



Design and Optimization of a Thinned Multi-Face Phased Array Antenna for L-Band Radar

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ARTICLE INFO	ABSTRACT
Published Online: 07 January 2026	In this paper, we present numerical results on the application of a genetic algorithm (GA) to thin a 640-element rectangular array (32×20) operating at 3.2 GHz. The inter-element distance is $\lambda/2$ (λ is the wavelength corresponding to the frequency 3.2 GHz). We first determine the optimal number of elements required for a thinned array steered to broadside ($\theta = 0^\circ$, $\phi = 0^\circ$) while maintaining a sidelobe level below -20 dB. We then investigate the beamforming performance for four scan directions: $(-20^\circ, 10^\circ)$, $(-35^\circ, 20^\circ)$, $(0^\circ, 15^\circ)$, and $(45^\circ, 35^\circ)$. Finally, we apply the same thinning procedure to the four faces of a phased array antenna system intended for radar applications. The percentages of active elements for the four faces are 53.1%, 53.7%, 58.1%, and 59.3%, respectively.
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KEYWORDS: Phased array, thinning, genetic algorithm, beamforming, multi-face Radar	

I. INTRODUCTION

Phased array antennas are fundamental to modern radar systems because they enable agile, precise beamforming and rapid electronic scanning without mechanical motion. By adjusting the relative phase and amplitude at each radiating element, phased arrays can steer narrow beams, form multiple simultaneous beams, and adapt beam shapes in real time, which enhances target detection, tracking accuracy, and clutter rejection [1,2]. These capabilities are crucial for airborne and shipborne surveillance radars, where wide-area search and fast track updates are required, as well as for fire-control radars that demand high accuracy and low latency [2]. Phased arrays also support advanced radar modes such as synthetic aperture radar (SAR) and inverse SAR for high-resolution imaging, as well as low probability of intercept (LPI) operation through agile beam and waveform control [2,3]. In automotive radar, compact phased arrays at millimeter-wave frequencies provide fine angular resolution and multi-target tracking, enabling advanced driver-assistance systems and autonomous driving functions [4]. Consequently, phased array antennas form the technological core of current and next-generation radar platforms across defense, aerospace, and automotive domains.

Beyond basic beam steering, many techniques are employed to improve radar phased array architectures, enhancing performance, efficiency, and robustness [5,6]. Examples include adaptive beamforming and space-time adaptive processing (STAP) for interference and clutter suppression [1,2]; subarraying and sparse array designs to reduce hardware complexity and cost while maintaining angular resolution [1,3]; and digital beamforming with fully active electronically scanned arrays (AESAs) to enable multiple simultaneous beams and agile waveform control [2,3]. Additional advances such as mutual-coupling compensation, calibration algorithms, and integrated RF/mmWave front-ends further refine array patterns and stability, supporting the stringent requirements of modern airborne, spaceborne, and automotive radar systems [1–4]. Another important technique is array thinning, in which only a subset of the potential element positions is populated while maintaining an aperture of the same overall size. Properly optimized thinning patterns can preserve main-lobe width and acceptable sidelobe levels with significantly fewer active elements, thereby reducing the number of transmit/receive modules, RF chains, and associated control electronics [1,3,5]. This reduction directly lowers hardware cost, DC power consumption, and thermal load, which is

especially beneficial for large airborne, spaceborne, and shipborne radar arrays where power and cooling are constrained [1,3,5].

Several design methods are used to realize thinned phased arrays while controlling sidelobes and preserving beamwidth. Classical approaches include deterministic schemes such as periodic and aperiodic thinning, minimum-redundancy arrays, and Dolph–Chebyshev-based deterministic layouts that trade off sidelobe level and element count [1,3,5]. More advanced techniques use numerical optimization, for example genetic algorithms, simulated annealing, particle swarm optimization, and convex or gradient-based methods to select the active element set that minimizes sidelobe levels or pattern ripple under a constraint on the number of elements and total radiated power [5–7]. Stochastic (random or quasi-random) thinning strategies are also employed to decorrelate grating lobes and distribute sidelobe energy more uniformly, which can be advantageous in wideband and wide-scan radar applications [5, 7].

