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Relatively Weighted Three Factor Novel Fitness Function for Multi-Objective Optimization of Mspa Using Genetic Algorithm

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Abstract

Micro Strip Patch Antenna (MPSA) is designed using standard design equations and multiple antenna parameters; mainly patch dimensions as variables. The theoretical values may not result in the desired performance. For over a quarter century, evolutionary algorithms have played a pivotal role in optimizing the design variables of MSPA, Genetic Algorithm (GA) being the most popular among them. The success of using GA for the optimization of MSPA lies in the right formation of fitness function (FF) using the right performance parameters. This study introduces a relatively weighted, three-factor novel FF for multi-objective performance optimization of MSPA by optimizing multiple antenna design parameters using GA. The proposed FF guided GA to simultaneously achieve multiple performance optimization objectives: resonance frequency fr of 5 GHz, bandwidth (BW) exceeding 300 MHz, and return loss S11 better than −50 dB by optimizing four critical design parameters—antenna width, length, and slot positions along the x and y axes. The performance of the proposed FF is then compared with six existing FFs from prior research, each with limited optimization capabilities. The results demonstrate that the proposed FF significantly improves optimization outcomes, yielding an MSPA that resonates exactly at 5 GHz, achieves a bandwidth of 315 MHz, and enhances return loss to −54.84 dB. These results confirm the effectiveness of the proposed FF in achieving high-performance, multi-objective, multi-parameter optimization of MSPAs using GA.

Keywords: Microstrip Patch Antennas, Genetic Algorithm, Fitness function, Chromosome

1. INTRODUCTION

MicroStrip Patch Antennas (MSPA) have gained popularity owing to their ease of production, low production costs, planar character, lightweight, and easy integration into integrated circuits, at microwave frequencies. The disadvantages are low efficiency, poor gain, narrow bandwidth, and low return loss. Another major challenge faced by the researchers is the deviation of the actual output from the desired design output while applying standard design equations for theoretically calculating values of design variables for use in simulation. The difference in the actual and desired output will subsequently reflect in the experimental outputs also. Therefore, theoretical values of the design variables need to be adjusted to achieve the desired design objective. Usually, this is done by trial and error, in which the designer varies the design variables. The trial-and-error method is only effective when a limited number of design variables are to be modified to achieve limited design goals. The action becomes cumbersome and may be difficult or even impossible when multiple variables such as the patch's dimensions and position of slot etc. need to be optimized to achieve various goals such as minimal return loss, increased bandwidth, and accurate resonance frequency.

Genetic algorithms (GA), introduced by John Holland in 1975, have been used to optimize design requirements in electromagnetic engineering [3][6][7], especially in MSPA design optimization. In general, when applied to design optimization, GA involves formulating a fitness function that includes one or more desired design outputs. The evaluation of the fitness function of every single value (chromosome) within a set of values (generation) for its fitness or cost against a preset value is iterative. The process involves the selection of the best individual based on their fitness for forming a set of new individuals, called generation. The evaluation continues until the desired output or the specified number of generations is reached, whichever occurs earlier. The success of the whole process depends on the selection of parameters for forming the fitness function. Effective formation of fitness functions can guide the optimization algorithms to better results[10,11,12,13,17,19,20,21,23,25,29,30]. The novel fitness function proposed here demonstrates the role of smart fitness functions in helping GA for optimizing patch antenna dimensions and slot position towards yielding better outputs compared to other fitness functions used in previous works in section 4 below.

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2. DESIGN OF MSPA

The "Transmission Line model" is used to model MPSA. This model represents MSPA as equivalent to a conductor with 'W" as width ‘h’ as height 'L' as length. Here, λ0 is the wavelength in free space and h is the height limited by 0.333λ0 ≤ h≤ 0.5λ0. The equations governing MSPA design are summarized as follows:

2.1 Substrate selection

The power loss owing to the dielectric [24] depends on the loss tangent. The dielectric constant usually lies in the 2.2 ≤ Ɛr ≤ 12. The substrate used here is RT-Duroid, with Ɛr =2.2. Its low-value loss tangent reduces dielectric losses[8].

2.2 Designing dimensions of the patch

Standard equations calculate the dimensions of the MSPA, and the performance of the patch antenna significantly depends on these dimensions. The following design equations provide the theoretical values of the dimensions of the patch as per the requirements [1][2][5][9]. 164

(i) Width of the patch (W)

$$W=\frac{1}{fr\sqrt{\mu_0\varepsilon_0}}\sqrt{\frac{2}{\varepsilon_r+1}} = \frac{C}{2fr}\sqrt{\frac{2}{\varepsilon_r+1}} \quad (1)$$

c = velocity of light in free space, f_r = resonance frequency, and εr = dielectric constant of substrate.

