QUANTUM-INSPIRED ANTENNA ARRAY DESIGN

Report submitted to GITAM (Deemed to be University) as a partial fulfillment of the requirements for the award of the Degree of Bachelor of Technology in (Electrical Electronics and Communication Engineering)

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DECLARATION

We hereby declare that the work presented in this report, titled "Quantum Inspired Antenna Array Design," is the original work of the project team. This work has not been submitted in whole or in part for any other degree or diploma at this or any other university. All sources of information and all materials used have been properly acknowledged and referenced. This report was completed under the guidance of our project guide, **Dr. Avishek Chakraborty**.

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CERTIFICATE

This is to certify that MEESALA EESHA (Regd. No.: BU22EECE0100424), MOKSHAGNA REDDY (Regd. No.: BU22EECE0100089), and ALURU RAKSHITHA (Regd. No.: BU22EECE0100222) has satisfactorily completed Mini Project Entitled in partial fulfillment of the requirements as prescribed by University for VIIth semester, Bachelor of Technology in "Electrical, Electronics and Communication Engineering" and submitted this report during the academic year 2025-2026.

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Chapter 1: Introduction

1.1 Overview of the problem statement

The traditional methods for optimizing antenna arrays, including Genetic Algorithms (GA) and Fast Fourier Transform (FFT), require a lot of computational power. This project tackles this issue by suggesting and examining a new approach that uses quantum-inspired methods. The aim is to create faster, smarter, and more efficient communication systems.

1.2 Objectives and goals

The main objective is to design and analyze antenna arrays using quantum-inspired algorithms. This will improve performance metrics like null depth, sidelobe suppression, and directivity.

The specific goals of the project are:

- Use Quantum Fourier Transform (QFT) for faster computation of radiation patterns.
- Integrate a Quantum Genetic Algorithm (QGA) to optimize array parameters.
- Compare the results against classical methods like GA, Discrete Fourier Transform (DFT), and FFT.
- Test the proposed methods on 16 and 32-element arrays using simulations.
- Explore potential applications in 5G/6G communication, radar, and satellites.

Chapter 2 : Literature Review

SL.NO	Title/Name of the paper	Author Name	Concept	Method Applied	Advantages and Disadvantages
1	Radiation Pattern Synthesis for Adaptive Antenna Arrays Using Improved Quantum Genetic Algorithm	Ming Liu, Chao-Wei Yuan, Tian-Song Li, Hong-Hai Wu	This paper focuses on creating radiation patterns for adaptive antenna arrays. The goal is to maximize the desired signal while reducing interference. It presents an improved Quantum Genetic Algorithm (QGA) that mixes quantum computing ideas, like qubits and superposition, with evolutionary optimization.	The improved Quantum Genetic Algorithm (QGA) optimizes the amplitudes and phases of antenna arrays. A simulation of a 32-element linear antenna array was conducted to test its performance.	Advantages: The method provides better interference suppression than traditional Genetic Algorithm (GA). It achieves deeper nulls at around -85 dB compared to about -70 dB with GA. It also has faster convergence due to adaptive rotation gates. Disadvantages: The computational complexity is greater than that of classical GA. Its effectiveness relies on tuning parameters, such as rotation angles and population size.
2	Array Antenna Power Pattern Analysis Through Quantum Computing	Luca Tosi, Nicola Anselmi, Alessandro Polo, Paolo Rocca	This paper looks at the power pattern of uniformly spaced linear antenna arrays using Quantum Computing. It uses the Quantum Fourier	Quantum Fourier Transform (QFT) was implemented on IBM Q Experience with the Qiskit framework to analyze power	Advantages: This approach offers exponential speed-up ($O(\log^2 N)$) over classical DFT ($O(N \log N)$). It allows for efficient computation of array power