Among the thinning techniques of phased array antennas, Genetic Algorithms (GAs) are widely used because they can efficiently search large, discrete design spaces where the presence or absence of each element is encoded as a binary gene. By defining a fitness function that penalizes high sidelobe levels, grating lobes, or pattern ripple while constraining the number of active elements, GAs iteratively evolve thinned layouts that achieve near-optimal trade-offs between aperture performance and hardware complexity [5,7,8]. This approach has been successfully applied to both linear and planar arrays, often outperforming classical deterministic thinning in terms of sidelobe control for a given element count and thus providing substantial reductions in active channels and power consumption [8,9].

In this work, we applied a genetic algorithm (GA) to thin the four faces of a phased array antenna designed for L-band radar applications. Each face of the antenna system is a 32×20 rectangular array, and was thinned to optimize the number of active elements while preserving beamforming capabilities and maintaining low sidelobe levels (below -20 dB). The thinning factors for the four faces are 53.1%, 53.7%, 58.1%, and 59.3%, respectively.

II. GENETIC ALGORITHM AND DESIGN PROCEDURE

Genetic algorithms (GAs) are stochastic optimization methods inspired by natural evolution, operating on a population of candidate solutions encoded as chromosomes (often binary strings). Each chromosome is evaluated by a fitness function that quantifies how well it satisfies the design objectives and constraints; fitter individuals are probabilistically selected for reproduction via operators such as selection, crossover, and mutation [10-11]. Crossover

recombines genes from two parents to form offspring, promoting exploration of new regions in the search space, while mutation randomly alters genes to maintain diversity and reduce the risk of premature convergence [1]. Over successive generations, this evolutionary process tends to concentrate the population around high-fitness regions, enabling GAs to find near-optimal solutions in complex, multimodal, and discrete design spaces where gradient-based methods are difficult to apply [11-12].

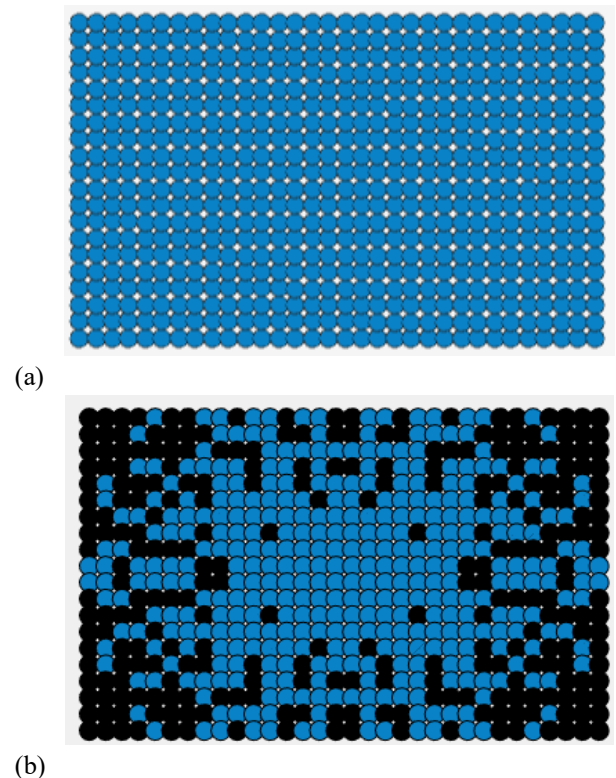


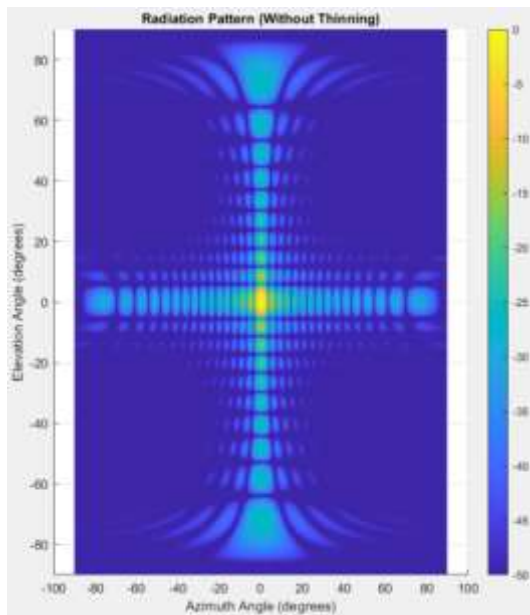
Figure 1: Schema of the 2D rectangular array of size 32 by 20 elements: (a) full array, and (b) thinned array.

