

ANALYSIS OF THE MICROSTRIP PATCH ANTENNA DESIGNED USING GENETIC ALGORITHM BASED OPTIMIZATION FOR WIDE-BAND APPLICATIONS

¹Raj Gaurav Mishra, ²Ranjan Mishra, ³Piyush Kuchhal, ⁴N. Prasanthi Kumari

University of Petroleum and Energy Studies, CoES, P.O. Bidholi,

Via Prem Nagar, Dehradun-248007, Uttarakhand, India.

¹rgmishra@ddn.upes.ac.in, ²rmishra@ddn.upes.ac.in, ³pkuchhal@ddn.upes.ac.in,

⁴prasanti@ddn.upes.ac.in

Abstract: In this paper, the design of a compact microstrip patch antenna using Genetic Algorithm (GA) based optimization is proposed for wide-band applications. The novelty of this work is the simplicity of the antenna design which is also inexpensive and easy to fabricate using FR4 substrate. Genetic Algorithm is used for the selection of parameters that constitutes antenna geometry to achieve wider bandwidth and minimal return loss (S_{11} parameter) at resonant frequency. The antenna design exhibits a very wide operating bandwidth of 7.16 GHz over the frequency range of 1.87 GHz to 9.03 GHz with VSWR 2, return loss (S_{11}) of 55.19 dB and radiation efficiency of 91.96% at a resonating frequency of 5.16 GHz. The proposed antenna also shows omni-directional radiation pattern that makes it suitable for wide-band applications. Further analysis of the antenna parameters and their effect on the performance is also discussed. All simulations in this work were carried out by using the ANSYS HFSS (High Frequency Structural Simulator) Software. To validate the design, an antenna prototype has been fabricated using an FR4 substrate and then characterized using a vector network analyzer. The measurements results were in good agreement with simulated results.

Keywords: Microstrip Patch Antennas, Wide-band Applications, Genetic Algorithm, GA, Antenna Optimization.

1. Introduction

MICROSTRIP antennas are expected to find many promising applications in wireless communications because of their attractive merits of low profile, light weight, ease of fabrication, and good ability to integrate with circuits [1]. However, it is well known that standard microstrip patch antennas exhibit very narrow operating bandwidth. Many efforts have been devoted to

solve this problem to some extent such as using a dielectric substrate of high permittivity [2], use of defected microstrip structure (DMS) [3], use of defected ground structure (DGS) at the ground plane [4] or a combination of them, addition of multiple substrates [5], [6], addition of air gaps and shorting pins [7], use of metamaterials [8], [9], addition of slots on patches [10], [11], use of modified patches are used instead of conventional shapes [12], optimization of patch shape and shorting position [13], and various existing optimization algorithms such as particle swarm optimization (PSO) [14] and creating complex patch structures using genetic algorithm [15], [16].

Major challenges for an efficient wide-band antennas are broad impedance bandwidth ($S_{11} < 10$ dB), flat gain response and less variation in group delay over the allocated bandwidth. Printed patch antennas are suitable for wide-band applications due to their excellent mechanical and electrical characteristics, compatibility for integration with other RF systems and mass production [17].

This paper consists of four sections, where Section II presents the Genetic Algorithm, its procedure for antenna design and resultant GA designed antenna configuration. Section 3 presents the performance of microstrip patch antenna designed using GA optimization using the simulated and measured results. It also presents the analysis of the effect of various geometrical parameters of the designed antenna on its performance. Finally, Section 4 summarizes the paper.

2. Genetic Algorithm and GA Procedure

A. Genetic Algorithm

The principle of the GA, first formalized by Holland and expanded to functional optimization by De Jong, comprises of the utilization of optimization search

techniques designed after the Darwinian concept of natural selection and evolution [15], [18].

Over a GA based optimization, the parameters of each individual of the population are typically encoded as a string of bits (known as chromosomes). The preliminary group of individuals (generation) is provided at random. The fitness of each individual is determined with the help of cost function. Mating these types of individuals produces a new generation. Fittest individuals are picked up and offered higher probabilities of producing new population. Crossover and mutation are generally utilized to enable global search of the cost function. The fittest individual may possibly be transferred unchanged to the next generation. This particular iterative operation produces efficient generations before a stop criterion is attained [15], [19]. A block diagram of a simplified genetic algorithm (GA) optimizer is introduced in Figure 1.