			Transform (QFT) algorithm to compute radiation patterns quickly.	patterns in array antennas. It was compared with the classical Discrete Fourier Transform (DFT).	patterns and has been tested on actual quantum hardware (IBM Q). Disadvantages: It is limited by the constraints of current quantum hardware, such as the small number of qubits and noise. It is still at the proof-of-concept stage.
3	On the Use of Quantum Fourier Transform for Array Antenna Analysis	Paolo Rocca, Luca Tosi, Nicola Anselmi, Andrea Massa	This paper presents a quantum computing approach for analyzing linear phased array (PA) power patterns. It reformulates the classical Discrete Fourier Transform (DFT) process into a Quantum Fourier Transform (QFT) framework to reduce the computational load. The paper focuses on using quantum algorithms for better antenna array analysis.	The excitations of the array are encoded into a quantum state vector, and the QFT is used to compute the radiation pattern. Validation is done using IBM Q Experience and Qiskit simulations, comparing the results with classical DFT to demonstrate accuracy.	Advantages: This method offers an exponential speed-up in computational complexity. The complexity of QFT grows as $O([\log M]^2)$ compared to DFT's $O(M \log M)$. It removes the need for squared modulus computation, matches classical results perfectly, and lowers computational costs for large arrays. Disadvantages: Practical implementation is limited by current quantum hardware capabilities. The results still

					depend on simulated environments (IBM Q and Qiskit) instead of large-scale real quantum processors.
4	Analysis and Synthesis of Phased Antenna Arrays through Quantum Computing	Luca Tosi, Nicola Anselmi, Paolo Rocca, Andrea Massa	This paper presents a method for phased array antennas using quantum computing. It replaces DFT with the Quantum Fourier Transform (QFT). This approach increases efficiency in beamforming and radiation pattern design. It allows for faster and better antenna systems.	The excitations of antenna arrays are encoded into quantum states. QFT and its inverse (IQFT) are applied to compute radiation patterns and synthesize excitations. The implementati on was tested using IBM Qiskit simulations, showing quantum-base d computation of array factors and power patterns.	Advantages: Achieves a significant speed increase in complexity at $O(\log^2 N)$ compared to FFT at $O(N \log N)$. Reduces the time needed for cost evaluations in large phased arrays. Shows proof-of-conc ept success for antenna analysis and synthesis. Disadvantage s: Limited by current quantum hardware, which has a small number of qubits and noise issues. Most results come from simulations; practical large-scale implementati on is not feasible yet.
5	A Novel Real-coded Quantum Genetic Algorithm in Radiation Pattern Synthesis for	Ming Liu, Chao-wei Yuan, Tao Huang	This paper presents a Real-coded Quantum Genetic Algorithm (RQGA) that uses real	The RQGA combines genetic evolution with quantum computing by coding chromosomes	Advantages: ROGA gives better nulls and converges faster than GA and QGA. It also ensures higher

	Smart Antenna		qubits and real quantum gates to represent genes and speed up convergence. Instead of using binary coding, it expresses genes as phase angles, which improves optimization precision and stability. This approach is applied to radiation pattern synthesis for smart antennas.	as real qubits. It uses selection, crossover, mutation, and real quantum gate rotation. This method was tested on a 16-element smart antenna array against GA and QGA.	precision, stability, and effective interference suppression in smart antennas. Disadvantages: RQGA requires a lot of computation and takes a considerable amount of time. Its performance relies on careful tuning of parameters.
6	The Application of Improved Quantum Genetic Algorithm to Beam Forming of Adaptive Array of Smart Antennas	Huahong Ma, Wenxia Wang	This paper presents an Improved Quantum Genetic Algorithm (IQGA) for adaptive beam forming in smart antennas. It combines real-number encoding, quantum gates, and improved variation operators to boost convergence speed and optimization quality.	The algorithm encodes excitation currents as real numbers and evaluates performance by using fitness functions that minimize side lobes and improve null depth. Through selection, mathematical crossover, mutation, and real quantum gate rotation, the population evolves toward optimal solutions.	Advantages: The algorithm reaches deeper nulls while suppressing interference better and converging faster. It increases system capacity and coverage, making it suitable for smart antenna applications. Disadvantages: It is computationally demanding, needing more processing time and resources. Its performance relies on careful adjustment of crossover,

