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A Linear Antenna Array Design Based On Chebyshev and Genetic Algorithm Integration for Side Lobe Level Reduction

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ABSTRACT

An antenna is key in designing communication systems, this is because it is the medium through which signals can be sent and received. The exponential rise in internet of things users has informed the choice of antenna researchers to focus more on designing wideband antennas that can guarantee directive radiation pattern with high gain and reduced side lobes level. This paper presents a linear antenna design array based on Chebyshev and genetic algorithm integration for high gain and reduced side lobe level for 5G applications. The antenna design proposed is flexible such that, the model is not limited by the number of antenna elements which is a major drawback in most reviewed works. To this end, the model's flexibility of proposing the inclusion of both even and odd numbers of antenna elements is a top-notch feature. All the required specifications that will make the model to outperform other existing models are incorporated in the developed antenna application (App) and implemented in MATLAB 2020a. In the developed antenna Application, the desired Side Lobe Level (SLL) can be configurable in order to obtain a reduced side lobe level and obtain maximum gain The Chebyshev and genetic algorithm integration is a novel model aim at reducing the side lobe level and increasing the directive gain.

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Chebyshev, genetic algorithm, Antenna, Side Lobe Level (SLL). 5G

INTRODUCTION

Emerging technologies are growing at an exponential rate due to wireless nodes connection in recent years (Shaheed Ahmad, 2020). This exponential rise in wireless connected nodes has given rise to increased data demands that consequently pave way for increased data traffic. In view of this challenge, researchers have been trying to proffer solutions by upgrading its capacity and performance with the emergence of 5G wireless communication system. (Muhammad Ikram, 2020). However, in the proposed migration to the 5G technology, the sub-6 GHz (4G/WLAN) technology still remains critical.[1] No wonder, many countries are rolling out this wireless technology in order to increase capacity and address low latency data communication by utilizing the mm-wave spectrum. At the world telecommunications conference (WRC-15) that took place in Geneva, Switzerland, several frequency bands for the next generation 5G networks were allocated in both the lower and millimeter wave frequency bands (Honari et al., 2017), However, it is worth noting how millimeter waves are short ranged and as a result, can be affected adversely by the propagation losses based on its low wavelength size (Peize, Zhang, 2019). The role of genetic algorithms in antenna designs can never be over-emphasized, this can be seen in its impactful integrations with other models for higher gain realization for emerging technologies such as 5G and beyond.

The paper is organized as follows: The technical review is presented in section ii, The proposed integration approach using Chebyshev and genetic algorithm is presented in section iii. Conclusion is presented in section iv.

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TECHNICAL REVIEW OF LITERATURE

This section provides the reader with the basic details at a glance the works done by other researchers in the field of antenna design using different approaches as summarized in table 1

Table 1

Authors	Title of Paper	Strength	Weakness
Brajlata et al (2018)	Design of 18- element Dolph Chebyshev linear array with suppressed Side Lobes Level (SLL)	The model was able to achieve a very narrow main beam width and reduced side lobe level and increased directivity and handle a trade-off between beam width and minimum side lobe level	The main lobe gain was not specified
Shaheen Ahmad (2020)	A linear antenna array based on Chebyshev current distribution for mm wave applications.	The algorithm was able to achieve an improve main lobe gain from 12.1dB to 14dB and reduced side lobe level from -16dB to -19dB,	The design was not cost effective because two separate designs were used and fabricated
Yasser Albagory & Fahad Alraddady (2021)	Spatial filtering to reduce the side lobe level (SLL) through the use of side lobe sequential damping (SSD) technique by the use of pattern subtraction	The algorithm :was able to achieve a deep side lobe level reduction of -70dB	The algorithm was designed to best work on uniform array geometry with inter-element spacing of less than one wavelength.
Nagavalli et al (2022)	A comprehensive study of Linear Antenna Arrays using nature-inspired algorithms	Achieved an improved scanning efficiency based on a pencil-like beam formation to reach the target locations	The antenna design was only meant for Radar applications
Chaker et al (2023)	A linear annular array design by evolutionary algorithm: A comparative study	The design was able to achieve very high convergence rate and significant reduction in side lobe level	The design was for one objective problem in 1-D
Ayman et al (2023)	On the optimal design of low side lobe level linear antenna arrays using a class of evolutionary algorithms	The side lobe level was reduced significantly by the evolutionary algorithm	The evolutionary algorithm was not robust against harsh weather conditions.