GA is an effective optimization approach that has been utilized in the wide area of electromagnetics. To obtain desired radiation patterns, GA based optimization of a set of metallic strips was presented in [20]. Design synthesis of

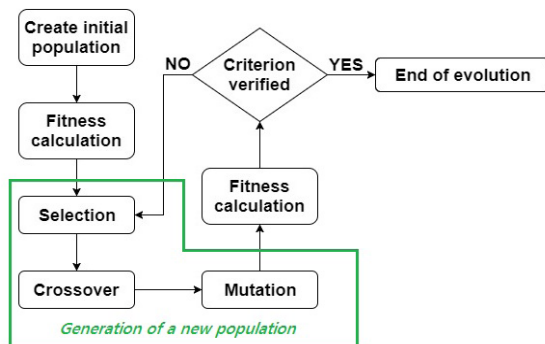


Figure 1. A simple genetic algorithm optimizer [15]

patch antennas formulated using GA was presented in [21]. Literature review shows that, GA has been employed to create broad-band patch antenna [22], multi-band patch antenna [23], and miniature patch antenna [24]. However, no references are found that has optimized the shape of multiple elements within an antenna, keeping it simple in design, low in cost and easy in fabrication with an objective to obtain a high-bandwidth and lower possible return losses (S_{11}) at resonating frequencies.

In this paper, Genetic Algorithm is used for designing a high-bandwidth patch antenna having low return losses at resonating frequency by optimizing the patch, feedline, ground plane and substrate geometries. All designs are simulated in the Ansys High Frequency

Structure Simulator (HFSS) environment in combination with a MATLAB code implementing the Genetic Algorithm (GA). A resultant VBS file (from the MATLAB code) is called into HFSS environment to perform further simulations. Next subsection discusses the GA algorithm and procedure for antenna in details.

B. Genetic Algorithm Procedure for Antenna Design

Stepwise Genetic Algorithm procedure for antenna design is summarized as follows:

Step 1: A primary population is created by producing a random binary string. GA parameters such as string of bits (chromosome), population size and total number of generations used for the purpose of optimization of antenna geometry parameters to achieve higher bandwidth is discussed in Table I.

Step 2: Design checks (as shown in Figure 2) are applied to validate the strings of bits (chromosomes). Then using solving conditions in HFSS, S_{11} parameters can be calculated and returned to primary function automatically (in MATLAB). The returned S_{11} parameter is used for calculation by fitness function (in MATLAB). Step 3: Evaluation of the fitness function as defined in the equation 1. If the stopping criterion is satisfied then stop the GA procedure, otherwise go to the Step 4.

By default, Genetic Algorithm minimizes the cost (fitness) function. The value of cost function will vary from 0 to the most optimal value of 120. The cost function is defined in equation 1.

$$Cost = [-(12 * BW) + S_{11(Res)}] \quad (1)$$

$$BW = \begin{cases} 5 \text{ GHz}; & \text{for } BW_{cal} \geq 5 \text{ GHz} \\ BW_{cal}; & \text{for } BW_{cal} < 5 \text{ GHz} \end{cases} \quad (2)$$

$$BW_{cal} = f_H - f_L \quad (3)$$

$$S_{11(min)} = \text{Min}[S_{11}(f_1), S_{11}(f_2), S_{11}(f_3), \dots, S_{11}(f_n)] \quad (4)$$

$$S_{11(Res)} = \begin{cases} -60 \text{ dB}; & \text{for } S_{11(min)} \leq -60 \text{ dB} \\ S_{11(min)}; & \text{for } S_{11(min)} > -60 \text{ dB} \end{cases} \quad (5)$$

Where, BW is bandwidth of the microstrip antenna calculated using equation 2. Bandwidth is simply the difference between the operating upper frequency, f_H and lower frequency, f_L . The value of BW_{cal} as used in equation 2 is calculated using the formulae shown in equation 3 (implemented in MATLAB code) utilizing the simulated values of return losses received after

simulating the design using HFSS. Similarly, the values of $S_{11}(f_1; \dots; f_n)$ (used in equation 4) are the simulated values of return losses at different frequencies. $S_{11(\text{Res})}$ is the value of return loss at resonating frequency calculated using equation 5.

Step 4: Using the operators of Genetic Algorithm such as scaling, selection, crossover, mutation, etc (refer Table I), next generation can be created.