For thinning a rectangular phased array (Fig. 1, the GA principle is applied by encoding the on/off state of each potential element position as a gene in a 2D (flattened) binary chromosome, where “1” denotes an active element and “0” an inactive one. The fitness function is typically defined from the resulting 2D array factor—evaluated over scan angle and frequency—to penalize high peak sidelobe levels, grating lobes, or pattern distortion while constraining the total number of active elements (and sometimes the total radiated power) [5,7-9]. During GA iterations, crossover exchanges sub-blocks or rows/columns between parent chromosomes, and mutation flips randomly selected element states, thereby exploring a wide variety of thinning patterns over the aperture. Through this evolutionary process, the GA converges to thinned rectangular layouts that preserve main-beam width and acceptable sidelobe behavior with significantly fewer elements, yielding reductions in RF chains, power consumption, and cost suitable for large radar arrays [5,8,9].

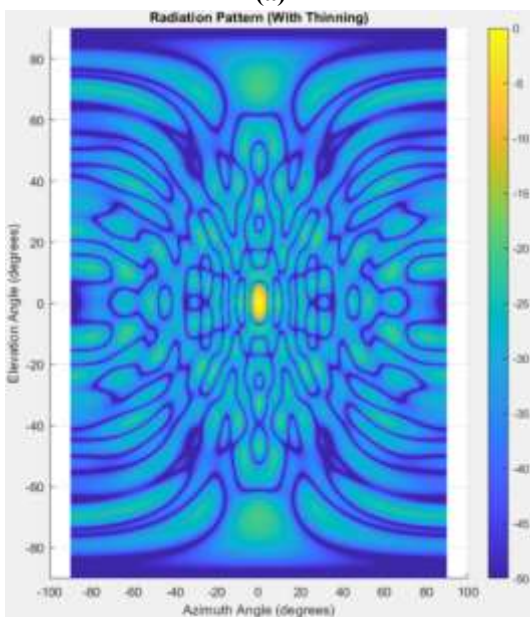
III. RESULTS AND DISCUSSIONS

1- Single Face Array

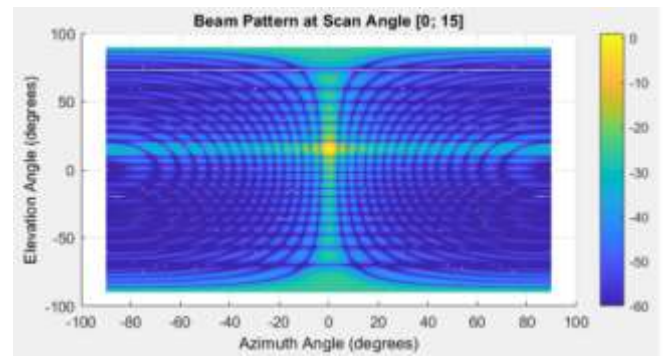
We simulated, using Ansys HFSS, a single face of the antenna system, consisting of a 32×20 rectangular array (640 isotropic radiating sources) with an inter-element spacing of $\lambda/2$, where λ is the wavelength at 3.2 GHz. Figure 2 shows a color map of the radiation patterns for both the full and thinned arrays at 3.2 GHz in the broadside direction. It can be observed that, after thinning 59.3% of the total number of elements while maintaining an SLL of -20 dB, the main beam remains directed toward the desired broadside direction ($0^\circ, 0^\circ$), despite an increase in the number of sidelobes.



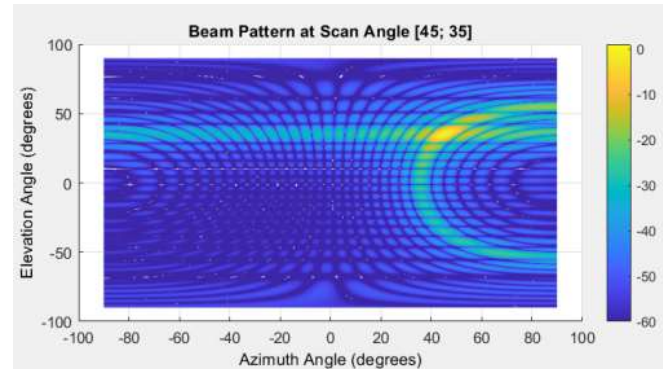
(a)