(ii) Effective dielectric constant

$$\varepsilon_{eff}=\frac{\varepsilon_r+1}{2}+\frac{\varepsilon_r-1}{2}\left(\frac{1}{\sqrt{1+\frac{12h}{w}}}\right) \quad (2)$$

The effective dielectric constant is also a function of frequency

$$f_r=\frac{v_0}{2\sqrt{\varepsilon_{reff}}(L+2\Delta L_{eff})} \quad (3)$$

(iii) Length of the Patch (L)

L is given by $L_{eff}-2\Delta L$ (4)

where Leff is given by $\frac{c}{2fr\sqrt{\varepsilon_{eff}}}$ (5)

(iv) Extension of patch antenna length ΔL

$$\frac{\Delta L}{h} = 0.412 \frac{(\varepsilon_{ef}+0.3)\left(\frac{w}{h}+0.264\right)}{(\varepsilon_{eff}-0.258)\left(\frac{w}{h}+0.8\right)} \quad (6)$$

(v) Calculating dimensions of the ground

Length of ground, Lg= 6h+L (7)

Width of ground, Wg=6h+W (8)

(vi) Dimensions of Strip line

The length of the strip can be found from

$$R_{in(x=0)} = cos^2\left(\frac{\pi}{L}x_0\right) \quad (9)$$

The width of the microstrip line is given by

$$Ws = \frac{1}{2f_{r\sqrt{\mu_0\varepsilon_0}}}\sqrt{\frac{2}{\varepsilon_r+1}} = \frac{v_0}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}} \quad (10)$$

Here $\lambda_0 = \frac{v_0}{fr}$, where λ_0 is wavelength in free space and v_0 is the velocity of light in free space. Also, $\lambda_{eff} = \frac{v_0}{fr}\sqrt{\varepsilon_{reff}}$, where λ_{eff} is the effective wavelength in the substrate and ε_{reff} is the effective dielectric constant of the substrate.

(vii) Transition line dimensions

The transition line is a quarter wave in length.

$$l = \frac{\lambda}{4} = \frac{\lambda_0}{4\sqrt{\varepsilon_{reff}}} \quad (11)$$

165

The width of the transition line W_T can be found from

$$Z_T = \frac{60}{\sqrt{\varepsilon_r}} ln\left(\frac{8d}{W_T} + \frac{W_T}{4d}\right) \quad (12)$$

where Z_T represents the characteristic impedance in the transition section.

2.3 Return loss

Return loss $R_L = 10log_{10}\frac{P_{in}}{P_{ref}}(dB)$ (13)

Here the incident power is P_{in} and the reflected power is P_{ref} [24]. Higher the ratio $\frac{P_{in}}{P_{ref}}$, the better the power transfer. Return loss equation R_L written using voltage and voltage-standing-wave-ratio $VSWR$ and impedance is as follows

$$R_L = 10\ log_{10}\left|\frac{1}{\rho}\right|\ (dB) = -20\ log_{10}|\rho|\ (dB) \quad (14)$$

$$R_L = 20\ log_{10}\left|\frac{VSWR+1}{VSWR-1}\right|\ (dB) = (40\ log_{10}\ e)artanh\left|\frac{1}{VSWR}\right|\ (dB)$$

$$R_L = 20\ log_{10}\left|\frac{Z_1+Z_2}{Z_1-Z_2}\right|\ (dB)$$

where ρ is the complex reflection coefficient, $VSWR$ is the voltage standing wave ratio, and Z_1 and Z_2 being the input and output port impedances.

3. THE GENETIC ALGORITHM

Some John Holland introduced the genetic algorithm in 1975, which was inspired by Darwin's theory of natural selection and evolution. A string of bits named chromosomes was used to represent the antenna design parameter values, and a set of such strings formed one generation. Initially, one generation is generated randomly. This generation is the first generation. Individual chromosomes in a generation are tested for their fitness individually. The fitness value is then compared with the desired fitness level of the fitness function [8][9]. The chromosomes with the best fitness in the generation were identified and selected to form the next generation. The bits of the best chromosomes undergo selection, crossover, and mutation. This generation evaluation continues until the desired fitness level is achieved for the fitness function, as illustrated in figure (1) below [4,8,9].

As mentioned above, the GA has been used for over a quarter-century, optimizing MSPA parameters for attaining desired or near-desired performance. The required performance as the optimization outcome is decided first, and the same is quantified as the fitness value of a fitness function. The fitness function is formulated by including the required antenna performance parameters to be optimized. The fitness value of the fitness function, which measures the antenna performance against the antenna design parameters, is evaluated for its fitness during the optimization cycle for achieving the desired output. This makes the formulation of the fitness function a crucial task in the optimization procedure. The design parameters that need to be optimized are coded suitably, and their range is set for the optimization. The basic unit for optimization is a chromosome, a code word containing a combination of separate binary codes for each parameter to be optimized.

Several chromosomes, the number of which varies depending on the requirement, form a generation. Initially, a pre-determined number of chromosomes is randomly generated. Then the fitness of individual chromosomes in that generation is evaluated for its fitness to a pre-determined level. The fitter chromosomes are allowed to carry forward to the next generation after selection based on their individual fitness value after crossover and mutation between a pre-defined numbers of selected chromosomes. This process continues till the desired fitness value is attained, or the number of generations defined in the cycle is reached.

4. FITNESS FUNCTIONS FROM PREVIOUS WORK

4.1 Antenna dimensions calculated using theoretical equations

In [8][9], the patch antenna is initially designed using theoretical equations, and the dimensions obtained for 5 GHz are as described below in Table number 1[9]. Figure 2 shows the performance of the proposed antenna when dimensions in Table 1 is used. Neither the bandwidth nor the operating frequency is nowhere near the desired value. The return loss is only -12.4 dB.