Step 5: Repeat the process from Step 2 onwards. Some checks are applied to validate the strings of bits (chromosome) in order to develop a valid microstrip patch antenna design. These design based checks helped in saving a lot of optimization time by discarding useless chromosomes from getting processed. These checks are shown in Figure 2. Length of substrate is shown as L_s , length of patch as L_p , length of feedline as L_{FL} , length of ground plane as L_g , width of substrate as W_s and width of patch as W_p .

The code for GA algorithm is integrated with HFSS environment using MATLAB. The initial geometry of the antenna is based on the values of bits (chromosomes) as discussed in Table II. A random single point crossover method and uniform mutation operation (with a factor of 0:01) is used. The convergence is obtained after 25th generation.

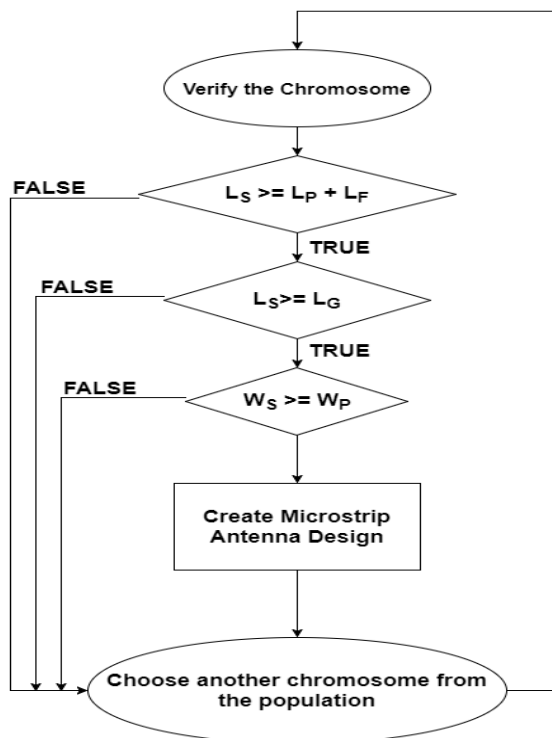


Figure 2. Flowchart of the design checks to validate the strings of bits (chromosomes)

Table 1. GA Parameters Used for the Purpose of Antenna Design

GA Parameters	Values
Number of decision variables	32 Bit (refer Table II)
Population type	Bit String
Population Size	200
Selection	Roulette
Scaling	Rank
Reproduction Elite Count	2
Crossover	Single Point Crossover
Fraction of Crossover	0.8
Mutation	Uniform (0.01)
Migration	Both front and back
Penalty factor	100
Initial Penalty	10
Total number of Generations	200

C. Resultant Microstrip Patch Antenna using Genetic Algorithm (GA)

The resultant antenna with GA is represented in Figure 3. In this design, a FR4 substrate is utilized as it is inexpensive and easier in fabrication. The FR4 substrate is having height of 1.6 mm, dielectric constant of 4.3, and loss tangent of 0.02. The antenna parameters are summarized in Table III.

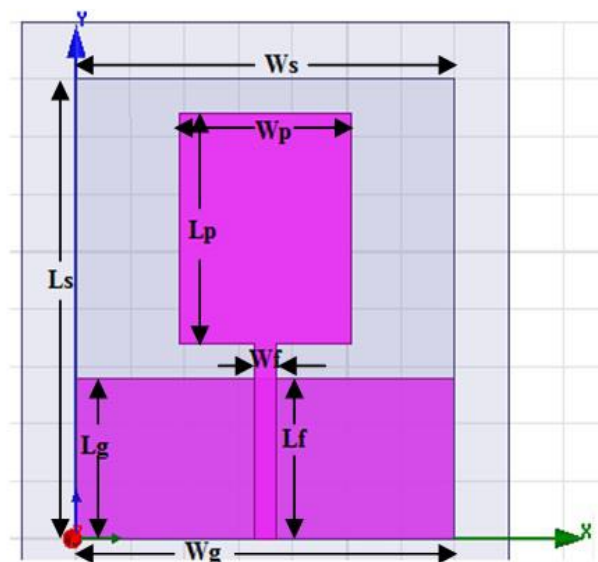


Figure 3. Proposed Microstrip Patch Antenna Configuration

Table 2. Proposed Antenna Geometry

Parameter	Value
Substrate Length (L_S)	40 mm
Substrate Width (W_S)	35 mm
Ground Plane Length (L_G)	14 mm
Ground Plane Width (W_G)	35 mm
Patch Length (L_P)	22 mm
Patch Width (W_P)	13 mm
Feedline Length (L_{FL})	17 mm
Feedline Width (W_{FL})	2 mm

