Proceedings of the Fourth International Conference on Trends in Electronics and Informatics (ICOEI 2020)
IEEE Xplore Part Number: CFP20J32-ART; ISBN: 978-1-7281-5518-0

Rectangular Microstrip Patch Antenna Miniaturization using improvised Genetic Algorithm

Dhakshinamoorthi M K, Gokulakkrizhna S, Denesh Kumar M, Subha M, Mekaladevi V
Department of Electronics and Communication Engineering
Amrita School of Engineering, Coimbatore
Amrita Vishwa Vidyapeetham, India
kdhakshna07@gmail.com, v_mekaladevi@cb.amrita.edu

Abstract—**This paper presents the antenna miniaturization at 2.4 GHz (desired frequency) using genetic algorithm. The microstrip patch antenna resonating at higher frequency is designed conventionally and the structure of the rectangular patch is modified through the algorithm in order to shift the resonant frequency while keeping the physical volume of the antenna constant. Genetic Algorithm has been used to shift the resonance frequency, but the resultant frequency is always random. Here the resultant frequency (2.4 GHz) is fixed with the help of a proper fitness function. Genetic algorithm was applied on patch surface of conventional 3 GHz and 4 GHz antennas and the rate of miniaturization is 24.4% and 45.8% respectively.**

Keywords—microstrip patch antenna, antenna miniaturization, genetic algorithm

I. INTRODUCTION

During the late half of 19th century, the discovery of Charles Darwin crated a huge impact in biological science. The life evolutionary process of micro-organisms includes selecting natural individuals and optimizing the individuals that are fit for life. At the same time, Gregor Mendel learned the basic law of genetic inheritance. Currently the advancement in computers and powerful computation techniques allows us to apply nature's optimization process in the form of Genetic Algorithm (GA).

Genetic algorithm is a powerful global optimization technique useful in wide area of electromagnetics [1] (mainly in antenna design structure). Genetic algorithm is categorized as global optimizers, while other traditional techniques like conjugate-gradient and the quasi-newton method are categorized as local techniques. Genetic algorithm optimization is highly robust, stochastic search method. It effectively solves complex, combinatorial and related problems. Its goal is to find the global maximum or minimum in a high-dimensional, multi-model function.

Genetic algorithm has been used to enhance the performance of antenna by optimizing the patch and improve directivity, gain, and bandwidth. Designing a Microstrip patch Antenna (MPA) is conventionally easy but enhancing antenna property like gain, directivity, radiation pattern or bandwidth is a tradeoff within the properties of antenna.

The few methodologies used to enhance the bandwidth or directivity is by creating slits or slots on the patch and by using suspended substrate in [2]. This makes the fabrication of the antenna complex. The dimension and position of slots on the antenna is completely nondeterministic as in [3-4]. Even the polarization property of the antenna is changed by introducing defected ground structure in [5]. Hence genetic algorithm has been applied on antenna to enhance a particular antenna property. An initial design of antenna resonating at particular frequency is designed and keeping the dimension of the antenna constant, Genetic algorithm is applied to make the antenna resonate at lower frequency [6-8]. This reduces the conventional size of the antenna. GA has also been applied to optimize the dimension of the feed to increase the return loss at resonating frequency [9]. The gain and bandwidth of the antenna are important properties for various antenna applications. In [10], GA is applied on the patch of antenna while keeping the patch dimension and feed position constant to enhance the gain of the antenna.

From the literature survey made on GA techniques, it is a tradeoff between the GA enhancing property and resonating frequency as explained in [11-12]. There is deviation in the resonating frequency after applying GA. Wireless LAN uses the IEEE 802.11 b/g/n standards and other wireless technologies like 802.15.4 based Zigbee/wireless HART, Bluetooth operates in the 2.4GHz frequency band.

In antenna miniaturization technique, the resonating frequency is randomly obtained. In few GA techniques the fitness function returns an infinity value which does not produce the best solution.

Our objective is to achieve miniaturization of a rectangular patch antenna at a desired frequency using an improved Genetic Algorithm i.e. to maximize the negative of return loss at 2.4 GHz. So in this paper the drawback of GA miniaturization is addressed by designing a fitness function that pushes the resonating frequency to desired frequency and by including logarithmic functions to prevent fitness value reaching infinity. From this, the antenna miniaturization can be achieved by using any patch antenna design to resonate at desired frequency.