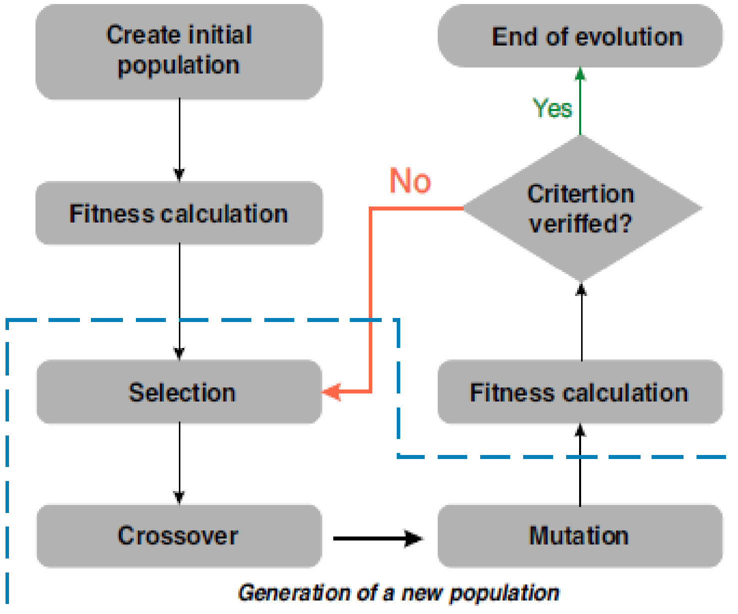

Fig 1. Genetic Algorithm optimization

Table 1. Dimensions calculated using standard equations

Wy is the width (mm)	Lx is the length (mm)
23.71	19.01

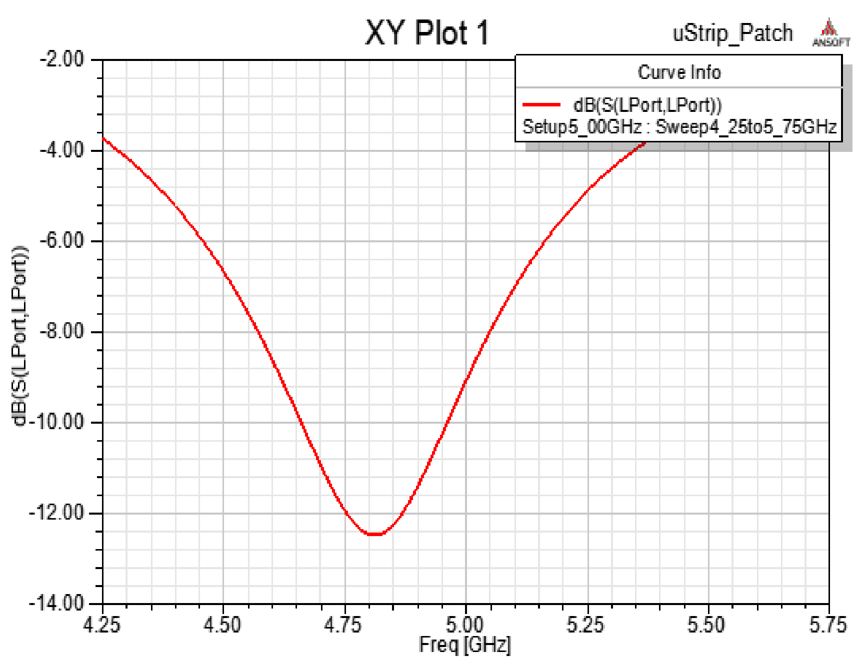

Fig 2. Performance of the proposed antenna with dimensions as in in Table 1

4.2 Fitness function optimizing antenna design by summing S_{11}

In [8][9] fitness function applies summation of $\boldsymbol{S_{11}}$ to calculate fitness of chromosomes. The fitness function used here is

Cost $=\sum_1^N Q_{fi}$, where $Q_{fi} = \begin{cases} 10, & for\ S_{11} \leq 10\ dB \\ 0, & for\ S_{11} > 10\ dB \end{cases}$ [8.9]

Upon optimization using the Genetic algorithm, the dimensions of the MSPA were optimized to the values as shown in table number 2 below [8]. The antenna performance showed significant improvement for these dimensions as per figure 3, compared to those obtained from theoretical calculations. The bandwidth is 280 MHz and the return loss improved to -24.16 dB while an operating frequency of 5GHz is achieved [8].

