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Design, Analysis, and Optimization of the Radiation Characteristics of a Circular Loop Antenna Using a Genetic Algorithm

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Abstract: This study presents the design, analysis, and optimization of the radiation characteristics of a circular loop antenna employing a Genetic Algorithm (GA) to achieve enhanced performance across desired frequency bands. The circular loop antenna was modeled and simulated using the GA tool box in MATLAB, and key parameters such as loop radius, conductor radius, feed position, and substrate properties were optimized using GA to improve gain, bandwidth, and radiation efficiency. The optimization process utilized a fitness function that minimized return loss and maximized radiation resistance, leading to an optimal configuration that outperformed conventional designs. Simulation results demonstrate that the GA-optimized antenna exhibits improved impedance matching and stable radiation patterns over a wide frequency range. The proposed method confirms the effectiveness of evolutionary algorithms in antenna design, providing a robust framework for the automated optimization of microwave and wireless communication antennas.

Keywords: Circular loop antenna, Optimization, Genetic Algorithm, MATLAB, Radiation resistance, Radiation pattern, Gain.

I. INTRODUCTION

Antennas are essential components in wireless communication systems, acting as interfaces between guided and free-space electromagnetic waves. Their design directly affects parameters such as gain, bandwidth, and radiation efficiency, which in turn determine the overall system performance. Among the various antenna configurations, loop antennas have gained considerable attention due to their simple structure, ease of fabrication, and ability to provide stable radiation characteristics over a wide frequency range (Balanis, 2016). In particular, the circular loop antenna is widely used in applications such as satellite communication, radio frequency identification (RFID), and biomedical telemetry, where compact size and omnidirectional radiation patterns are desirable (Stutzman& Thiele, 2013).

However, designing antennas with optimal radiation characteristics is inherently challenging because antenna performance depends on multiple interrelated parameters, including geometry, feed position, and substrate material. Traditional analytical and empirical design methods often fail to capture the nonlinear dependencies among these parameters, leading to suboptimal designs. Consequently, optimization algorithms have become increasingly popular in antenna engineering for fine-tuning antenna geometries to meet specific performance objectives (Chakrabarty& Biswas, 2020).

Among the available optimization techniques, Genetic Algorithms (GAs**)** have emerged as one of the most effective evolutionary computation approaches for solving complex, multidimensional electromagnetic problems (Goldberg, 1989). GAs are inspired by the principles of natural selection and genetics, enabling global exploration of the design space without the need for gradient information. Their ability to handle nonlinear, discontinuous, and multi-objective problems makes them particularly suitable for antenna design and optimization (Deb, 2001). In recent years, GAs have been successfully applied to optimize various antenna structures, including microstrip patch antennas, Yagi–Uda arrays, and loop antennas, demonstrating significant improvements in bandwidth, gain, and radiation efficiency (Nayeri et al., 2015; Khan & Naqvi, 2019).

This study focuses on the design, analysis, and optimization of the radiation characteristics of a circular loop antenna using a Genetic Algorithm. The key objective is to improve the antenna's impedance matching, directivity, and overall efficiency by optimizing design parameters such as loop radius, conductor radius, feed location, and substrate properties.

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Electromagnetic simulations are integrated with the GA optimization framework in MATLAB to automatically search for parameter combinations that yield superior performance compared to conventional designs.
The main contributions of this research are threefold:

1. To design a circular loop antenna suitable for operation in a targeted frequency band.
2. To analyze its radiation behavior using computational electromagnetic tools.
3. To employ a Genetic Algorithm for optimizing its radiation characteristics, thereby demonstrating the efficiency of evolutionary optimization in antenna design.

The proposed approach contributes to the growing body of research on intelligent antenna systems, highlighting how evolutionary algorithms can automate and enhance the design process for next-generation wireless communication technologies (Sengupta et al., 2021).

II. LITERATURE REVIEW

1. **Overview of Circular Loop Antennas**
Circular loop antennas are a classical antenna topology with a compact geometry and useful radiation characteristics for narrowband and broadband low-profile applications. Foundational treatments of loop antennas and their fundamental parameters (radiation resistance, field patterns, input impedance) appear in canonical antenna texts (Balanis, 2016; Stutzman& Thiele, 2013). Small loops (circumference $\ll \lambda$) behave primarily as magnetic dipoles with low radiation resistance and limited efficiency, whereas large loops (circumference $\sim\lambda$) can support travelling-wave behavior and improved radiation performance. Design choices such as loop radius, conductor cross-section, feed method, and presence of dielectric substrates strongly influence impedance matching, bandwidth, and pattern stability (Balanis, 2016).[6]investigated the performance of loop antennas operating deep down inside the human body for use in biotelemetry by studying the radiation characteristics of loop antennas for biomedical implants. Their result showed that, even though electrically small loop antennas are known for their small radiation resistance, high permittivity and conductivity of the biological tissues in the MICS band will make the electrical size of the loop large enough to achieve reasonable radiation resistance.