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3. **Chebyshev and Genetic algorithm integration approach**

Methodology

1. Input desired side lobe level $R0$, input number of elements N
2. Set the operating frequency, the speed, and compute wave length as $\lambda = \frac{c}{frequency}$ (1)

   Where c= velocity
3. Compute inter element spacing as $d=\alpha\lambda$ (2)

   $where, \alpha \ni 0,1,$ compute k as $K = \frac{\pi d}{\lambda}$ (3)
4. Compute Chebyshev order N1 as $N1=N-1$ (4)

   Compute side lobe level in absolute unit as $R_a = 10^{\frac{R_0}{20}}$ (5)

   Compute scaling factor $Z_0 = \cosh\left(\frac{acosh(R_a)}{N1}\right)$ (6)

   Determine maximum. Allowable spacing as $d_{max} = \frac{acos\left(\frac{-1}{Z_0}\right)}{\pi}$ (7)
5. Expand the 'AF' as a power series of $cosu$, substitute $cosu = \frac{Z}{Z_0}$ (8)

   in the 'AF' terms, Equate the 'AF' to $TN_1(z)$,

   Determine the Chebyshev excitation amplitudes for each power of Z
6. Compute array factor (AF) at different angles (from 0 to 180^0) by Plugging excitations in the AF formula thus:

   $AF^e = \sum_{n=1}^{M} a_n cos[(2n-1)u]$, $M = \frac{N}{2}$ for even number of elements (9)

   $AF^o = \sum_{n=1}^{M+1} a_n cos[(2n-1)u]$, $M = \frac{N-1}{2}$ for odd number of elements (10)

   Where a_n is the excitation amplitude of the nth element
7. Determine Chebyshev side lobe level from AF, Compute Chebyshev Gain, HPBW,FNBW, and directivity
8. Input population size or number of chromosomes for genetic algorithm , input number of iterations or number of generations for genetic algorithm
9. The number of genes in each chromosomes corresponds to decision variables: excitation amplitudes and the array spacing for genetic algorithm.
10. Initialize the chromosomes such that initial GA excitations are randomly generated within the chebyshev excitations also randomly generate genetic algorithm spacing between 0.5 and 1, set mutation rate as 0.2, set selection rate as 0.5 (half of the population) compute number of survival as $Selection\ Rate\ X\ Population\ Size$
11. Set iterations to 1
12. Check genetic algorithm fitness
13. Rank chromosome with the least cost (side lobe level) as the most fit (rank highest)
14. Selection: base on their cost, select the first half of the rank chromosomes as the survival.
15. Pairing: compute cross over point as $\alpha = rand*number\ of Genes$, compute two new variables in the offspring's chromosomes from two pairs:

    $P_{new_1} = P_{m\propto} - \beta[P_{m\propto} - P_{d\propto}]$ (11)

    $P_{new_2} = P_{d\propto} + \beta[P_{m\propto} - P_{d\propto}]$ (12)

Where $\beta \in 0, 1$

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16. Mutation: randomly select chromosomes for mutation excluding the best individual also compute the number of genes to be mutated using

$$R_{sel} \times (N_{pop} - 1) \times N_{var} \tag{13}$$

Where, R_{sel} is selection rate, N_{pop} is population size, N_{var} is number of genes or decision variables

17. Check genetic algorithm fitness
18. Rank Chromosomes
19. Perform iteration
20. The best chromosome has the best genes i.e the solution (excitations and spacing)
21. Compute array factor using equation 9 and 10
22. Determine genetic algorithm side lobe level from array factor, compute array factor gain, HPBW, FNBW, and directivity
23. End

Figures 1-5 illustrate the flowchart of the proposed smart antenna design using Chebyshev-genetic algorithm integration approach.