Table 2. Dimensions obtained on optimization

Wy is the Width (mm)	Lx is the Length (mm)
23.35	**19.00**

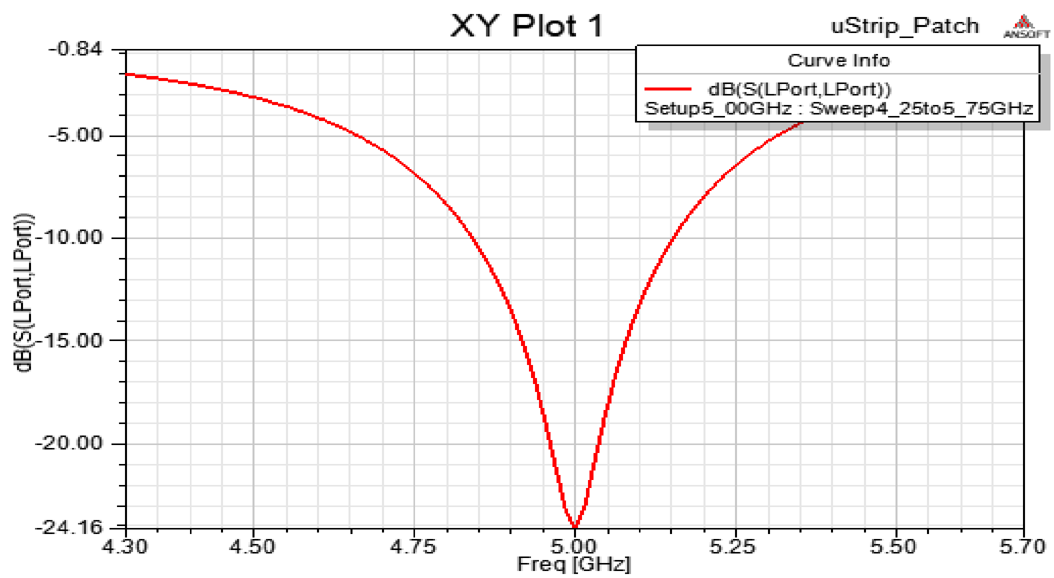

Fig 3. Performance of the proposed antenna with dimensions as per Table 2

4.3 Fitness function minimizing S_{11}

In [14] the MSPA dimensions were optimized for an antenna to resonate at 5.8 GHz after optimization. The fitness function used is $fitness = \min(S_{11})$. The GA optimization returned an optimized antenna resonating at 5.7 GHz instead of 5.8 GHz. The optimized antenna deviated from the desired design requirement of 5.8 GHz and is having a minimum return loss of -37.41 dB at 5.7 GHz as shown in figure 4 below

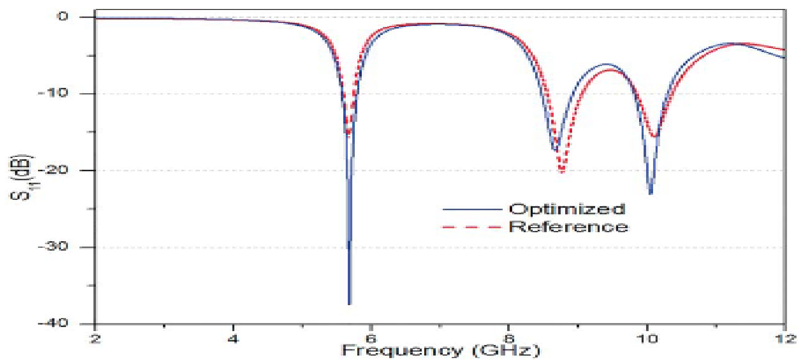

Fig 4. Performance of the antenna optimized using fitness function in section 4.3

The bandwidth is also calculated as follows

$$LB = (\frac{f_{max} - f_{min}}{f_{med}}) \times 100\%$$

where f_{max} and f_{min} are the maximum and minimum frequencies when $S_{11} \leq -10\ dB$, and f_{med}, the average between $f_{max}\ and\ f_{min}$. This will not ensure a symmetrical bandwidth spanning on either side of the desired resonance frequency of 5.8 GHz. Here the minimum of S_{11} is at 5.7 GHz. This will result in the bandwidth shifting from the desired center frequency of 5.8 GHz.

4.4 Minimization of S_{11} below the desired level

The fitness function in [18] below when applied for GA optimization minimizes S_{11} at two different frequencies under constraints. The bandwidth achieved in the first band is only 190 MHz with S_{11} just below -16 dB level as given in figure 5.

$$f(\vec{x}) = \min_{f \in F_{off}} S_{11} + \min_{f \in F_{off}} S_{11} = d_1 + d_2 \qquad [18]$$

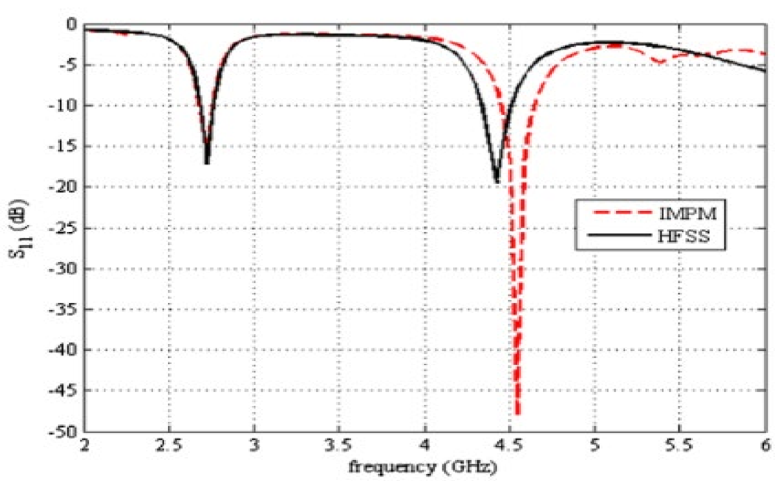

Fig 5. Performance of the antenna optimized using fitness function in section 4.4

4.5 Fitness function maximizing the magnitude of S_{11}

Genetic Algorithm optimizing antenna using fitness function in [22], maximizing the magnitude of S_{11}, is illustrated here.

$$Maximize = \left\langle |S_{11}| = \left|20\, log \sqrt{1 - \frac{P_{out}}{P_{in}}}\right| \right\rangle \qquad [22]$$

The return loss shows improvement from -4.25 dB to -20 dB as per figure 6 and figure 7 below. No other parameter is optimized here.