2. **Performance Metrics and Design Challenges**
Key radiation characteristics of interest are gain/directivity, radiation pattern (omnidirectional vs. directional), impedance bandwidth, radiation efficiency, and polarization. For circular loop antennas, the principal design challenges include:

- Achieving acceptable impedance matching without sacrificing radiation efficiency.
- Enhancing bandwidth for applications that require multi-band or wideband operation.
- Controlling nulls and sidelobes in the radiation pattern when the loop approaches resonant circumference. These trade-offs are nonlinear and multimodal in the design parameter space, motivating computational optimization rather than ad-hoc tuning.

3. **Optimization in Antenna Design — Evolutionary and Heuristic Methods**
Optimization methods have been widely used to automate antenna design. Early analytical optimizations gave way to heuristic and evolutionary techniques as computational EM solvers became affordable. Genetic Algorithms (GAs), Particle Swarm Optimization (PSO), Simulated Annealing (SA), and hybrid/metaheuristic approaches have all been applied to antenna problems (Goldberg, 1989; Deb, 2001). Comparative surveys indicate that no single optimizer universally dominates: GAs and PSO are popular due to their global search capability and ease of adapting to discrete/continuous design variables (Chakrabarty & Biswas, 2020; Sengupta et al., 2021).Abdelsayed et al (2019), considered the recent extension of the theories and techniques of antennas into the optical regime, allowing for applications in biological sensing and energy harvesting and decided to enhance these applications by introducing some degree of reconfigurability to the antenna design and operation. They therefore employed the covariance matrix adaptation evolutionary strategy (CMA-ES) in order to optimize the loading configuration of the loop antenna to make a high degree of radiation pattern control possible and efficiently implemented the CMA-ES global optimizer in MATLAB. This resulted to enhanced directivity in the $\emptyset = 0^0$ direction, and showed that, adding capacitive loads to a nanoloop significantly modifies its directivity with energy directed broadside

4. **Genetic Algorithms (GAs) in Antenna Optimization**
GAs are perhaps the most-cited evolutionary approach in antenna literature. They encode antenna parameters into chromosomes and use selection, crossover, and mutation to evolve populations toward better fitness (Goldberg, 1989; Haupt & Werner, 2007). Advantages relevant to loop antenna design include:

- Ability to handle mixed-variable problems (continuous geometry and discrete substrate choices).
- Robustness to multimodal objective landscapes (multiple local minima).

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- Flexibility to incorporate multi-objective fitness functions (e.g., simultaneously maximize gain and minimize return loss).

Representative contributions show GAs improving gain, bandwidth, and impedance matching in diverse antenna types: microstrip patches, Yagi–Uda arrays, fractal elements, and loop antennas (Nayeri et al., 2015; Khan & Naqvi, 2019). Haupt & Werner (2007) provide a consolidated treatment on GA implementations for electromagnetic design, including practical issues such as representation, fitness scaling, and constraint handling. Idakwo et al, (2019) studied the radiation characteristics of circular loop antenna using genetic algorithm technique operating at a frequency bandwidth of 935-955MHz, with the aim of optimizing the loop and conductor radii that will give the highest radiation efficiency of the proposed circular loop antenna design. They implemented GA in MATLAB and their result obtained in terms of efficiency versus loop radius, showed that efficiency of the circular loop antenna increases with loop size. The radiation pattern obtained is omnidirectional with no back and side lobes. The study showed that for maximum radiation efficiency of a small loop antenna it is appropriate to carefully select the conductor and antenna loop diameters.Elson (2022), applied the method of genetic algorithm to optimize the parameters on yagi-uda antenna design having 7 elements (1 reflector, 1 active element and 5 directors).

5. **GA Applications to Loop Antennas — Summary of Findings**

Studies specifically addressing loop antennas have used GA to tune parameters such as loop radius, conductor radius, segment discretization (for non-circular shapes), feed location, loading elements, and substrate characteristics. Typical findings:

- GA-driven designs often achieve improved impedance matching at target frequencies compared to manual designs, reducing return loss and VSWR.
- Optimizations that include radiation pattern constraints (e.g., sidelobe level, beamwidth) produce loop geometries with more desirable directivity for directional applications.
- Multi-objective GAs can trade off bandwidth versus efficiency, producing Pareto-optimal design families for different application priorities.
  (See reviews/compendia in Nayeri et al., 2015; Khan & Naqvi, 2019.)

6. Comparisons: GA vs PSO and Other Methods

PSO has emerged as a competitive alternative due to faster convergence on some continuous problems (Kennedy & Eberhart, 1995). Hybrid approaches — GA+local-search or GA+PSO mixtures — are frequently proposed to combine GA's global exploration with a faster local convergence phase, addressing GA's sometimes slow fine-tuning. Comparative studies suggest:

- GA excels when the design space contains discrete choices or highly rugged fitness landscapes.
- PSO may converge faster on smooth continuous spaces but can get trapped in local minima without diversification mechanisms (Sengupta et al., 2021).
  The choice often depends on the problem encoding and computational budget.

7. Simulation and Experimental Practices

High-fidelity evaluation of candidate designs requires coupling GA with full-wave electromagnetic solvers (method-of-moments, FEM, FDTD). This integration raises computational cost: each individual requires an EM simulation. Approaches to manage cost include surrogate modeling (kriging, neural nets), reduced-order models, coarser simulation during early GA generations, and parallel evaluation of populations (Nayeri et al., 2015). Experimental validation remains essential: measured S-parameters and far-field patterns are required to confirm simulated GA-optimized designs.