II. DESIGN METHODOLGY

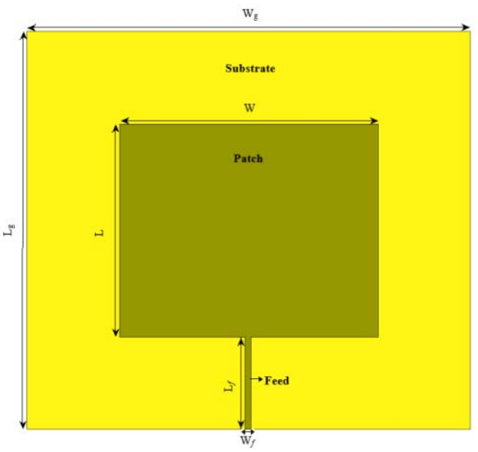
A. Antenna Configuration

The selection of the operating frequency and substrate are the initial steps to design a MPA. The frequency of the proposed design is 2.40 GHz. Initially 3 GHz and 4 GHz antennas are designed and GA is implemented to resonate the antenna at 2.40 GHz which is the desired frequency while keeping the initial dimensions constant. The abundantly available substrate material FR4 Epoxy with a height of 1.6 mm and dielectric constant of 4.4 is used. The summary of dimensions is shown in table I.

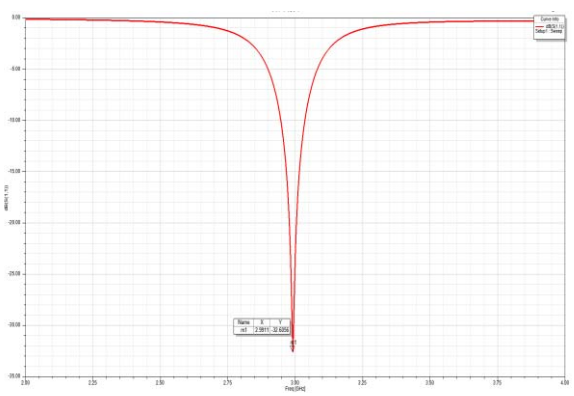
TABLE I. ANTENNA PARAMETERS

Parameters	Values (mm)		
	3 GHz	*4 GHz*	*2.4 GHz*
W	27.3	19.5	34.5
L	22	16.3	28
W_f	0.7	0.765	0.765
L_f	9.6	9.6	9.6
W_g	46.5	38.7	53.7
L_g	41.2	35.7	47.2

The rectangular patch is used since it can be analyzed using both cavity and transmission-line models, which are unerring for thin substrates [13]. Since the dimensions of patch are finite, fields at the edges of patch undergoes fringing which is responsible for the radiation of the antenna.



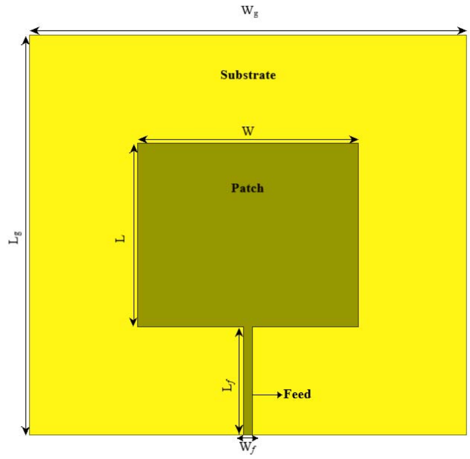
(a)



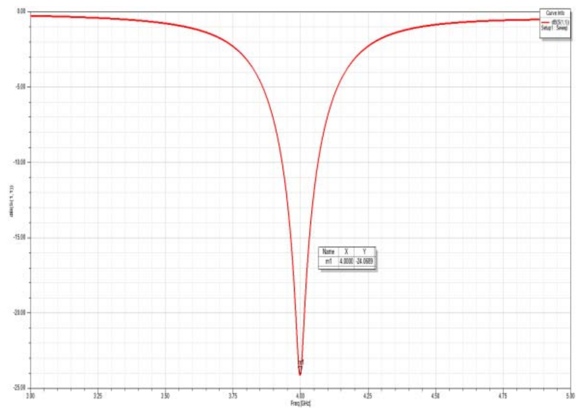
(b)

Fig. 1. (a) 3 GHz MPA (b) Frequency vs Return loss

The above antenna resonates at 3 GHz with a return loss of -32.5 dB as shown in fig. 1. The antenna has a gain of 2.09 dB and has an efficiency of 56%. The antenna is designed using Ansys HFSS software.