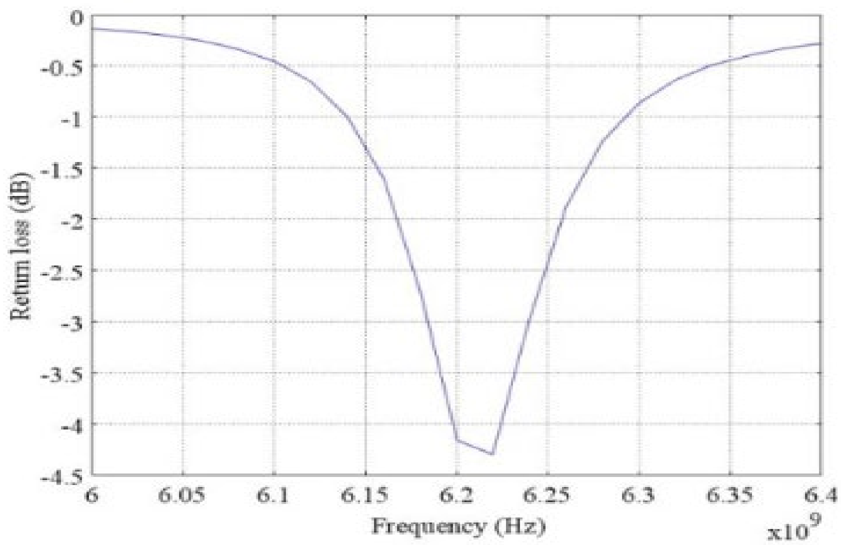

Fig 6. Before optimization

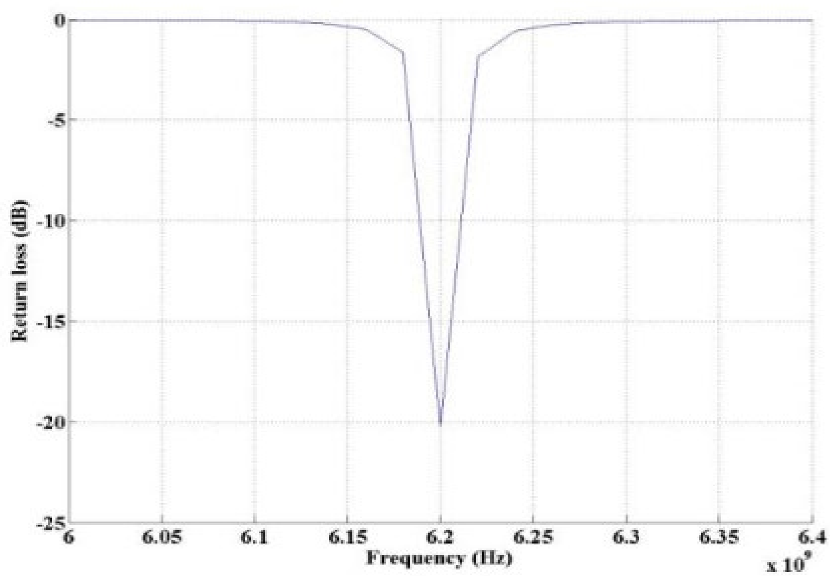

Fig 7. After optimization

4.6 Fitness function maximizing the sum of the magnitude of S_{11}

Reference article [16] showcases maximization the fitness function, which includes the sum of the two terms. The first term is the summation of S_{11} over the desired band of frequencies n_1 and the second term is also a summation of S_{11}, but with a penalty for a better values of S_{11} at the undesired frequency band n_2

$$F = \sum_{i=1}^{n1} R_i + \sum_{i=1}^{n2} (20 - R_i) \qquad [16]$$

$$R_{i=} \begin{cases} |S_{11}(f_i)|, & 5 \le |S_{11}| \le 20 \\ 20, & |S_{11}| > 20 \\ 0, & |S_{11}| < 5 \end{cases}$$

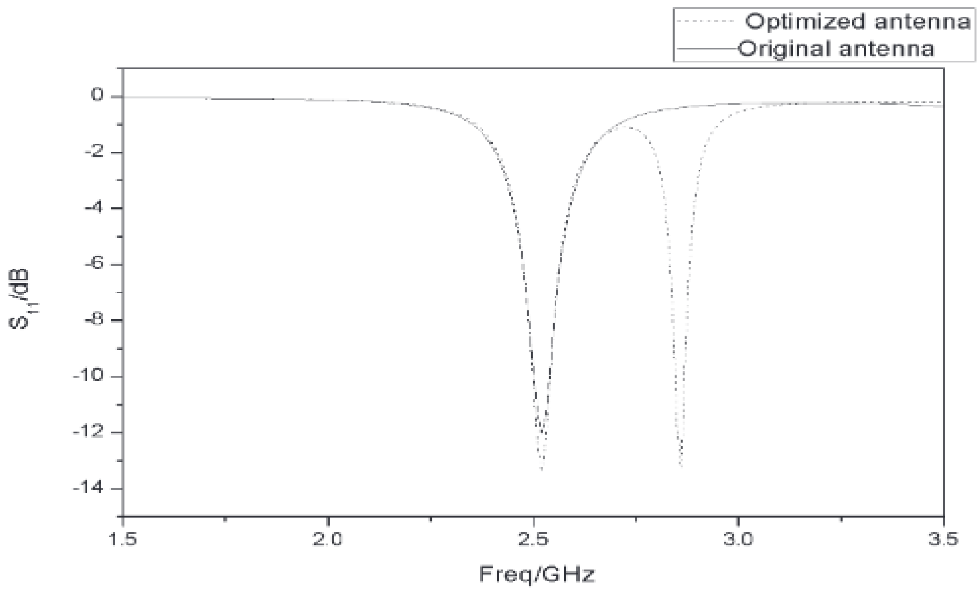

Fig 8. Performance of the antenna optimized using fitness function in section 4.6

The optimized antenna using fitness function in [16] returns an S_{11} of nearly -13 dB and the resonant frequency is shifted from the desired 2.4 GHz as shown in figure 8.