8. Current Gaps and Research Opportunities

Despite success, several gaps remain:

- Computational Efficiency**:** Faster surrogate-assisted optimization and better parallelization strategies are needed for practical industrial workflows.
- Manufacturability-aware Optimization**:** Most studies optimize idealized geometries; incorporating fabrication tolerances, substrate variability, and conductor losses more explicitly is an open area.
- Robust / Broadband Optimization**:** Achieving robust performance across environmental variations (temperature, nearby objects, plasma environments) needs more attention.
- Hybrid Objectives and Multi-physics problems**:** Co-optimizing antennas with matching networks, active components, or propagation media (e.g., plasma) presents complex coupled problems that require advanced multi-objective strategies.

The literature demonstrates that Genetic Algorithms are powerful and flexible tools for optimizing circular loop antennas' radiation characteristics. GAs are particularly effective for multimodal, constrained, and multi-objective antenna design problems and have produced measurable improvements in impedance matching, bandwidth, and radiation patterns.

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Nevertheless, efficient integration with EM solvers, manufacturability considerations, and robustness to real-world perturbations remain active research directions.

III. METHODOLOGY

a. Antenna Source Current

The task of determining the source current of the circular loop antenna was carried out using the moment method (MoM). The Method of Moments (MoM) is a powerful numerical technique used to solve integral equations. It is useful for discretizing continuous integral equation to a set of discrete linear equations, Akonjom (2024)[1]. Here, it is employed to discretize the Pocklington's integral equation of the proposed circular loop antenna given by equation (1) below.

$$E_z(z') = \frac{j}{\omega\varepsilon}\int_{-l/2}^{l/2} I_z(x',y',z')\left[k^2+\frac{\partial^2}{\partial z^2}\right]\frac{e^{-jkR}}{4\pi R}\,dl' \qquad (1)$$

Where
$r = (x,y,z)$and $r' = (x',y',z')$, are the coordinates of the observation and source points respectively and $R = \sqrt{(x-x')+(y-y')+(z-z')}$, the distance from the source point to the observation point. E_z denotes the electric field at source, $K = \sqrt{\omega^2\mu\varepsilon} = \frac{2\pi}{\lambda}$ represents the wave constant, $\omega = 2\pi f$is the angular frequency, f is the antenna frequency, λ is the wavelength, μ the permeability and ε the permittivity of free space. The kernel$\left[K^2+\frac{\partial^2}{\partial z^2}\right]$ denotes the wave equation differential operator in free space.I_z is the constant current distribution in the loop, l the circumference of the circular loop and $E_z(z')$ the electric field generated at the source by current.
From the moment method, the impedance matrix given in equation 2 below was generated, from which, the input impedance was determined.

$$\begin{bmatrix} z_{n1m1} & z_{12} & z_{13} & z_{14} & z_{15} & z_{16} & z_{n7} \\ z_{21} & z_{22} & z_{23} & z_{24} & z_{25} & z_{26} & z_{27} \\ z_{31} & z_{32} & z_{33} & z_{34} & z_{35} & z_{36} & z_{37} \\ z_{41} & z_{42} & z_{43} & z_{44} & z_{45} & z_{46} & z_{47} \\ z_{51} & z_{52} & z_{53} & z_{54} & z_{55} & z_{56} & z_{57} \\ z_{61} & z_{62} & z_{63} & z_{64} & z_{65} & z_{66} & z_{67} \\ z_{m7} & z_{72} & z_{73} & z_{74} & z_{75} & z_{76} & z_{77} \end{bmatrix}\begin{bmatrix} i_1 \\ i_2 \\ i_3 \\ i_4 \\ i_5 \\ i_6 \\ i_7 \end{bmatrix} = \begin{bmatrix} v_1 \\ v_2 \\ v_3 \\ v_4 \\ v_5 \\ v_6 \\ v_7 \end{bmatrix} \qquad (2)$$

The input impedance $z_{mn} = 4.050\Omega$ was therefore calculated. With an input voltage, $V_m = 2.4\ V$ fed to the antenna feed-gap, the uniform current distribution in each segment of the circular loop is computed as, $I_n = 0.593\ A$. The loop was divided into seven segments. N is the number of segments of the circular loop antenna while M is the number of weighted functions. At a radiation angle of 30^0, the output current of the circular loop antenna was computed as $I_o = 0.839A$.

b. Antenna Design Model

The first step on optimization procedure is to model the design problem mathematically (Akonjom, 2024). The design model of this circular loop antenna consists of multiple design parameters such as; frequency, wavelength, conductor radius and hence its diameter, loop radius and diameter. These parameters effectively describe the characteristics of the circular loop antenna.

i. Antenna Operating Frequency, f: Considering a frequency bandwidth of 905 MHz to 1.015 GHz, the circular loop antenna
ii. will operate at a frequency, f given as;

$$f = ½(USB + LSB) \qquad (3)$$

Where; USB and LSB are the upper and lower sidebands of the bandwidth considered.