				MATLAB simulations confirm the effectiveness of this strategy.	mutation, and rotation parameters.
7	Optimizing antenna beamforming with quantum computing	Annalise Stockley, Keith Briggs	The paper addresses optimizing large-scale antenna arrays with limited phase shifts, which leads to an NP-hard optimization problem. It demonstrates reformulating this into quadratic minimization problems solvable by quantum annealing.	Reformulated the antenna beamforming problem into a quadratic unconstrained binary optimization (QUBO) form and solved it using a bisection approach with simulated annealing and D-Wave quantum annealer.	Advantages: Handles larger antenna-array optimization than classical methods and offers potential time/energy savings with near-optimal results. Disadvantages: Embedding on quantum hardware is slow, making total run-time comparable to classical methods and introducing small heuristic deviations.
8	The Magic of Quantum Computing for Microwave Computer-Aided Design: A Brief Overview	Lida Kouhalvandi, Serdar Ozoguz, Ladislau Matekovits	Presents how quantum computing can improve microwave and RF design, showing case studies of low-noise amplifiers and phased-array antennas with reduced size, power and computation time.	Applies quantum computing principles (including quantum Fourier transform) to design and optimise microwave components like LNAs and phased-array antennas, reducing computation time and power.	**Advantages:** Enables faster, energy-efficient design of active and passive microwave elements with miniaturisation potential. **Disadvantages:** Still in early stage; limited experimental validation and quantum hardware availability.

Chapter 3 : Strategic Analysis and Problem Definition

3.1 SWOT Analysis

Strengths

- Innovation: Uses quantum principles for a unique approach.
- Performance: QGA offers deeper nulls and faster convergence than classical methods.
- Efficiency: QFT provides an exponential speed-up in analysis.
- Relevance: Addresses key challenges in 5G/6G massive MIMO systems.

Weaknesses

- Complexity: More computationally demanding than simple classical algorithms.
- Sensitivity: Performance depends on careful parameter tuning.
- Hardware: Limited by current, noisy quantum hardware.

Opportunities

- Future Networks: Well-suited for 6G and beyond.
- Hybrid Solutions: Can lead to solvers that combine classical and quantum computing.
- Research: Potential for significant academic contribution.

Threats

- Obsolescence: Rapid tech advancements could lead to better algorithms.

- Limitations: Simulations may not capture real-world hardware issues.
- Competition: Other research groups may be working on similar problems.

3.2 Project Plan - GANTT Chart

Phase	Task	Start	End
Phase 1: Foundation	Proposal & Research	Week 1	Week4
Phase 2: QGA Testing	Code & Results	Week5	Week 10
Phase 3: QFT Implementation	Code & Analysis	Week 11	Week 16
Phase 4: Analysis	Comparative Reports	Week 17	Week 22
Phase 5: Finalization	Final Report	Week 23	Week 24

3.3 Problem statement

- Classical antenna array optimization is computationally intensive and prone to getting stuck in local optima. This project addresses this by using quantum-inspired algorithms, specifically QGA and QFT, to achieve superior performance and a significant reduction in computational time.

Chapter 4 : Methodology

4.1 Description of the approach

The methodology for this project follows a quantum-inspired approach that combines qubit representation, superposition, and quantum gates to improve optimization and speed up convergence. The process uses a two-pronged strategy: QGA and QFT.

- **QGA Process Flow:** The process starts by initializing a population of qubits. Rotation gates are then applied to update the "chromosome," which is the qubit-based solution. The fitness of the solution is assessed by its radiation pattern. This cycle continues until an optimal solution is found. The goal is to optimize the amplitudes and phases of the antenna array elements. The QGA approach achieves deeper nulls and faster convergence compared to classical GA.

- **QFT Process Flow:** Excitations are encoded as a quantum state. A QFT circuit is then applied, and the quantum state is measured to compute the radiation pattern. QFT efficiently computes the radiation patterns of the antenna array, reducing computational complexity from O(NlogN) to O(log^2 N).

The overall system flow involves inputting antenna array geometry and excitation parameters. These are processed by the Quantum-Inspired Algorithm Layer, which uses QGA for optimization and QFT for efficient computation. The performance is evaluated based on metrics such as Sidelobe Level (SLL), nulls, and beamwidth. The output consists of the optimized radiation patterns.

4.2 Tools and techniques utilized

The project will employ several tools and techniques for simulation, analysis, and implementation:

Software and Libraries:

- MATLAB Antenna Toolbox: Used for simulating linear and phased antenna arrays.
- Qiskit (IBM): A Python-based quantum computing SDK used for implementing QFT in antenna analysis.
- ProjectQ: An open-source quantum simulation framework.

Hardware and Platforms:

- IBM Q Experience: Provides access to real and simulated quantum processors for QFT experiments.
- D-Wave Quantum Annealer: Used for solving beamforming optimization problems, which are NP-hard.

Methodologies:

- Quantum Genetic Algorithm (QGA): An optimization technique that provides deeper nulls and faster convergence than classical GA.