(b)



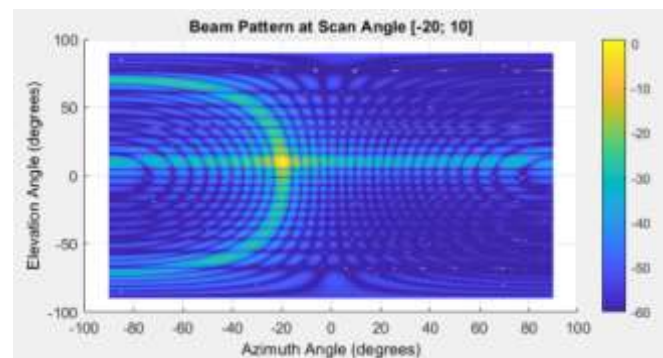
(c)



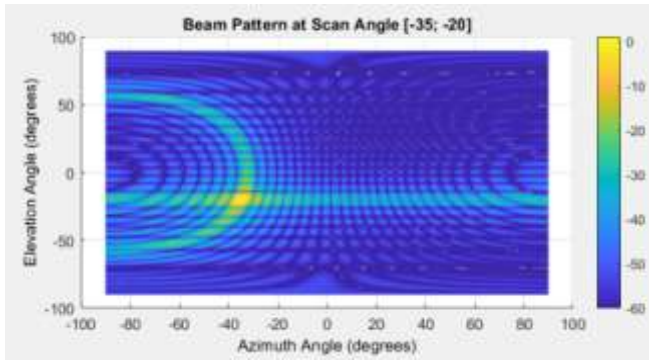
(d)

Figure 2: 3D response pattern of the single face: (a) full array, and (b) thinned array.

Figure 3 shows the radiation patterns of the thinned array for the scan directions $(-20^\circ, 10^\circ)$, $(-35^\circ, 20^\circ)$, $(0^\circ, 15^\circ)$, and $(45^\circ, 35^\circ)$. The results indicate that, despite a reduction of approximately 40.7% in the number of active elements, the array is still able to steer its main beam accurately toward the desired directions. As in the broadside case, the number of sidelobes increases; however, the sidelobe level remains below -20 dB. These findings confirm that array thinning can significantly reduce hardware complexity and cost while preserving acceptable beamforming performance.



(a)



(b)

Figure 3: 3D response patterns showing the Beamforming of the thinned array for different scanning angles: (a) $(-20^\circ, 10^\circ)$, (b) $(-35^\circ, 20^\circ)$, (c) $(0^\circ, 15^\circ)$, (d) $(45^\circ, 35^\circ)$,

2- Multi-Faces Array

The proposed phased array antenna system consists of four identical faces, each covering 90° of the surrounding surveillance sector. To improve overall coverage, the faces are tilted by 15° , as illustrated in Fig. 4. Each face is implemented as a 32×20 rectangular array of 640 isotropic radiating elements, with an inter-element spacing of $\lambda/2$.

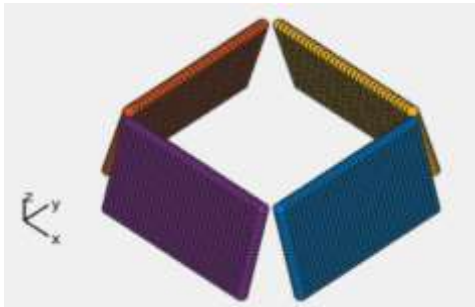


Fig.4: Geometry of the 4 faces full antenna array (genrated with Matlab toolbox)

The genetic algorithm was applied independently to each of the four arrays. The resulting radiation patterns for the thinned configurations are presented in Fig. 5. The thinning factors for faces 1 through 4 are 53.1%, 53.7%, 58.1%, and 59.3%, respectively, with corresponding sidelobe levels of -20.4 , -20.0 , -20.1 , and -20.3 dB.