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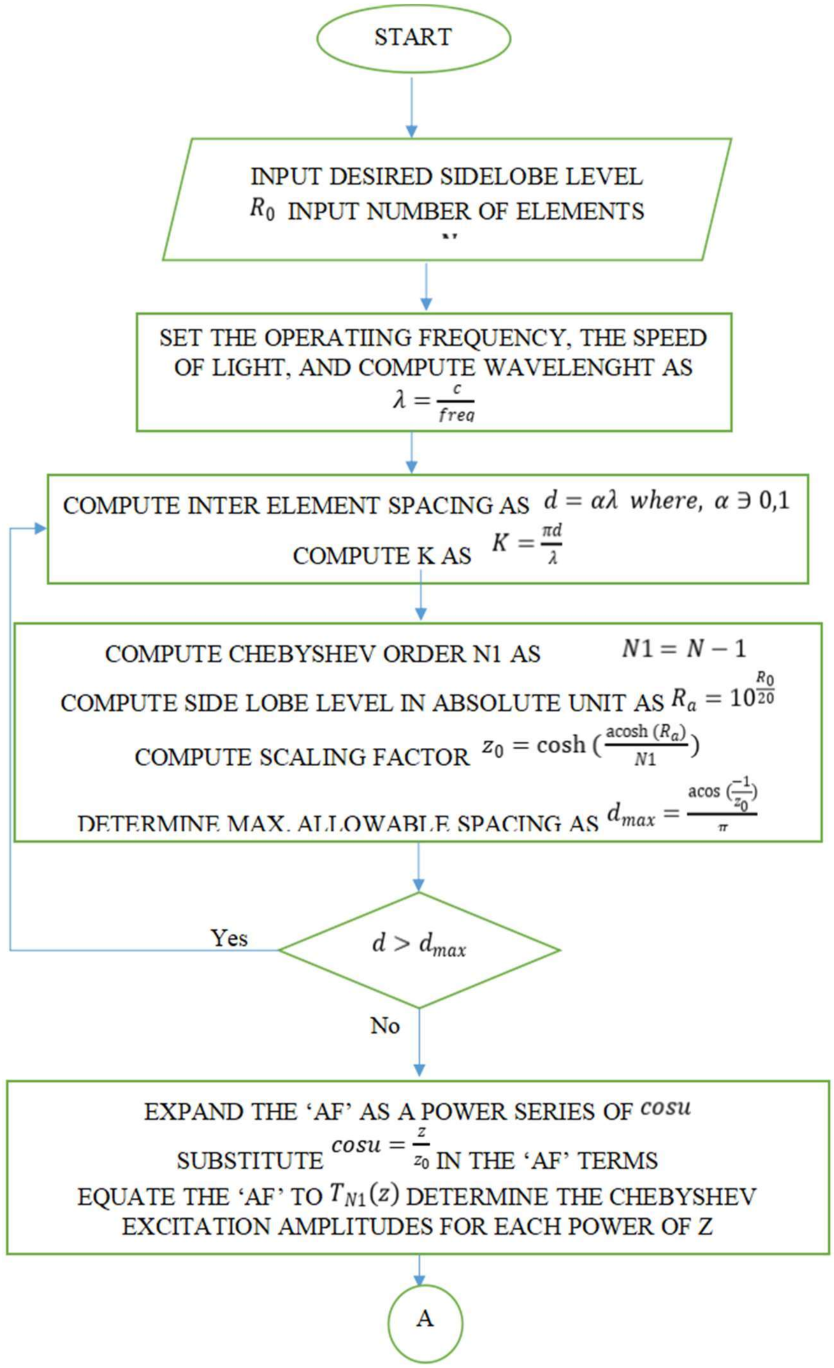

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A

COMPUTE ARRAY FACTOR AF AT DIFFERENT ANGLES (FROM 0 TO 180^0) BY PLUGGING EXCITATIONS IN THE AF FORMULA THUS:

$$AF^e = \sum_{n=1}^{M} a_n \cos[(2n-1)u],\ M = \frac{N}{2} \quad for\ even\ number\ of\ elements$$

$$AF^o = \sum_{n=1}^{M+1} a_n \cos[2(n-1)u],\ M = \frac{N-1}{2} \quad for\ odd\ number\ of\ elements$$

Where a_n is the excitation amplitude of the nth element

DETERMINE CHEBYSHEV SIDE LOBE LEVEL FROM AF
COMPUTE CHEBYSHEV GAIN, HPBW, FNBW, AND DIRECTIVITY

INPUT POPULATION SIZE OR
NUMBER OF CHROMOSOMES FOR
GA
INPUT NUMBER OF ITERATIONS

THE NUMBER OF GENES IN EACH CHROMOSOMES CORRESPONDS TO DECISION VARIABLES: EXCITATION AMPLITUDES AND THE ARRAY SPACING FOR GA

INITIALIZE THE CHROMOSOMES SUCH THAT INITIAL GA EXCITATIONS ARE RANDOMLY GENERATED WITHIN THE CHEBYSHEV EXCITATIONS
ALSO RANDOMLY GENERATE GA SPACING BETWEEN 0.5 AND 1
SET MUTATION RATE AS 0.2
SET SELECTION RATE AS 0.5 (HALF OF THE POPULATION)
COMPUTE NUMBER OF SURVIVAL AS

