

V. CONCLUSION

The new phased-array MIMO radar antenna technology with emission beam formation, which applies frequency diversity to phased-MIMO radar. This approach divides the series of transmit antennas into several overlapping subnets, each subnet coherently transmitting a different waveform, which is orthogonal to the waveforms transmitted by other subnets, at a separate transmit frequency. That is, a small frequency increase is used in every subnet. Each subnetwork forms a directional beam and all beams can be oriented in different directions. The subnetworks jointly offer flexible business modes, such as the MIMO

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network that offers a gain in spatial diversity and a phased-array that offers a coherent directional gain. In addition to combining the advantages of the phased array in directional amplification and the MIMO radar in obtaining spatial diversity, this system also offers range-dependent bundle diagrams that offer many new application possibilities. The proposed technique has shown to combine the benefits of phased array radar with the benefits of MIMO radar and therefore the performance is superior. The Simulation results confirm our theoretical observations and show the effectiveness of the proposed progressive MIMO radar technique. The system model and the send/receive beam have been derived. Various practical problems related to this new network are also being studied. System performance is examined by analyzing the send-receive beam-patterns. The proposed technique is authenticated by mathematical simulation results. Only non-adaptive beamforming algorithms are considered in this article. If an adaptive beamforming algorithm is used. There is a technical challenge to achieve the real covariance matrix because the transmission beam-pattern is dependent on the range.

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