(a)



(b)

Fig. 2. (a) 4 GHz MPA (b) Frequency vs Return loss

The second antenna resonates at 4 GHz with a return loss of -24 dB as shown in fig. 2. The antenna has a gain of 2.51dB and has an efficiency of 60%. The antenna is designed using Ansys HFSS software.

B. Genetic Algorithm Procedure

The patch area is divided into 10 X 10 cells. The Binary Coded GA is employed where 1 represents conducting cells and 0 represents non-conducting cells. The flowchart of the GA implemented in this design is shown in fig. 3.

In this GA optimization, each individual is encoded with a 2D chromosome. The initial population is generated randomly. In each generation, the population undergoes crossover and mutation where new individuals are produced. Crossover involves mating the existing individuals in the current population to produce offspring. Mutation involves adding extra abilities to the individuals. The offspring can be either better or worse. So each individual is assigned a fitness value based on their characteristics. Better individuals are chosen when a proper fitness function is defined. When new individuals are produced these are added to existing population. Based on the fitness value, the worst individuals are discarded in each generation keeping the population size constant. Elitism is incorporated in the algorithm in order to sustain the best individual in each generation.

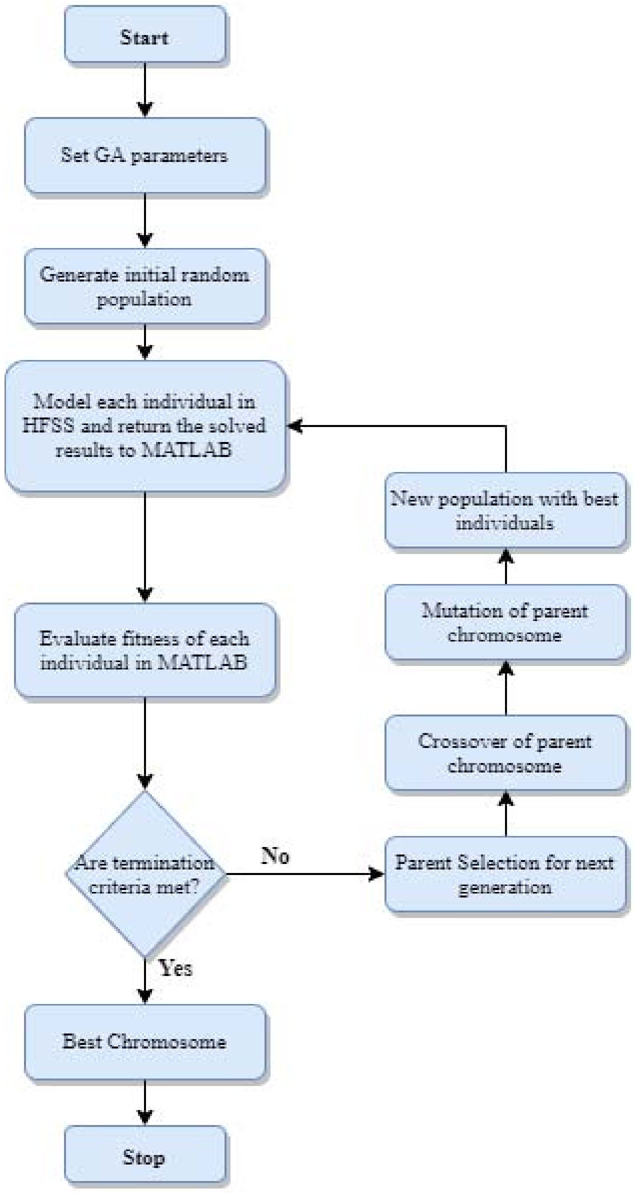


Fig. 3. Flow chart of GA implemented in this design

The objective of our GA design is to maximize the negative of return loss at the desired frequency (2.4 GHz). Rank Selection and random mutation with mutation probability of 0.3 is used. Rank Selection is used because it provides more diversity in the population and the convergence rate is high. The maximum mutation percentage of an individual is 0.02 i.e. maximum 2 of 100 bits can be randomly mutated in a chromosome. To achieve the objective, GA architecture employs 20 individuals in each generation with maximum number of generations 15. A single point, two point and uniform crossover is randomly used with crossover probability of 100%.