3. Results and Discussion

A. Performance of Microstrip Patch Antenna designed using GA Optimization

The simulated return losses (S_{11}) and VSWR obtained for the proposed antenna is presented in Figure 4. We can see that the bandwidth is about 7.16 GHz, and the resonance frequency is nearly 5.16 GHz. The objective of the design was to have the maximum bandwidth and good return losses (S_{11}) at the resonant frequency.

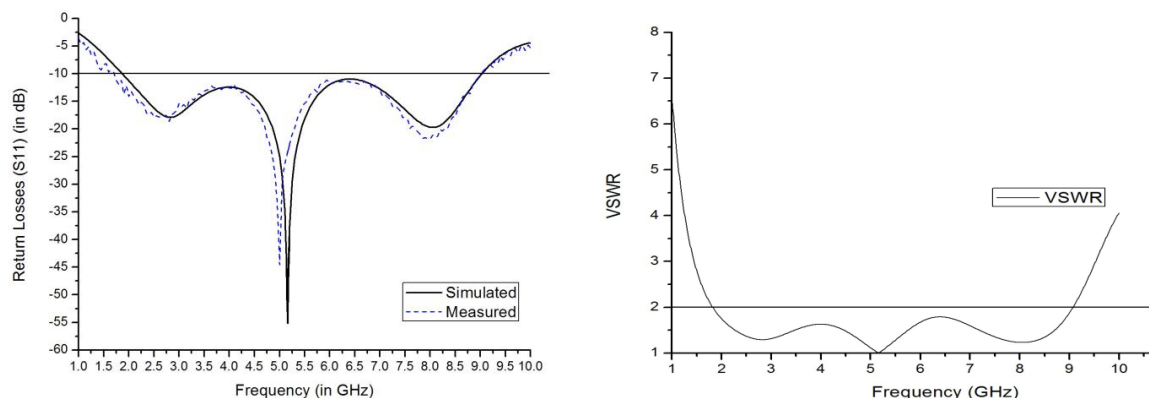
Figure 5 displays the current distribution of the proposed antenna design at the resonant frequency of 5.16 GHz.

1) Prototyping and Measurement Results: A prototype of the resultant microstrip patch antenna designed using Genetic Algorithm (GA) fabricated using FR4 substrate is shown in Figure 7. To measure scattering parameters, Rohde & Schwarz vector network analyzer having frequency range constrained to 20 GHz is used. The measured results are then reviewed with the simulated ones as shown in Figure 4(A). The result shows that the proposed antenna offers a wider bandwidth of 7.16 GHz. The measured results goes along with the simulated ones but with some discrepancies occurred due to the manufacturing inaccuracy as well as the conditions of measurement.

As displayed in Figure 7, the presented antenna offers a satisfactory omni-directional radiation pattern required to receive signals coming from all directions. The next subsection presents the study performed to determine the effect of various parameters of antenna geometry that affects the bandwidth and return losses.

Table 3. GA Parameters Used For The Purpose of Antenna Design

	Patch		Substrate		Feedline		Ground Plane	
Length (L _P)	Width (W _P)	Length (L _S)	Width (W _S)	Length (L _F L)	Width (W _F L)	Length (L _G)	Width (W _G)	
XXXXX	XXXXX	XXXXX	XXXXX	XXXX		XXX	XXXXX	Same as sub- strate
5 bits	5 bits	5 bits	5 bits	4 bits		3 bits	5 bits	
5-36 mm	5-36 mm	18-49 mm	18-49 mm	4-19 mm		1-8 mm	10-41 mm	width
		Resolution: 1 mm (for each parameter)						
		0,1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31 (total 32 bits)						