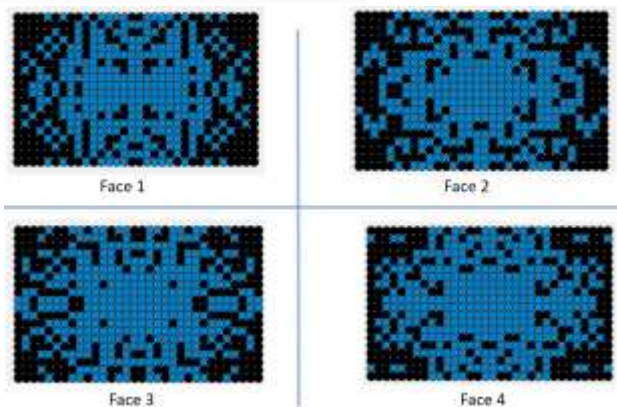
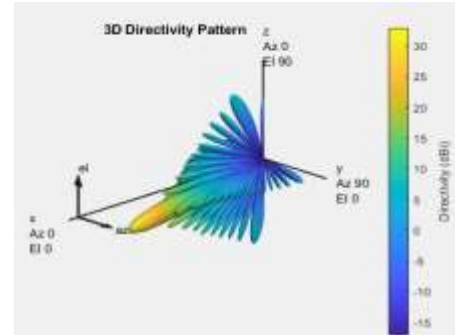
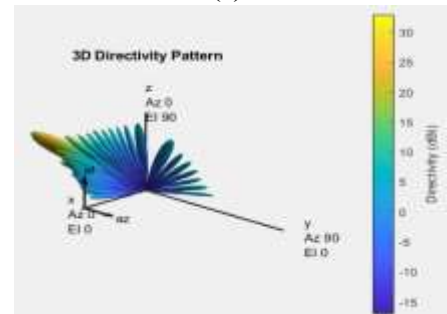


Fig. 5: Schemas of the 4 thinned faces of the phased array antenna system

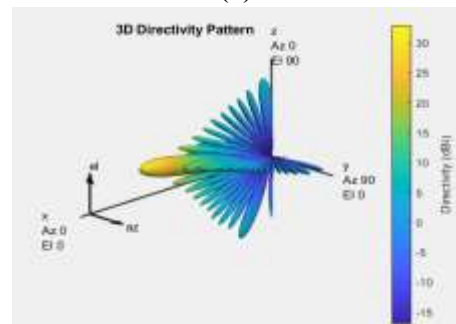
The simulated 3D radiation patterns of the thinned arrays are shown in Fig. 5. The four beams are oriented toward different sectors of the surveillance region surrounding the multi-face antenna system. Each pattern exhibits a highly directive main beam accompanied by multiple sidelobes with relatively low levels. This beamforming configuration enables effective target detection and tracking over all azimuthal directions in space.



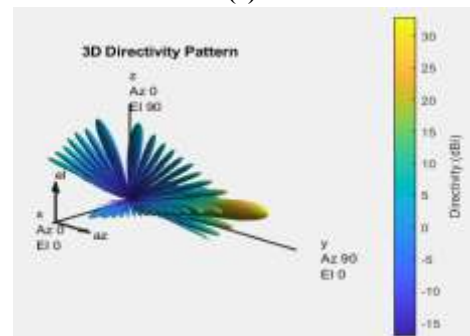
(a)



(b)



(c)



(d)

Figure 5: 3D radiation patterns of the 4 thinned rectangular arrays corresponding to the 4 faces of the phased array antenna system.

IV. CONCLUSION

In conclusion, this study has demonstrated the effectiveness of the genetic algorithm (GA) for thinning a 640-element (32×20) rectangular array operating at 3.2 GHz. An optimal trade-off between the number of active elements and radiation performance was achieved for broadside operation ($\theta = 0$, $\phi = 0$), while maintaining sidelobe levels below -20 dB. The beamforming capabilities of the optimized array were then assessed for four scanned directions: $(-20^\circ, 10^\circ)$, $(-35^\circ, 20^\circ)$, $(0^\circ, 15^\circ)$, and $(45^\circ, 35^\circ)$, confirming that satisfactory performance can be preserved under scanning. Finally, the same thinning strategy was successfully extended to a four-face phased array antenna intended for radar applications, yielding activation percentages of 53.1%, 53.7%, 58.1%, and 59.3% for the four faces, respectively. These results highlight the potential of GA-based thinning for reducing array complexity and cost while retaining suitable beamforming characteristics.

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