Therefore, $f = ½(905 + 1015) = \frac{1920}{2} = 960$ MHz

iii. Antenna Wavelength, λ:

$$\lambda = \frac{v}{f} \qquad (4)$$

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Where, v = velocity of light in free space = $3.0 \times 10^8\ ms^{-1}$

Therefore, $\lambda = \frac{3\times10^8}{9.60\times10^8} = 0.3125\ m$

iv.Feed Gap size, g:
But;

$$g = \frac{\lambda}{4}\left(1 - \left(\frac{1}{2N}\right)\right) \quad (5)$$

Where;
λ is the antenna wavelength and N the number of turns in the antenna.
For $\lambda = 0.3125\ m$ and N = 1, the numerical value of g is:

$$g = \frac{0.3125}{4}\left(1 - \left(\frac{1}{2\times1}\right)\right) = 0.0391\ m.$$

v.Diameter of conductor, D:

$$D = 2r \quad (6)$$

Where, r is the radius of the antenna conductor.

vi.Circumference of loop, C: The circumference, C of the antenna is the overall length of the antenna. It is a function of the loop radius, R given below.

$$C = 2\pi R \quad (7)$$

Where, R is the radius of the circular loop.
The design parameters R and r to be used are optimized values obtained using Genetic Algorithm technique in MATLAB and are used to compute the circular loop antenna radiation resistance and ohmic resistance respectively.

vii.Radiation Resistance,

$$R_r = \frac{20\pi^2 C^4}{\lambda^4} \quad (8)$$

Where; $C = 2\pi R$ and, R = radius of loop

viii.Ohmic or Loss Resistance,

$$R_l = \frac{r}{R}\sqrt{\frac{\omega\mu_o}{2\sigma}} \quad (9)$$

Where:

$\omega = 2\pi f =$ Angular frequency in radians-per-second (Rad/s)
$f =$ Operating frequency of antenna in hertz (Hz)
$\mu_o =$ Permeability of free space in Henry-per-meter (H/m) and
$\sigma =$ Conductivity of the wire in Siemens-per-meter (S/m)

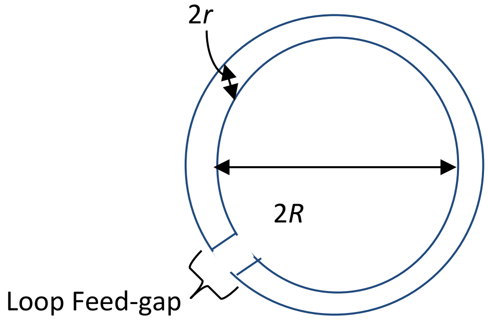

Figure1 Physical Structure of circular loop antenna showing loop diameter, conductor diameter

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c. Genetic Algorithm (Flow Chart)

Genetic algorithm (GA) is implemented in this work to optimize the conductor radius, r and the loop radius, R of the antenna. Our interest is to increase the antenna radiation resistance and reduce the loss resistance (the dependent variables) considerably to boost the antenna efficiency. Bearing in mind that the numerical computation of loop antenna radiation resistance and loss resistance depends on the independent variables; antenna loop radius (which imparts radiation resistance) and the conductor radius (which imparts loss resistance), we have considered the loop antenna radiation resistance and loss resistance as the objective functions for implementing genetic algorithm. The antenna loop radius, R and the conductor radius, r, are set as constraints for the optimization process. The flowchart for execution of GA is shown in figure 2 below.