4.7 Fitness function averaging the sum of S_{11} over desired frequency bands

Research article [15] optimizes path antenna dimensions for increasing only the bandwidth as shown below in figure 9, The fitness function used is

$$Cost/Fitness = \frac{1}{N} \sum_{i=1}^{N} Q(f_i) \qquad [15]$$

where $Q(f_i) = \begin{cases} 10 & S_{11} < -10 \\ |S_{11}(f_i)|, & S_{11} \ge -10 \end{cases}$ [15,26,27,28]

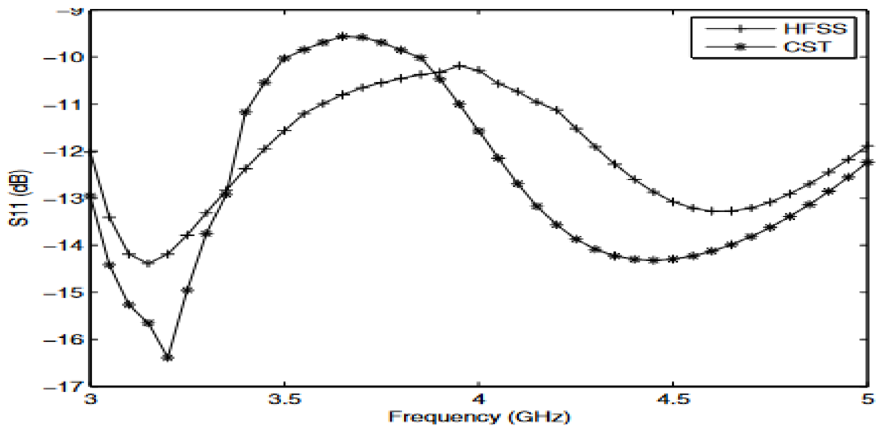

Fig 9. Performance of the antenna optimized using fitness function in section 4.7

5. PROPOSED WORK

In this study, a novel fitness function formulation applying carrot and stick policy is used to achieve desired level of multi-objective optimization: resonance frequency ***fr*** of 5 GHz, bandwidth (***BW***) exceeding 300 MHz, and return loss S_{11} better than −50 dB. Multiple antenna design parameters optimized to achieve multi-objective optimization are the width of the antenna **Wy**, length of the antenna **Lx** and the **X** and **Y** axes positions of the slot in the patch. The proposed fitness function is

$$\mathrm{F} = \boldsymbol{f_p} + \boldsymbol{b_p} + \boldsymbol{s_p} \qquad (15)$$

where $\boldsymbol{f_p}$ is the fitness component for resonant frequency, $\boldsymbol{b_p}$ is the fitness component associated with bandwidth, $\boldsymbol{s_p}$ is the fitness component for return loss and **F**, the overall fitness of chromosome.

$$\boldsymbol{f_p} = \begin{cases} 100, & Diff_p = 0 \\ 0, & Diff_p \geq 100, \\ 100 - Diff_p, & Diff_p < 100 \end{cases} \qquad (16)$$

Here $Diff_p = (\frac{abs(f_r - 5\ GHz)}{15}) \times 10$ and f_r - actual resonant frequency.

$Diff_p$ is the penalty for deviating from the desired resonant frequency of 5 GHz. $Diff_p$ was fixed at 10 units for a deviation of 15 MHz from the desired resonant frequency. The actual center frequency f_r is fixed at the frequency for which maximum return loss is measured. With the desired 300 MHz bandwidth spanning either side of the center frequency at 150 MHz each, a deviation of 150 MHz is penalized by a value of 100. A shift in the actual center frequency beyond 150 MHz on either side was treated with a maximum penalty of 100, thus discouraging those chromosomes from being selected for the next generation. The maximum fitness was assigned to the antenna operating at 5 GHz. For all the other operating frequencies, a graded penalty was assigned based on the deviation of the operating frequency from the desired frequency of 5 GHz. The higher the deviation, the higher is the penalty.

$$\boldsymbol{b_p} = \begin{cases} 0, & BW < 100\,MHz\ or\ f_p = 0 \\ BW + f_p/4, & 100 \leq BW < 150 \\ BW + f_p/2, & 150 \leq BW < 200 \\ BW + 3f_p/4, & 200 \leq BW < 250 \\ BW + f_p, & BW \geq 250 \end{cases}, \qquad (17)$$

BW is the bandwidth around the center frequency, given by

$$\text{BW} = \sum_{i=1}^{20} K, \quad K = \begin{cases} 10, & S_{11} \leq -10\,dB \\ 0, & S_{11} > -10\,dB \end{cases} \quad (18)$$

The desired bandwidth was set at 300 MHz, the frequencies on either side of the center frequency were sampled at intervals of 15 MHz, and S_{11} is measured for the sampled frequency and fitness values assigned as above. Sampling was performed on either side up to 150 MHz from the center frequency. The fitness gained based on the achieved bandwidth is calculated by adding the actual BW to the penalized value of f_p. For BW less than 100 MHz or if $f_p = 0$, the fitness value assigned is zero, and for BW greater than 250 MHz, the fitness value is the sum of BW and the total value of f_p. For all the other BW, the penalized value of f_p is added to the actual BW. When $f_p = 0, b_p$ is also 0. This ensures that the fitness gained from the bandwidth achieved in the undesired range of frequencies does not contribute to overall fitness. Thus, the fitness function selects only those antennas that operate near the desired operating frequency and have the best bandwidth for the next generation.