**Figure 4.** (A) Simulated vs. measured return loss (S_{11} parameters); (B) Simulated values of VSWR

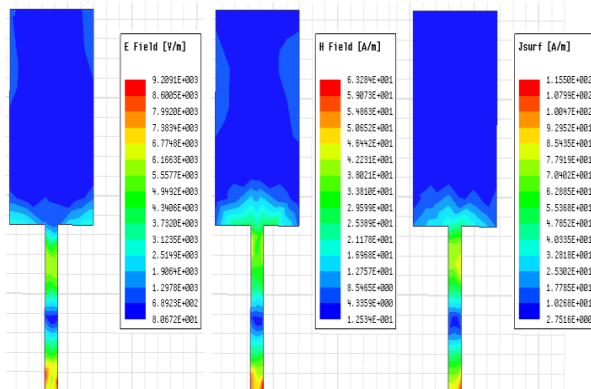


Figure 5. Current Distribution of the Proposed Antenna

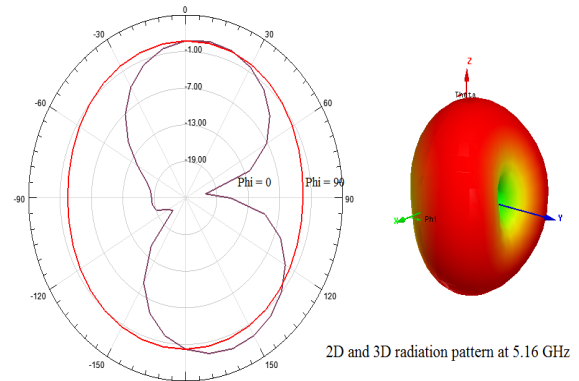


Figure 7. 2D and 3D Radiation Pattern (at= 0 and 90 degrees)

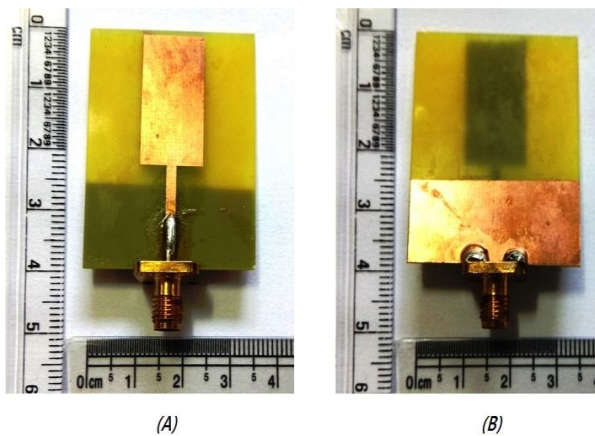


Figure 6. Photograph of the prototyped antenna (A) Radiating Patch with Feedline (B) Partial Ground Plane

B. Parametric Analysis of the Proposed Antenna

In the following subsection, an analysis is carried out to determine the effect of the bandwidth-enhancer design parameters of the microstrip patch antennas. Figure 8-12 demonstrates all analyzed parameters. The participation of a specific parameter is analyzed at a time, while preserving all other parameters to their suboptimal values.

1) Effect of length of the patch (L_P): First, the effect of varying the length of the rectangular patch (L_P) as illustrated in Figure 3 is studied. It is observed that the return loss (S_{11}) at the resonating frequencies is improved while increasing the L_P from 18 mm to the optimal value of 22 mm. The other values of antenna's geometrical parameters are kept constant as shown in Table III. This is represented in the Figure 8.

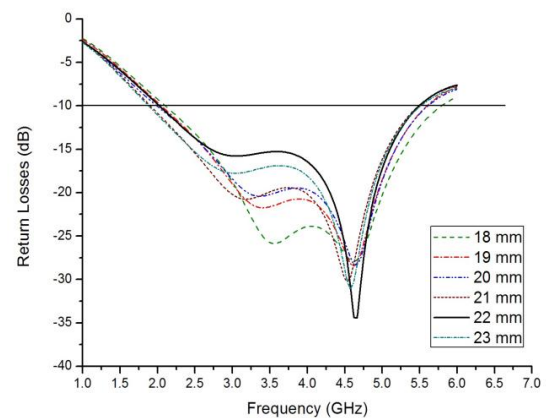


Figure 8. Effect of changes in the length of the patch (keeping $W_P = 16$ mm as constant)