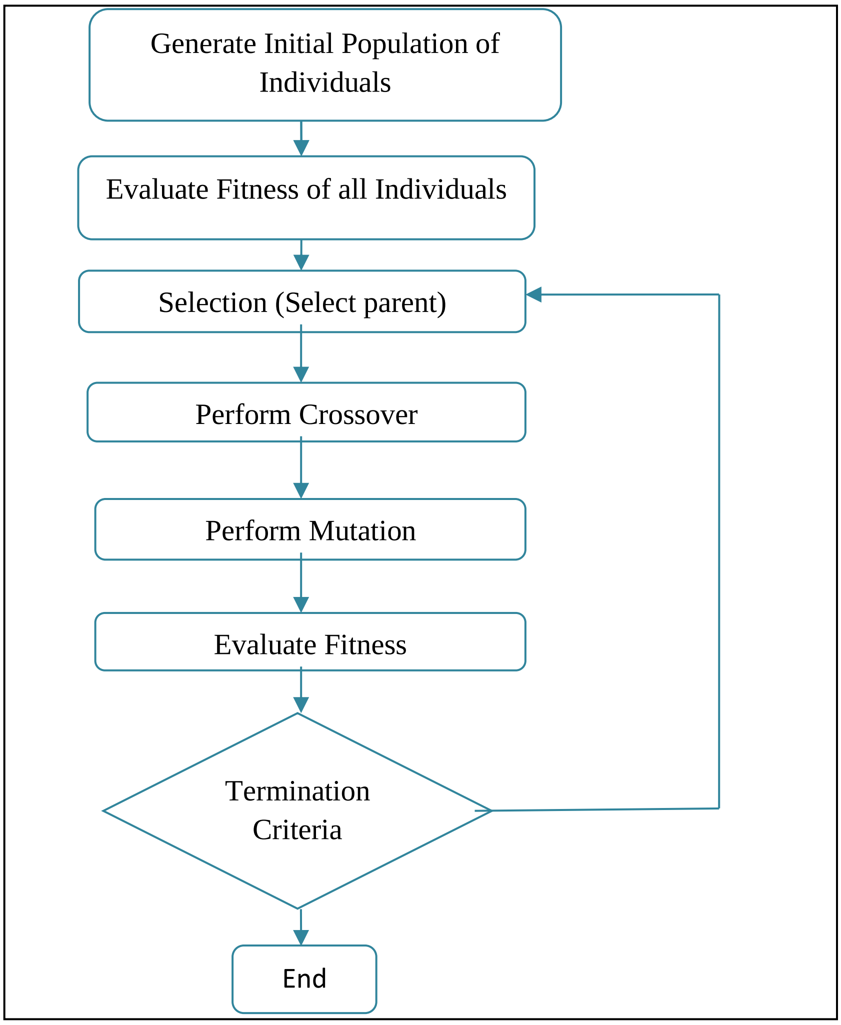

Fig. 3.3: Flowchart for executing Genetic Algorithm Optimization technique

For uniform current distribution in the loop;

$$R < 0.016\,\lambda \qquad (10)$$

Therefore, $R < 0.016(0.3125)m < 0.005m$
Objective Function: Maximize radiation resistance, Minimize ohmic resistance.
Constraints: Subject to;

$$0 < R \leq 5mm \qquad (11)$$

$$0.1mm \leq r \leq 2.0mm \qquad (12)$$

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$$r - R \leq -1 \qquad (13)$$

The stages of implementation of genetic algorithm are executed using Genetic Algorithm tool box in MATLAB to run the codes. These codes are also indicated.

i. Generation of Initial Population: An initial population size of 50 individuals each with a pair of genes corresponding to the variables R and r is generated using Genetic Algorithm (GA) in MATLAB.
ii. Evaluate Fitness of Individuals: The fitness of each individual above is evaluated using the fitness function encoded in the MATLAB code. The fitness function used in the stages of GA execution if the efficiency of each individual.
iii. Select Parents: From the 50 fit individuals, 20 parents were selected based on their fitness values. The Roulette Wheel Selection method; where individuals with higher fitness values have a higher chance of being selected, was used.
iv. Perform Crossover: The crossover stage is a recombination stage which involves combining part of two parents to create offspring. This generated 20 new offspring for mutation.
v. Perform Mutation: Mutation introduces random changes to the offspring so as to maintain genetic diversity. A mutation rate of 0.1 was considered, this produced 20 new offspring for the next stage.
vi. Evaluate Fitness of Offspring: The fitness of the 20 newly generated offspring was evaluated also using the same fitness function (efficiency of individual).
vii. Termination: The termination criterion is met since the data converges for 20 new offspring converges as shown in table 1 below.

```
>> offspring_fitness = [R r]

offspring_fitness =

    0.0048    0.0001
    0.0048    0.0001
    0.0048    0.0001
    0.0048    0.0001
    0.0048    0.0001
    0.0048    0.0001
    0.0048    0.0001
    0.0048    0.0001
    0.0048    0.0001
    0.0048    0.0001
    0.0048    0.0001
    0.0048    0.0001
    0.0048    0.0001
    0.0048    0.0001
    0.0048    0.0001
    0.0048    0.0001
    0.0048    0.0001
    0.0048    0.0001
    0.0048    0.0001
    0.0048    0.0001
```

Table 1: Convergence values for GA termination

From the table above, the best fitness values that produced the highest efficiency are R = 4.8mm and r = 0.1 mm respectively for the genetic algorithm. These are the optimized values of the loop antenna parameters (loop radius and conductor radius) which are used for the design model and for determining other characteristics of the circular loop antenna.

Therefore, the circumference of the loop, C is calculated using equation (7) as thus:

$$C = 2\pi R = 2 \times \frac{22}{7} \times 0.0048 = 0.0302\, m$$

d. Circular Loop Antenna Characteristics

To describe the performance of an antenna, definitions of various parameters are necessary. Some of them are interrelated and not all of them need be specified for complete description of the antenna performance, (Balanis, 2005). Their formulas are used to compute the numerical values.

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i. Radiation Resistance, R_{rad}: The radiation resistance determines the power radiated by the antenna in free space. It is calculated using equation (8) as;

$$R_{rad} = \frac{20\pi^2 C^4}{\lambda^4} = \frac{31.2 \times 10^3 \times (0.03017)^4}{(0.3125)^4} = 1.715 \times 10^{-2}\ \Omega$$

ii. Ohmic Resistance, R_{ohm}: The ohmic resistance represents the antenna's electrical power lost as heat in the antenna conductors. It is computed using equation (9) as;

$$R_{ohm} = \frac{R}{r}\sqrt{\frac{\omega\mu_o}{2\sigma}} = \frac{0.0048}{0.0001}\sqrt{\frac{5.695 \times 10^9 \times 1.257 \times 10^{-6}}{2 \times 5.96 \times 10^7}} = 3.407 \times 10^{-5}\Omega$$

iii. Efficiency, η: The antenna efficiency take into account losses at the input terminals and within the structure of the antenna, (Balanis). It is the ratio of the radiation resistance to the sum of the radiation resistance and loss resistance, computed thus:

$$\eta = \frac{R_{rad}}{R_{rad} + R_{ohm}} \tag{14}$$

$$\eta = \frac{1.715 \times 10^{-2}}{1.715 \times 10^{-2} + 3.407 \times 10^{-5}} = 0.998 \ \approx = 99.8\ \%$$

iv. Radiation Power Density, P_{rad}: The power density of an antenna is a measure of the amount of power radiated per area in the radiation field of the antenna measured from its centre.