B

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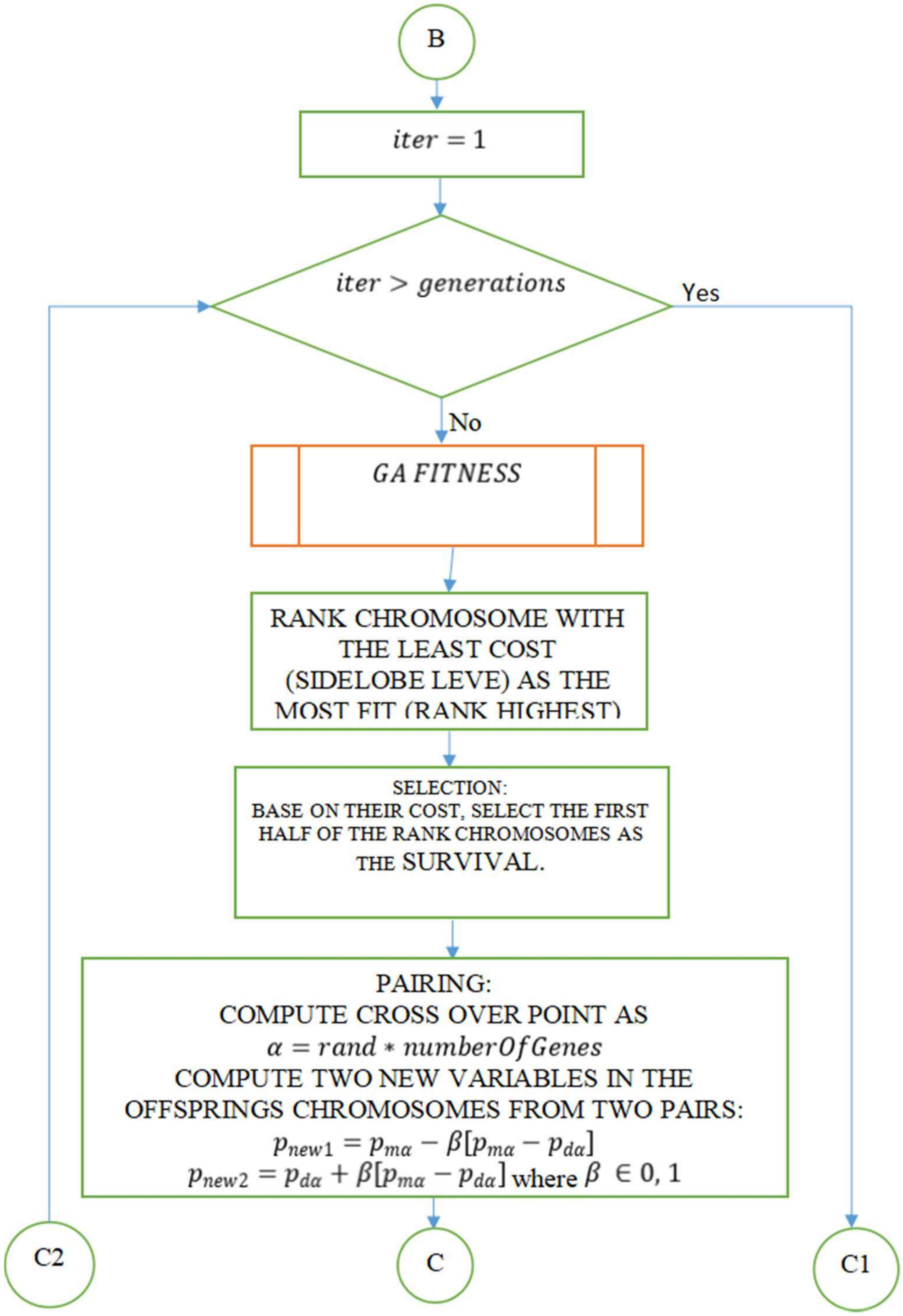