The fitness of the each individual in a population is determined using the below functions (1) and (2).

$$\text{Fitness} = \begin{cases} \log\left(\frac{\sum_N L(fi)}{N}\right), & s11_{min} > -9.5\text{dB} \\ \log\left(\frac{\sum_N L(fi)}{(N|fr-fd|)}\right), & \text{otherwise} \end{cases} \quad (1)$$

$$L(f_i) = \begin{cases} |s11(f_i)|, & s11(f_i) \geq -13\text{dB} \\ 13, & \text{otherwise} \end{cases} \quad (2)$$

Where f_i: Frequency of each sample
N: Total no. of samples under consideration
f_d: Desired frequency
f_{rl}: The individual resonance frequency
$s11_{min}$: The s11(dB) parameter at resonance frequency.

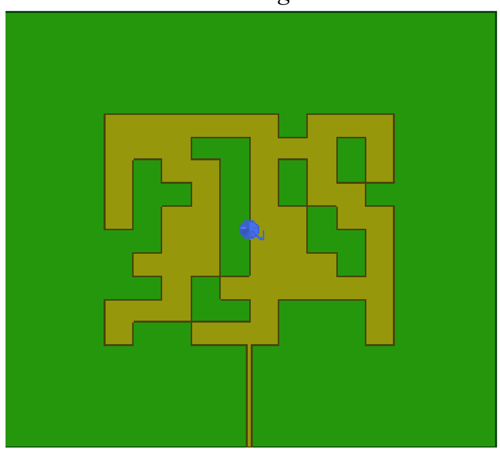
The GA process is executed until it meets the below termination criteria defined by (3).

$$2.39 < f_{rl} < 2.41 \;\&\; s11_{min} < -13.5 \quad (3)$$

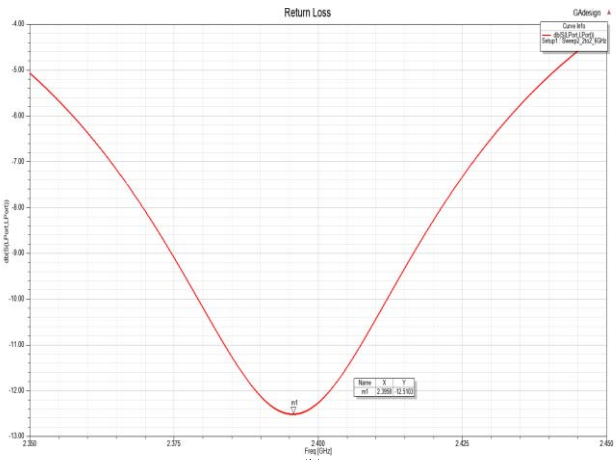
Each individual of the population has a fitness values that is determined by the above fitness function. The convergence of the GA optimization significantly depends on the pressure kept on the individual by the fitness function. The objective is to bring the resonant frequency at 2.4 GHz and the return loss at that frequency should be below -13.5dB. The first priority is to bring the return loss below -9.5 dB and then the individuals with resonant frequency near the desired frequency are given more significance by dividing the existing fitness value by difference between desired frequency and resonating frequency. Logarithmic functions are included in order to give more significance to the frequencies very near to the desired frequency. From (3), it can be inferred that the GA is terminated when the resonating frequency is between 2.39 and 2.41 GHz and the corresponding return loss at that frequency is below -13.5dB.

III. Results

A. From 3 GHz coventional Design



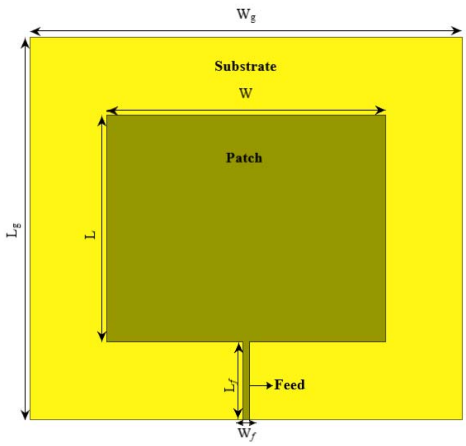
(a)