$$P_{rad} = (I_o)^2 R_{rad} \tag{15}$$

$$P_{rad} = (0.839)^2 \times 1.715 \times 10^{-2} = 1.21 \times 10^{-2}\ W/m^2$$

v. Radiation Intensity, U : The radiation intensity in a given direction is the power radiated from an antenna per unit solid angle, (Balanis, 2005). It is calculated thus;

$$U = \frac{P_{rad}}{4\pi R^2} \tag{16}$$

$$U = \frac{1.21 \times 10^{-2}}{4\pi \times (0.0048)^2} = 41.8\ W/sr$$

vi. Directivity, D: The directivity of an antenna describes how much it concentrates energy in one direction in preference to radiation in other directions, (Stutzman, 2013). In linear scale, the value is 1.5 for small loop antenna. Therefore, the directivity of a small single turn circular loop antenna is

$$D = 1.5\ dB \tag{17}$$

$$D = 10log1.5 = 1.761\ dB$$

vii. Gain: The gain is a measure of the ability of the antenna to direct the input power into radiation in a particular direction and is measured at the peak radiation intensity, (Milligan, 2005). It is computed thus:

$$G = \eta D \tag{18}$$

$$G = 0.998 \times 1.761 \approx 1.757\ \text{Db}$$

viii. Bandwidth, B_w: The bandwidth of an antenna is defined as the range of frequencies within which the performance of the antenna, with respect to some characteristic, conforms to a specified standard, (Balanis, 2005). It is computed thus:

$$B_w = USB - LSB \tag{19}$$

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$$B_w = \frac{1015 - 905}{1000000} = 1.10 \times 10^{-4}\ Hz$$

ix.Effective Area of radiation, A_{rad}: This is a measure of the total area that captures the maximum amount of power radiated out of the antenna. It is calculated thus:

$$A_{rad} = \frac{G\lambda^4}{4\pi} \qquad (20)$$

$$A_{rad} = \frac{1.757 \times 0.3125^4}{4\pi} = 0.0132\ m^2$$

x..Physical Area of Antenna, A: This is a measure of the actual geometrical area of the antenna. It is computed using equation (21) below.

$$A = \pi R^2 \qquad (21)$$

$$A = \pi(0.0048)^2 = 7.24 \times 10^{-5} m^2$$

IV. RESULTS

Table 2 shows, a summary of the parameters and performance characteristics of the circular loop antenna which are calculated from the optimized values of loop and conductor radii respectively. These are used for the antenna design.

Table 1 Values of the Antenna Parameters

S/No.	PARAMETER/CHARACTERISTIC	SYMBOL	VALUE
1	Conductor radius (m)	r	0.0001
2	Antenna loop radius (m)	R	0.0048
3	Feed gap (m)	g	0.0391
4	Input current (A)	I_o	0.839
5	Input impedance,	Z_{mn}	4.05
6	Antenna Bandwidth (dBi)	B	1.10×10^{-4}
7	Resonance frequency (MHz)	f	960
8	Wavelength (m)	λ	0.3125
9	Radiation resistance (Ω)	R_{rad}	1.715×10^{-2}
10	Ohmic resistance (Ω)	R_{ohm}	3.407×10^{-5}
11	Efficiency (%)	η	99.8
12	Power Density (W)	P_{rad}	41.8
13	Radiated Power Intensity (W/sr)	U	1.21×10^{-2}
14	Directivity	D	1.761
15	Gain (dBi)	G	1.757
16	Maximum Effective Area (m^2)	A_{rad}	0.0132
17	Physical Area (m^2)	A	7.24×10^{-5}

Table 2: Summary of Computed Circular Loop Antenna Characteristics.

The implementation of a genetic algorithm (GA) using codes executed in the GA toolbox in MATLAB was employed to find the optimal parameters that can be used to design and analyze a circular loop antenna with optimized radiation characteristic. The codes used in GA toolbox in MATLAB to implement the genetic algorithm processes, and the data generated in each step are clearly presented as figures and tables in section 3. Results from GA, on convergence showed a loop radius of 0.0048m and a conductor radius of 0.0001m. These values were then used to compute the optimal values of the radiation resistance and the loss resistance, from which other radiation characteristics of the circular loop antenna were computed and summarized in table 2 above.

The optimized antenna parameters were used to develop MATLAB codes used for the simulation of the circular loop antenna model. The codes used to simulate the far-field radiation pattern (shown in figure 2) of the antenna, are clearly stated in the appendices of this work.