Figure 1: Flow Chart for Chebyshev and genetic algorithm integration

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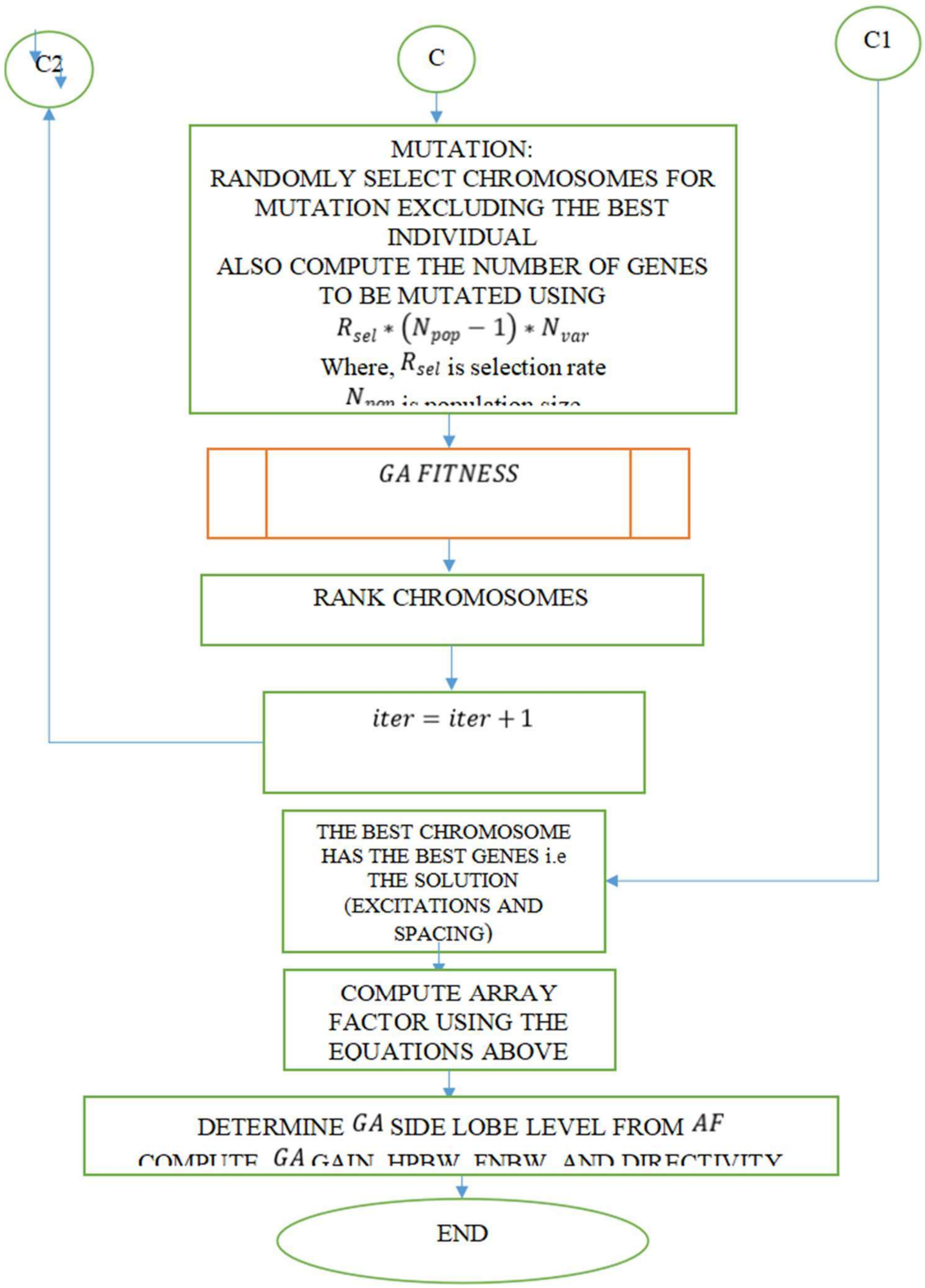