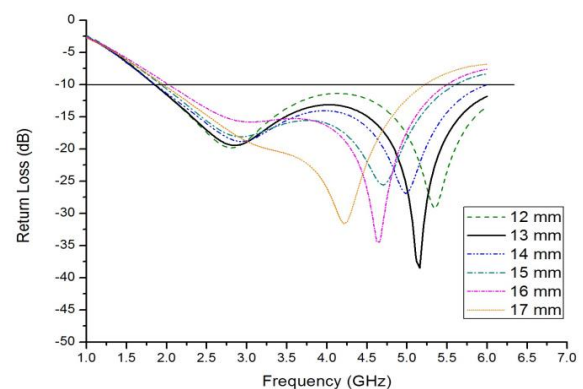


Figure 9. Effect of changes in the width of the patch (keeping $L_P = 22$ mm as constant)

2) Effect of width of the patch (W_P): In this subsection, the effect of varying the width of the rectangular patch (W_P) as illustrated in Figure 3 is studied. It is observed that the overall impedance bandwidth is improved while increasing the W_P from 12 mm to the optimal value of 16 mm. This is represented in the Figure 9.

3) Effect of width of the feedline (W_{FL}): In this subsection, the effect of varying the width of the feedline (W_{FL}) as illustrated in Figure 3 is studied. It is observed that the overall bandwidth is improved along with the return loss (S_{11}) at the resonant frequency while decreasing the W_{FL} from 4 mm to the optimal value of 2 mm. This is due to the effective impedance matching. This is represented in the Figure 10.

4) Effect of length of the ground plane (L_G): The ground plane contributes to the radiation. In this subsection, the effect of varying the length of the ground plane (L_G parameter) as illustrated in Figure 3 is studied. It is observed that the overall bandwidth is improved while using the partial length of ground plane (L_G). The most optimal partial ground plane length is found to be 14 mm. This is represented in the Figure 11.

5) Effect of length of the substrate (L_S): The length of substrate is considered to be important as it impacts the overall size of the microstrip patch antenna. In this subsection, the effect of varying the length of the substrate (L_S) as illustrated

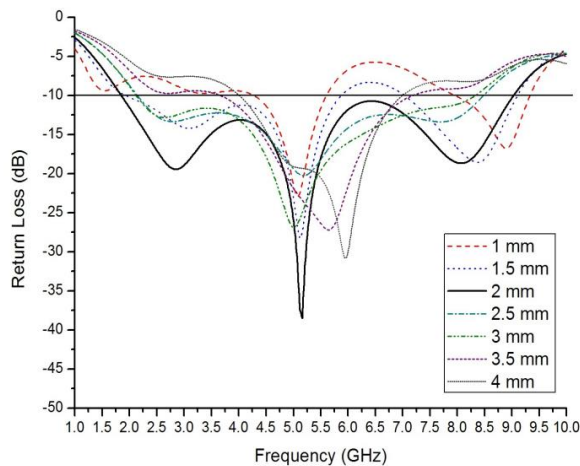


Figure 10. Effect of changes in the width of the feedline (keeping $L_P = 22$ mm and $W_P = 13$ mm as constant)

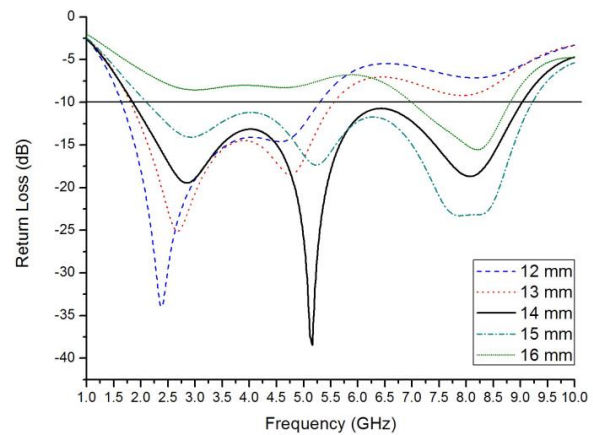


Figure 11. Effect of changes in the length of the ground plane (keeping $L_P = 22$ mm, $W_P = 13$ mm, $W_{FL} = 2$ mm as constant)

In Figure 3 is studied. It is observed that the overall bandwidth is improved along with the return loss (S_{11} at the resonant frequency) while decreasing the L_S from 43 mm to the optimal value of 40 mm. This is represented in the Figure 12.