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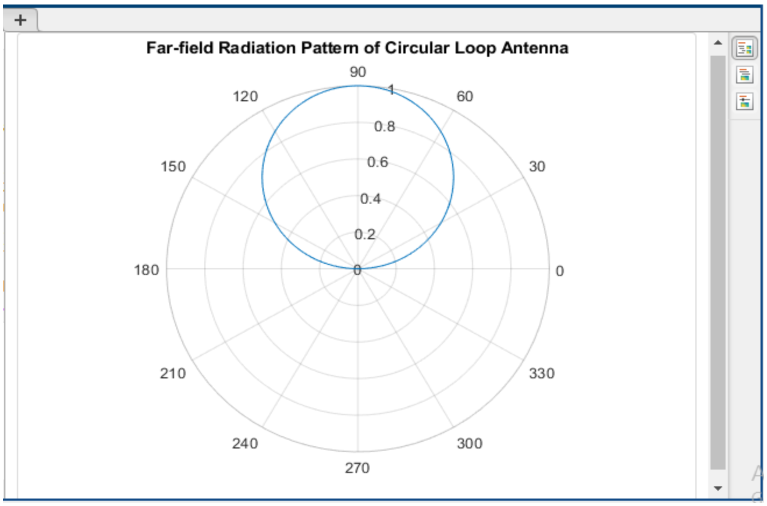
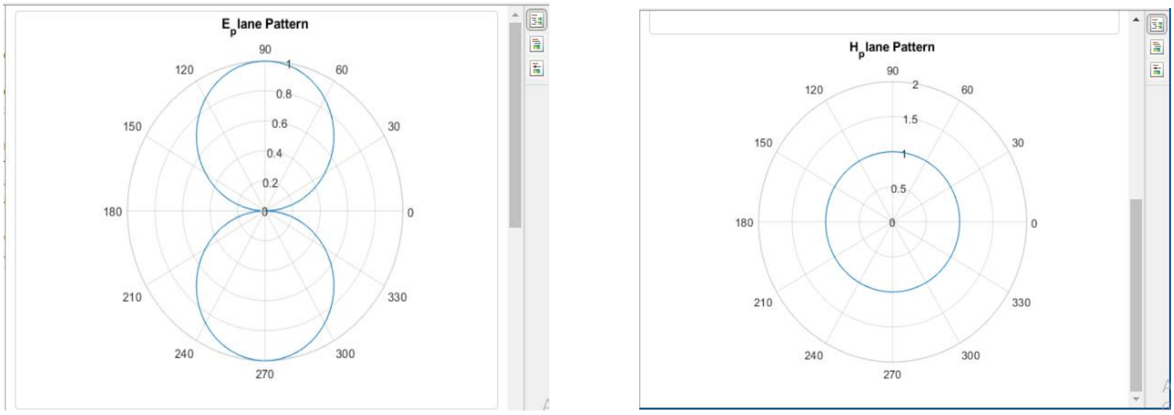


Figure 2: Far-field Radiation Pattern of Circular Loop Antenna.

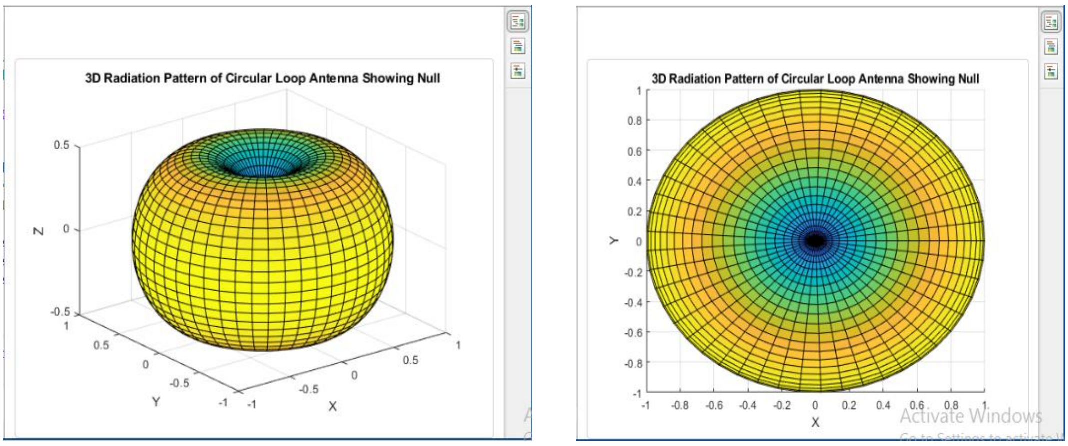
The far-field radiation patterns in the E-field and H-field planes of the antenna are shown in figure 3. The E-field pattern (a) is a figure-8 shape without side lobes when viewed from the plane of the antenna, and (b) is the H-plane pattern.



(a) (b)

Figure 3: Circular Loop Antenna Radiation Pattern in the E-plane and H-plane.

Figures 4 (a) and (b) are diagrams showing the 3-dimensional radiation pattern of circular loop antenna showing the null (the area that is devoid of radiation). Both diagrams are the same but, in (b), the null is rotated to bring to clear view the region in which there is no field strength. The null is a unique property of small loop antennas.



(a) (b)

Figure 4 3-D Radiation Pattern of the Circular Loop Antenna showing the Null.

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The plot of efficiency versus loop radius shown in figure4 below shows the efficiency increasing as the loop radius increases. This indicates that the size of the antenna loop diameter directly determines the efficiency of radiation as the plot shows efficiency increasing significantly from 93% at loop radius of 4.0m to 99.8% at loop radius of 4.80m. The plot has shown that with a genetic algorithm (GA) optimized loop radius of 0.0048m, we can achieve a circular loop antenna that's at an efficiency of 99.8%.