Figure 2: Flow Chart for Chebyshev and genetic algorithm integration

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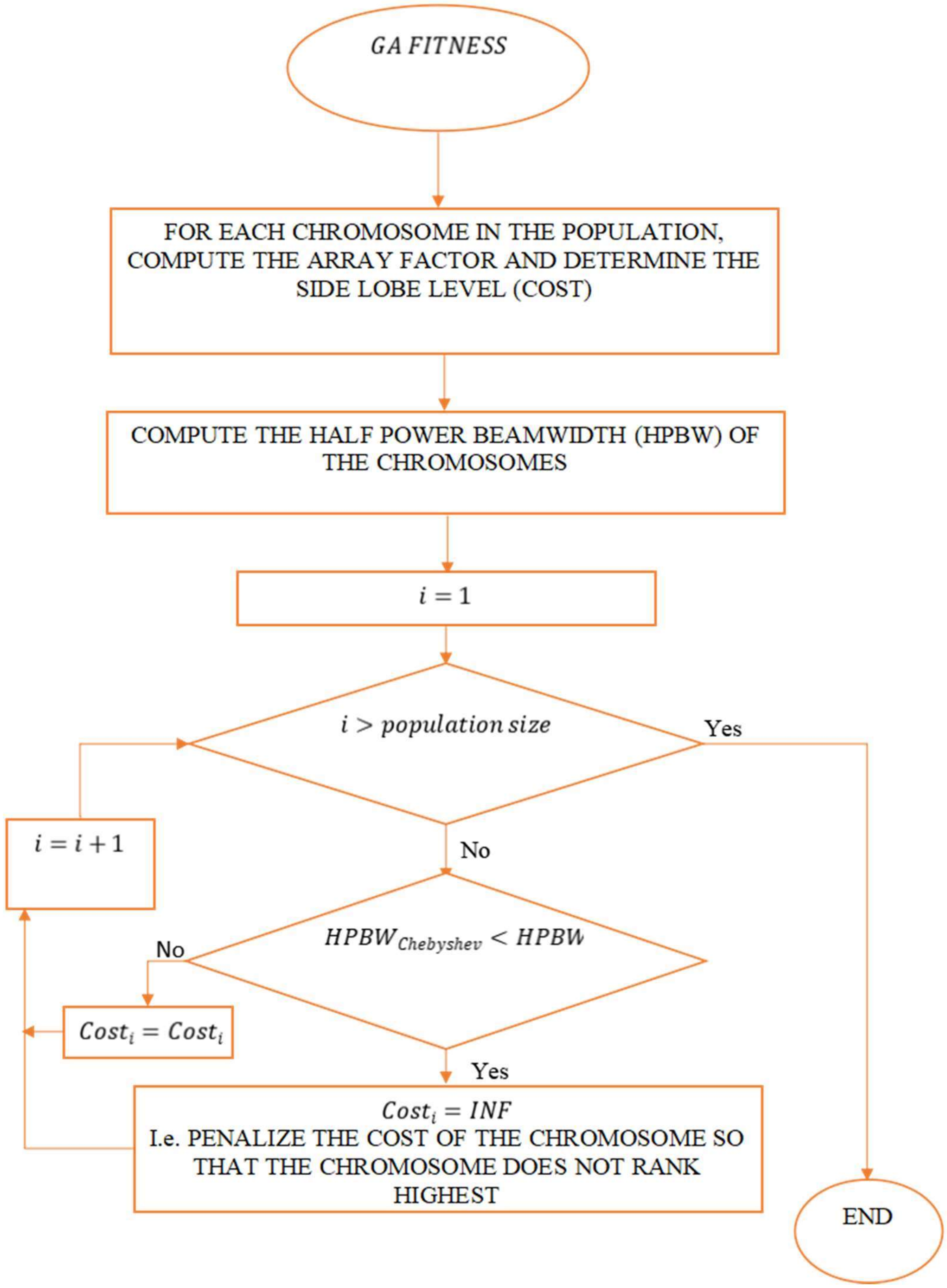

Figure 3: Flow Chart for Chebyshev distribution and real coded genetic algorithm integration

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RESULT AND DISCUSSION

This section presents the results from the designed linear antenna array based on Chebyshev and genetic algorithm integration. The designed antenna was simulated in MATLAB 2020a software and results obtained are presented in this section as well.

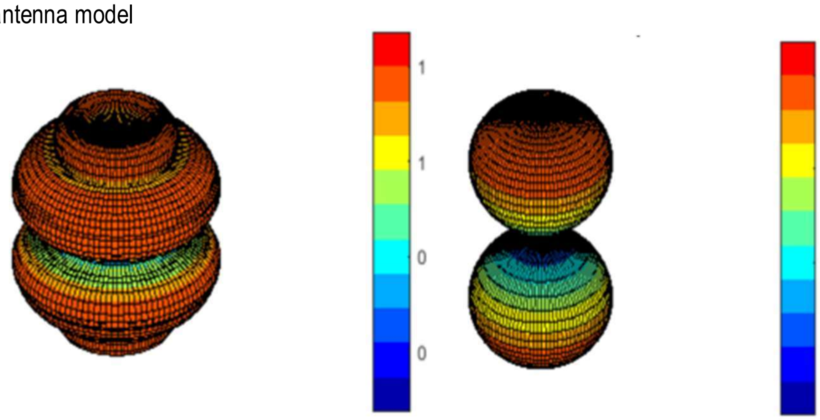
Developed Antenna Application

In the developed antenna Application, the desired Side Lobe Level (SLL) can be set in order to obtain a reduced or suppressed side lobe level to give rise to a high directivity and maximum gain; also both even andodd elements can work perfectly in this developed antenna application as opposed to others that only either even or odd element arrays can work in their models. The developed model is an iterative or search algorithm, which implies that optimum results are obtained at higher iterations.