$\boldsymbol{s_p}$ is given by

$$s_p = \begin{cases} 0, & 0 < \boldsymbol{S_{11}} < 10 \\ 10 + \boldsymbol{f_p}, & 0 \leq \boldsymbol{S_{11}} < 20 \\ 20 + \boldsymbol{f_p}, & 2\,0 \leq \boldsymbol{S_{11}} < 30 \\ 30 + \boldsymbol{f_p}, & 30 \leq \boldsymbol{S_{11}} < 40 \\ 40 + \boldsymbol{f_p}, & 40 \leq \boldsymbol{S_{11}} < 50 \\ 50 + \boldsymbol{f_p}, & 50 \leq \boldsymbol{S_{11}} \end{cases} \quad (19)$$

The inclusion of the term $\boldsymbol{s_p}$ in the fitness function forces the optimization for the betterment of $\boldsymbol{S_{11}}$ along with **BW** and center frequency $\boldsymbol{f_r}$. The grading of $\boldsymbol{s_p}$ ensures the optimization to converge on the minimum value for $\boldsymbol{S_{11}}$ **.** Further the relativity of $\boldsymbol{s_p}$ to $\boldsymbol{f_p}$ ensures antennas resonating near desired frequency and with better $\boldsymbol{S_{11}}$ alone is selected for next generation.
Here graded penalty is introduced for differences and graded fitness for similarity between actual and desired antenna performance parameters. The higher the difference, heavier will be the penalty. Likewise better the similarity higher will be the fitness level. Other than the graded penalty, the novelty can also be found in the dependence of the fitness function components in deciding the final fitness of a chromosome.
Both $\boldsymbol{b_p}$ and $\boldsymbol{s_p}$ are made dependable to $\boldsymbol{f_p}$ in a graded manner to ensure that the optimized antenna achieves all the desired antenna performance parameters rather than converging on a chromosome returning high value for one parameter and low value for another so that their total fitness value **F** returning high fitness value.

Optimization was performed using HFSS and MATLAB. The four MSPA design parameters such as width of the antenna **Wy**, length of the antenna **Lx** and the **X** and **Y** axes positions of the slot in the antenna are coded into binary strings of 48 bits, with 12 bits each representing the four parameters. The 12 MSB bits represents the width of the antenna followed by the length of the antenna and the X- axis position of the slot. The 12 LSB bits represents the Y-axis position of the slot. The first generation was made up of 50 randomly generated chromosomes, each representing an antenna dimension that was generated randomly using MATLAB from within the range set by the values listed in Table numbers 3 and 4.

Table 3. Range of dimension for optimization

Wy is the Width (mm)	Lx is the Length (mm)
Min =22.00	Min = 17.60
Max = 24.60	Max = 21.00

Table 4. Range of starting positions of slot for optimization

X-axis	Y – axis
From -9.5 mm to 8.5 mm	From -11.9. mm to 9.9 mm

Each string of bits was passed on to the HFSS software from MATLAB. All 50 antenna structures were simulated by HFSS one by one, measurements were taken, and their fitness value was evaluated using fitness function F. Based on the fitness value, the best chromosomes were passed on to the next generation after selection and then subjected to cross-over and mutation at a pre-determined rate. The substrate used was RT Duroid 5880 with a height of 1.6 mm and all other dimensions as per the standard equations from the design section. This is repeated for 50 generations or until the desired result, that is, a fitness value of 650 or higher , is achieved. This process is illustrated in figure 10.

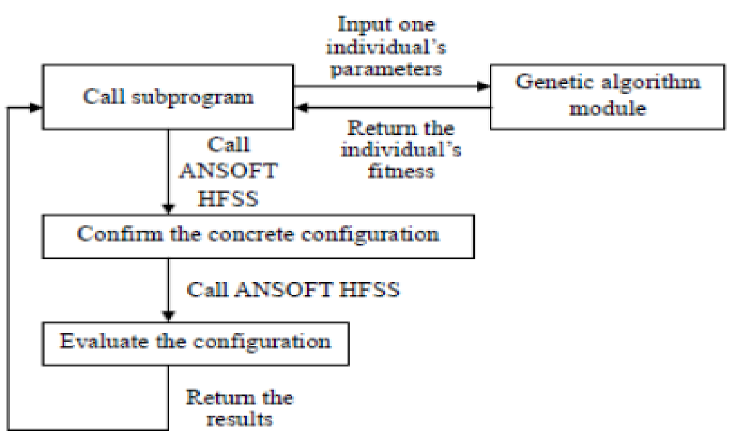

Fig 10. Optimization using HFSS and Matlab

The MSPA dimensions when subject to optimization using the proposed fitness function with GA returned the optimized length **Lx**, width **Wy** as per table 5 below. The optimized slot positions: X and Y - axes are given in table 6.