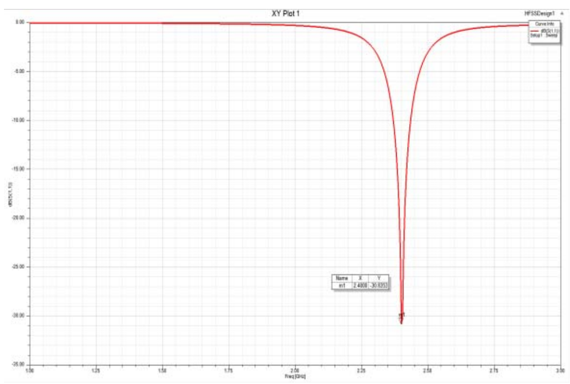
(b)

Fig. 4. (a) GA optimized structure (b) Frequency vs Return loss

GA was applied on the patch of 3 GHz conventional design. The simulation of GA was terminated at 20th Generation. The antenna which was designed using Ansys HFSS resonates at 2.3958GHz with a return loss of -12.51 dB as shown in fig. 4(b). Fig 4(a) shows the corresponding modified patch after GA was implemented.



(a)

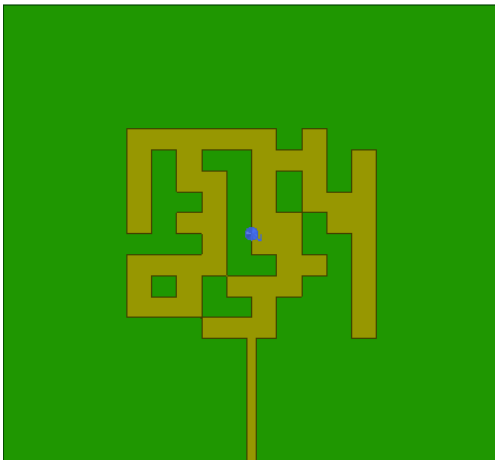


(b)

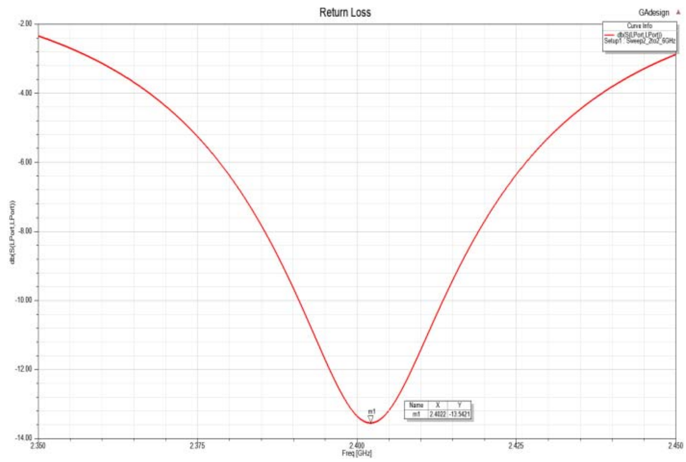
Fig. 5. (a) Conventional 2.4 GHz MPA (b) Frequency vs Return loss

The conventional design of MPA in fig. 5 resonating at 2.40GHz with return loss of -32dB has a dimension of [53.7 x 47.2 x 1.6] mm^3. The optimized design resonating at 2.3958GHz has a dimension of [46.5 x 41.2 x 1.6] mm^3. Hence an antenna miniaturization of 24.4% is achieved.

B. From 4GHz coventional Design



(a)



(b)

Fig. 6. (a) GA optimized structure (b) Frequency vs Return loss

GA was applied on the patch of 4 GHz conventional design. The simulation of GA was terminated at 10th Generation as the result was converged. Here it has been viewed that, the antenna that was designed using Ansys HFSS resonates at 2.402 GHz with a return loss of -13.54 dB as shown in fig. 6(b) and fig. 6(a) is the modified patch after GA was implemented.

This design resonating at 2.402 GHz has a dimension of [38.7 x 35.5 x 1.6] mm^3. Here an antenna miniaturization of 45.8% is achieved.

The results of the proposed work are compared with the existing works in table II.

TABLE II. COMPARISON OF PROPOSED WORK WITH EXISTING WORKS

Works	Performance Metrics						
	f_o^a (GHz)	f_r^b (GHz)	ε_r	t^c (mm)	S11 (dB)	10dB – BW (MHz)	% of Reduction
[6]	3	1.738	2.2	1.58	-24	10 MHz	42
[7]	0.405	0.4035	2.9	3	-15	20 MHz	-
[10]	4.9	2.16	4.3	1.6	-20	-	82
Proposed Work	3	2.3958	4.4	1.6	-12.5	30 MHz	24.4
	4	2.4022			-13.5	22 MHz	45.8

a. Initial Frequency.
b. Final resultant Frequency.
c. Thickness of the substrate.