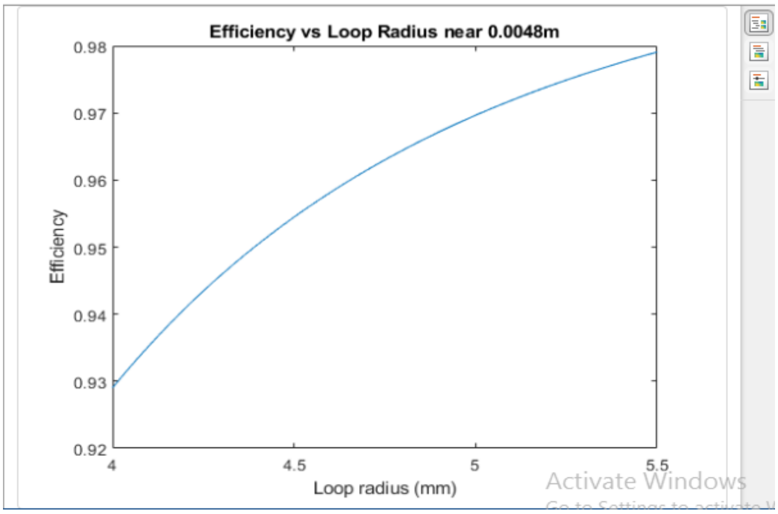

Figure 5: Plot of Efficiency vs Loop radius

The graph of figure 6 below is a plot of the antenna gain against the loop radius. The plot shows increasing gain for all constraints (0.001 to 0.048) of the antenna loop radius. From the graph, it is shown that as the loop radius increases from 0, the gain increases from its negative value to the maximum value as the loop radius is optimized to 0.0048m. The value of the antenna's gain is very close to the directivity indicating very high efficiency.

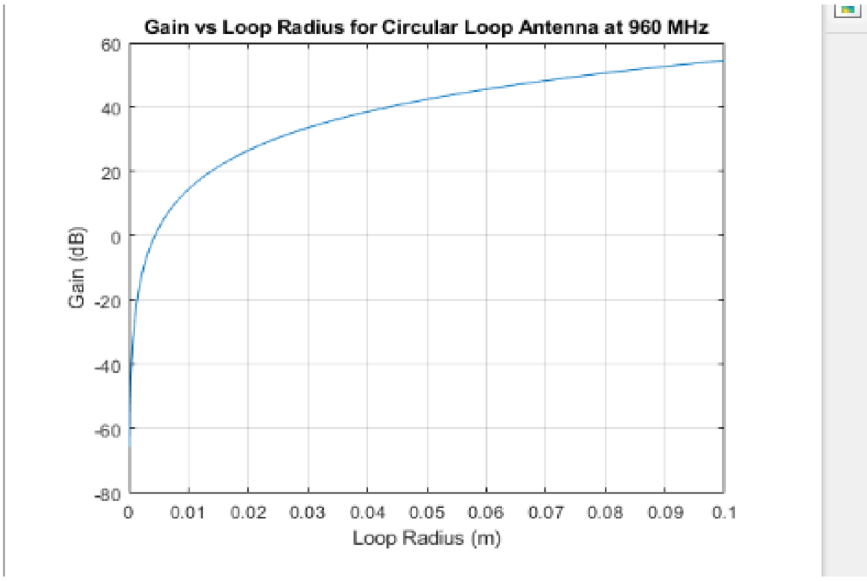

Fig. 6 Plot of Gain vs. Loop Radius.

V. SUMMARY/ CONCLUSION

This study was undertaken to design, analyze and optimize the radiation characteristics of a circular loop antenna to improve its performance in terms of radiation resistance, radiation efficiency, directivity and gain, for use in wireless communication network. Using the genetic algorithm technique executed in MATLAB, we considered the physical dimensions of the antenna (loop radius and conductor) within a range of constraints for the optimization with the objective function of maximizing radiation resistance and minimizing loss (ohmic) resistance (since loop resistance imparts radiation resistance and conductor radius imparts ohmic resistance, Balanis (2005).

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Result from GA converged to a loop radius of R = 0.0048 m a conductor radius of r = 0.0001 m from which the length of conductor (circumference, C = 0.0302 m) was computed. The feed-gap, g was also computed and given as g = 0.0391 m. These parameters are used for the optimized circular loop antenna physical design model shown in figure 1. The optimal values of the circular loop antenna radiation resistance, ohmic resistance and other radiation characteristics of the proposed circular loop antenna were computed. The optimized antenna characteristics displayed in table 2 were used for simulation of the antenna's far-field radiation pattern shown in figures 2 and 3. The pattern shows omni-directional radiation (radiation of electromagnetic waves in all directions) without back or side lobes. This will also contribute to minimize ohmic resistance as no power is lost to the lobes. The efficiency of the proposed antenna design was also simulated in MATLAB as shown in the plot of efficiency versus loop radius. The graph showed that the efficiency of the antenna increases as the loop radius increases. Therefore, this study has shown that Genetic Algorithm (GA) is a powerful tool for antenna design optimization. And that if the conductor diameter and the loop diameter of a circular loop antenna are carefully chosen, significant improvements in radiation resistance, radiation efficiency, gain and directivity can be achieved.

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