Figure 4.1: Developed Antenna Application (Antenna App) Logo

Simulated results

The sub-section illustrates the results obtained from the simulations obtained based on the developed antenna model



4.2(a) Chebyshev 3D Radiation Pattern plot (b) Chebyshev & Genetic algorithm 3D

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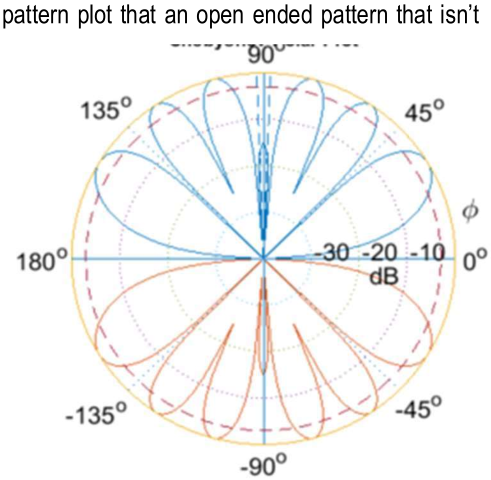
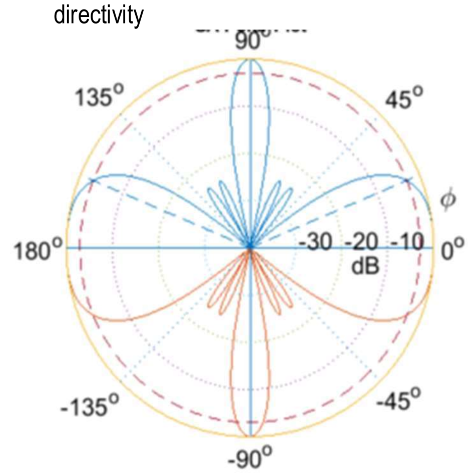
Radiation Pattern

Figure 4.2a above shows a plot of the 3D Chebyshev radiation pattern. It can be observed from the 3D Chebyshev radiation pattern plot that an open ended pattern that isn't tapering is obtained instead of obtaining a rounded tapering end depicting high directivity. It can be observed from the 3D plot of 4.2b that a rounded tapering end is obtained, depicting high directivity





4.3(a) Chebyshev algorithm polar plot (b) Genetic algorithm polar plot

Figure 4.3a shows the polar plot of Chebyshev algorithm while Figure 4.3b shows the polar plot of the genetic algorithm. A polar diagram is a plot that indicates the magnitude of the response in any direction or directional response of an antenna. One fundamental fact about antenna radiation and polar diagrams or plots is that, the receiving pattern is identical to the far field radiation pattern of the antenna when used for transmitting. This is in conformity with the reciprocity theorem of electromagnetics. In light of the above explanation, it can be observed from Figure 4.3b that, the radiation pattern or response is highly polarized along the vertical and horizontal axis only, also the antenna beam width is narrower as a result produces a more directive pattern. The implication of having a highly polarized radiation pattern as seen in the genetic algorithm is that high directive gain values will be achieved compared to the non-polarized plots as shown in figure 4.3a.

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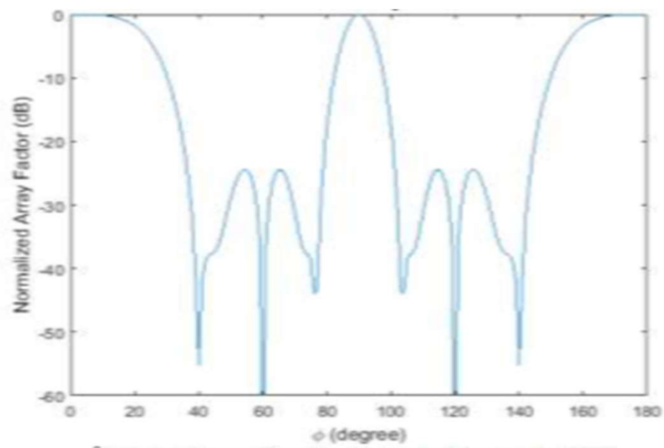

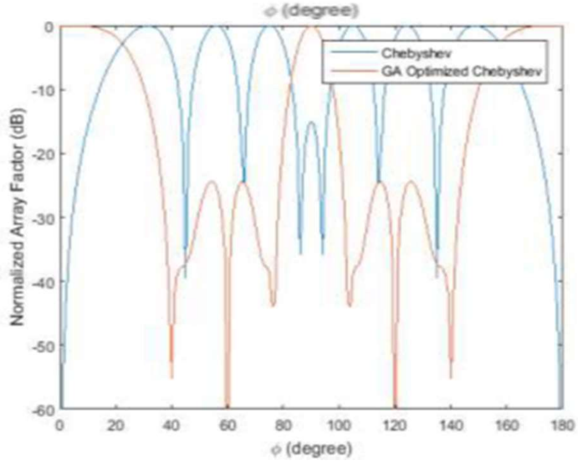

4.4(a) Genetic algorithm Normalized Array Factor (b) Chebyshev & Genetic algorithm Normalized Array Factor