IV. CONCLUSION

Miniaturization of rectangular microstrip patch antenna was achieved at 2.4 GHz by using genetic algorithm. In this paper, the rate of miniaturization achieved was 24.4% and 45.8%. This is achieved due to the changes in structure of patch which in return change the electrical length that results in the shift in resonance frequency. The results can be enhanced with more division of cells but the size of cell cannot be very small as it leads to fabrication complexity.

REFERENCES

[1] Weile, Daniel S., and Eric Michielssen. "Genetic algorithm optimization applied to electromagnetics: A review." *IEEE Transactions on Antennas and Propagation* 45, no. 3 (1997): 343-353.

[2] Liu, Neng-Wu, Lei Zhu, and Wai-Wa Choi. "Low-profile wide-beamwidth circularly-polarised patch antenna on a suspended substrate." *IET Microwaves, Antennas & Propagation* 10, no. 8 (2016): 885-890.

[3] Liu, Neng-Wu, Lei Zhu, Zhong-Xun Liu, and Ying Liu. "Dual-Band Single-Layer Microstrip Patch Antenna With Enhanced Bandwidth and Beamwidth Based on Reshaped Multiresonant Modes." *IEEE Transactions on Antennas and Propagation* 67, no. 11 (2019): 7127-7132.

[4] Shackelford, Aaron K., Kai-Fong Lee, and Kwai Man Luk. "Design of small-size wide-bandwidth microstrip-patch antennas." *IEEE antennas and propagation magazine* 45, no. 1 (2003): 75-83.

[5] Pavithra, S., A. Sivapradhayni, and V. Mekaladevi. "Suppression of Cross Polarization with Various Geometries of DGS in the Design of Microstrip Patch Antenna." In *2019 International Conference on Communication and Electronics Systems (ICCES)*, pp. 464-467. IEEE, 2019.

[6] Herscovici, Naftali, Manuel Fuentes Osorio, and Custodio Peixeiro. "Miniaturization of rectangular microstrip patches using genetic algorithms." *IEEE Antennas and Wireless Propagation Letters* 1 (2002): 94-97.

[7] Soontornpipit, Pichitpong, Cynthia M. Furse, and You Chung Chung. "Miniaturized biocompatible microstrip antenna using genetic algorithm." *IEEE Transactions on Antennas and Propagation* 53, no. 6 (2005): 1939-1945.

[8] Vedi, Yash, S. Siddhartha, M. Susila, and Mitali Gulati. "Patch-Surface Optimization & Design using Genetic Algorithm." *International Journal of Pure and Applied Mathematics* 119, no. 12 (2018): 12593-12602.

[9] Errifi, Hayat, Abdenacceur Baghdad, and Abdelmajid Badri. "Design and optimization of aperture coupled microstrip patch antenna using genetic algorithm." *International Journal of Innovative Research in Science, Engineering and Technology* 3, no. 5 (2014): 2319-8753.

[10] Lamsalli, Mohammed, Abdelouahab El Hamichi, Mohamed Boussouis, Naima Amar Touhami, and Tajeddin Elhamadi. "Genetic algorithm optimization for microstrip patch antenna miniaturization." *Progress In Electromagnetics Research* 60 (2016): 113-120.

[11] Khan, Muhammad Umar, Mohammad Said Sharawi, and Raj Mittra. "Microstrip patch antenna miniaturisation techniques: a review." *IET Microwaves, Antennas & Propagation* 9, no. 9 (2015): 913-922.

[12] Sudhakaran, Gopika, Bindu Kandipati, G. Bhuvan Surya, V. Karthikhaa Shree, M. Sivaprasad, and M. Jayakumar. "Evolutionary algorithm based structural optimization for patch antenna design and its performance analysis." In *2017 International Conference on Advances in Computing, Communications and Informatics (ICACCI)*, pp. 2189-2192. IEEE, 2017.

[13] Schaubert, Daniel H., David M. Pozar, and Andrew Adrian. "Effect of microstrip antenna substrate thickness and permittivity: comparison of theories with experiment." *IEEE Transactions on Antennas and Propagation* 37, no. 6 (1989): 677-682.