- Quantum Fourier Transform (QFT): A quantum algorithm that offers an exponential speedup for computing radiation patterns.

- Quantum-Inspired Metaheuristics: These methods are used to enhance global search and convergence.

4.3 **Design considerations**

The project design includes a system flow that integrates the quantum-inspired algorithms with a performance evaluation layer. The architectural diagrams illustrate the separate process flows for both QGA and QFT, demonstrating how they work together to produce optimized patterns. The project will test the algorithms on both 16 and 32-element arrays and measure key metrics like null depth, beamwidth, sidelobe level, and convergence speed to validate the approach.

Chapter 5 : Implementation

5.1 Description of how the project was executed

5.2 Challenges faced and solutions implemented

Chapter 6: Results

6.1 outcomes

6.2 Interpretation of results

6.3 Comparison with existing literature or technologies

Chapter 7: Conclusion

Quantum-inspired methods offer a highly promising approach for complex antenna array optimization. The **Quantum Genetic Algorithm (QGA)** provides superior performance, achieving deeper nulls and faster convergence than classical GAs. Additionally, the **Quantum Fourier Transform (QFT)** offers a significant computational advantage for radiation pattern analysis, reducing complexity and computation time. The feasibility of these methods has been validated through simulations on frameworks like IBM Qiskit, demonstrating their ability to match classical results while paving the way for future speed-ups with advancing quantum hardware.

Chapter 8 : Future Work

Quantum-inspired methods have emerged as a highly promising approach for solving complex antenna array optimization problems. The **Quantum Genetic Algorithm (QGA)**, for instance, has demonstrated superior performance over classical GAs, achieving significantly deeper nulls and faster convergence. This leads to better interference suppression and more precise radiation patterns. Furthermore, the **Quantum Fourier Transform (QFT)** provides a major computational advantage for radiation pattern analysis, reducing complexity and computation time exponentially. While current implementations rely on simulations, such as those on IBM Qiskit, these methods have been successfully validated, proving their feasibility and potential to usher in a new era of faster and more efficient antenna design for future technologies like 6G

References:

1. M. Liu, C.-W. Yuan, T.-S. Li, and H.-H. Wu, "Radiation Pattern Synthesis for Adaptive Antenna Arrays Using Improved Quantum Genetic Algorithm," in *Proceedings of the 2018 IEEE International Conference on Mechatronics and Automation (ICMA)*, Changchun, China, 2018, pp. 2008-2013.
2. L. Tosi, N. Anselmi, A. Polo, and P. Rocca, "Array Antenna Power Pattern Analysis Through Quantum Computing," *IEEE Transactions on Antennas and Propagation*, vol. 68, no. 12, pp. 8387-8395, Dec. 2020.
3. P. Rocca, L. Tosi, N. Anselmi, and A. Massa, "On the Use of Quantum Fourier Transform for Array Antenna Analysis," *IEEE Antennas and Wireless Propagation Letters*, vol. 18, no. 1, pp. 110-114, Jan. 2019.
4. L. Tosi, N. Anselmi, P. Rocca, and A. Massa, "Analysis and Synthesis of Phased Antenna Arrays through Quantum Computing," *IEEE Access*, vol. 7, pp. 17772-17781, Dec. 2019.
5. M. Liu, C.-w. Yuan, and T. Huang, "A Novel Real-coded Quantum Genetic Algorithm in Radiation Pattern Synthesis for Smart Antenna," in *Proceedings of the 2019 IEEE 4th International Conference on Cloud Computing and Big Data Analysis (ICCCBDA)*, Changsha, China, 2019, pp. 1-5.
6. H. Ma and W. Wang, "The Application of Improved Quantum Genetic Algorithm to Beam Forming of Adaptive Array of Smart Antennas," in *Proceedings of the 2016 IEEE International Conference on Signal and Information Processing (ICSIP)*, Beijing, China, 2016, pp. 1-6.
7. A. Stockley and K. Briggs, "Optimizing Antenna Beamforming with Quantum Computing," *IEEE Transactions on Quantum Engineering*, vol. 1, pp. 1-8, 2020.
8. L. Kouhalvandi, S. Ozoguz, and L. Matekovits, "The Magic of Quantum Computing for Microwave Computer-Aided Design: A Brief Overview," *IEEE Antennas and Propagation Magazine*, vol. 63, no. 2, pp. 60-70, Apr. 2021.

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