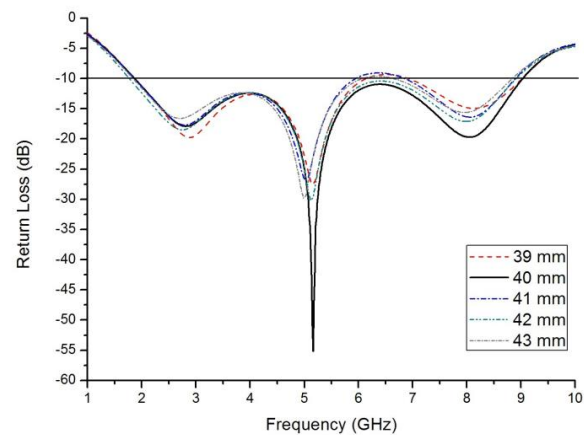


Figure 12. Effect of changes in the length of the substrate (keeping $L_P = 22$ mm, $W_P = 13$ mm, $W_{FL} = 2$ mm, $L_G = 14$ mm, $W_S = 35$ mm as constant)

6) Effect of width of the substrate (W_S): Similar to the length of substrate, its width is also impacting the overall size of the microstrip patch antenna and thus considered to be an important factor in design. In this subsection, the effect of varying the width of the substrate (W_S) as illustrated in Figure 3 is studied. It is observed that the overall bandwidth is improved along with the return loss (S_{11} at the resonant frequency) while decreasing the W_S

from 38 mm to the optimal value of 35 mm. This is represented in the Figure 13.

This analytical study has confirmed the validity of the converged GA optimized design of proposed microstrip patch antenna.

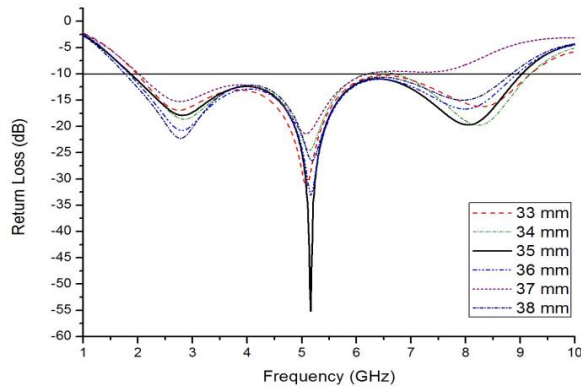


Figure 13. Effect of changes in the width of the substrate (keeping $L_P = 22$ mm, $W_P = 13$ mm, $W_{FL} = 2$ mm, $L_G = 14$ mm, $L_S = 40$ mm as constant)

C. Comparison of the Proposed Antenna with Existing Literature

Table 4 shows a comparison between a couple of recently designed wide-band antennas and the proposed antenna design. The proposed antenna demonstrated a wider bandwidth and improvements in the return loss (S_{11} parameter) at 5.16 GHz.

Table 4. Comparison between Proposed Antenna Design (This Work) and the Recently Proposed Antennas (Existing Literature)

Antenna	Bandwidth	Antenna Size	Substrate	Return Loss (in dB)	Res. Freq.
This work	7.16 GHz	40 x 35 x 1.6 mm ³	FR4	55.19 dB	5.16 GHz
[25]	500 MHz	70 x 70 x 0.8 mm ³	FR4	20 dB	5.51 GHz
[26]	2.26 GHz	38.92 x 45 x 1.6 mm ³	FR4	20.50 dB	8.92 GHz
[27]	470 MHz	47 x 10 x 5 mm ³	FR4	36 dB	1.92 GHz
[28]	1.5 GHz	96 x 72 x 1.6 mm ³	FR4	35 dB	5.7 GHz
[29]	730 MHz	38 x 10 x 1.6 mm ³	FR4	21 dB	5.36 GHz

4. Conclusion

This paper presented the simulated and measured outcomes of a microstrip patch antenna designed using Genetic Algorithm (GA) based optimization. This motivation of this work is to improve the antenna's bandwidth and to attain good return losses (S_{11}) at resonant frequency. The proposed design exhibits a very broad bandwidth of 7.16 GHz, VSWR 2, return loss (S_{11}) of -55.19 dB and radiation efficiency of 91.96% at a resonating frequency of 5.16 GHz. The proposed antenna is compact in size and displays stable far-field radiation patterns throughout its operating range. Based on these qualities, the proposed antenna is appropriate for wide-band wireless communication applications.

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