Figure 4.4a shows the normalized array factor of the genetic algorithm while Figure 4.4b shows a comparison between the Chebyshev algorithm and the genetic algorithm. Array factor is a function which is dependent only on the geometry of the array and the excitation (amplitude, phase) of the elements. Array Factor is maximum when the array phase function is zero. It has the following advantages: increased in signal strength, high directivity is obtained, minor side lobes are reduced drastically, power wastage is reduced and finally better performance is obtained. In light of the above, it can be observed that the genetic algorithm produced a better array factor plot at its peak. This implies that the directivity that will be obtained from this algorithm obviously will be high, also the minor lobes (side lobe levels) will be reduced greatly as compared to the Chebyshev algorithm.

Figure 4.5 shows a plot of the generations (iterations or genetic algorithm setting) which in this case is 300 against the cost (desired side lobe level Chebyshev setting) of -15dB as simulation result from the developed Chebyshev and genetic integration algorithm. This proves the flexibility nature of the algorithm in terms of setting the parameters to a desired optimum level. .

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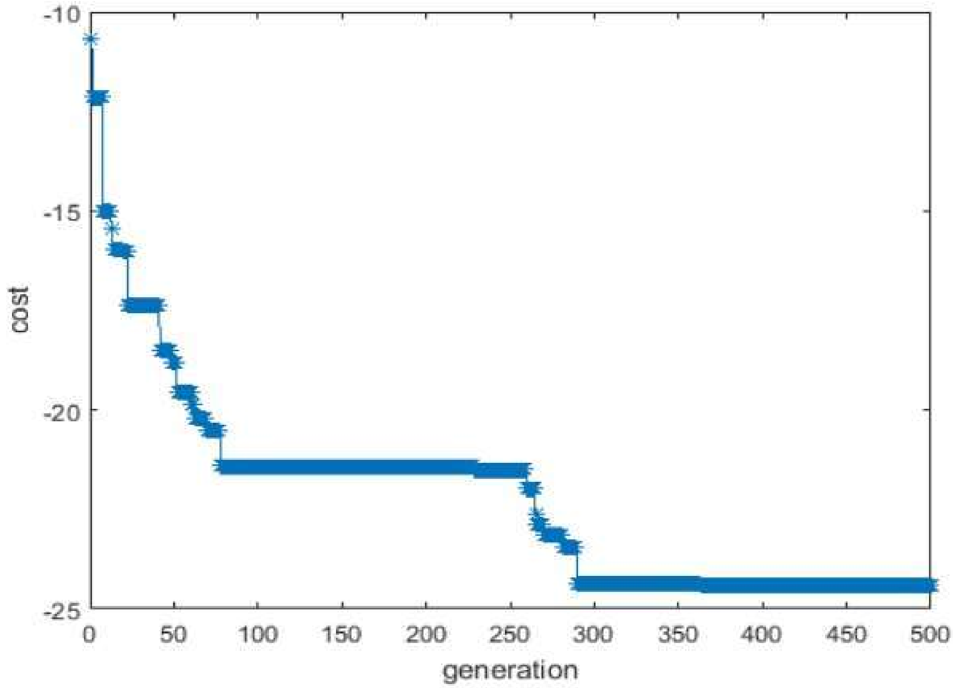

Figure 4.5: A Plot of 300 generations against cost

Table 1: Comparison between Chebyshev Array vs Genetic and Chebyshev integration

Antenna parameters	Chebyshev Array	GA Optimized
1. Optimum Side Lobe Level	24.4207dB	1.9284e-15dB
Half Power Beam width (HPBW)	4.0565 degrees	134.6 degrees
First Null Beam Width (FNBW)	8 degrees	28 degrees
Directivity	0.0090 dB	6.1457 dB
Element spacing (λ)	0.5000	0.9996

Table 1 shows the comparison between the results obtained from the optimized genetic and Chebyshev integration algorithm and those obtained from the only Chebyshev algorithm. It can be observed from the results obtained that, the integration of Chebyshev and genetic algorithm yields better results considering the antenna parameters used.

CONCLUSION

This paper has presented a linear designed antenna model that is based on Chebyshev and genetic algorithm integration and its implementation was done using the developed antenna application and MATLAB R2020a software. Based on the simulated results, the proposed model out-performed the single Chebyshev algorithm in terms of achieving high gain and reduced side lobe level. Other integration

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approaches are encouraged using artificial intelligence techniques.

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