Table 5. Dimensions obtained after optimization using graded penalty in the fitness function

Wy is the Width (mm)	Lx is the Length (mm)
23.85	18.99
Fitness value = 100+300=400	

Table 6. Optimized position of slot

X-axis	Y – axis
-9.2 mm	-3.8. mm
Fitness value = 100+415+150= 665	

The slot position is represented by its positions with respect to x-axis and y-axis. The slot position is optimized in the range of -9.5 mm to 8.5 mm for X-axis and from -11.90 mm to 9.90 mm for Y-axis as given in table 4.

Performance of the optimized antenna and its structure is shown are figure 11 and figure 12 below. Optimized slotted MSPA returned a BW of 315 MHz with a minimum return loss of -54.84 dB while resonating exactly at the desired operating frequency of 5 GHz for the dimensions as per table 5 and slot position as given in table 6.

6. RESULTS AND DISCUSSION

GA is widely used for optimizing MSPAs. The core of the optimization is the formation of a proper fitness function. The fitness function also referred to as the cost function or objective function is formed using one or more of the antenna performance parameters that need to be optimized for the desired result. Based on the desired output the fitness level to be achieved at the end of the optimization is set. The formation of fitness function plays a key role in guiding optimization techniques to achieve better results. The novel fitness function proposed here optimized the antenna dimensions to achieve better results compared to the fitness functions used in [8,9,14,18,22,16,15].

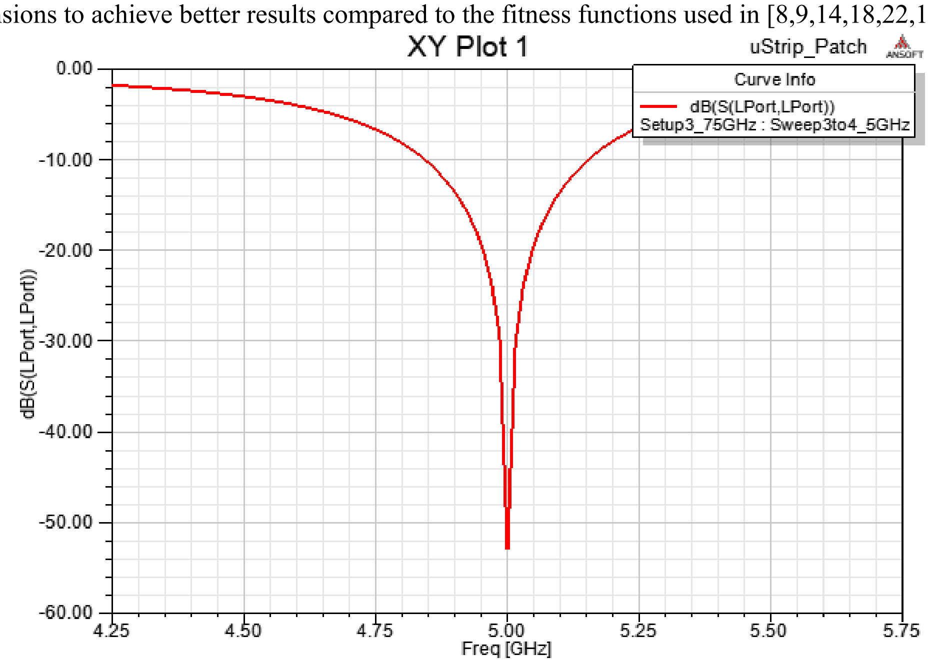

Fig 11. Performance of the antenna optimized using the proposed fitness function

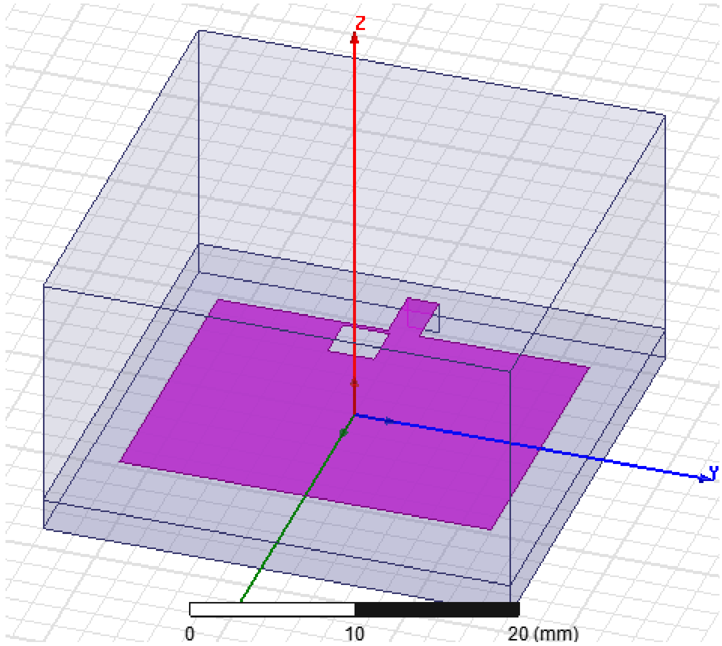

Fig 12. Optimized antenna using the proposed the fitness function

In this study, a novel fitness function was proposed to simultaneously optimize antenna bandwidth, return loss (S_{11}), and resonant frequency. The results indicate that the proposed fitness function significantly outperforms those used in earlier studies [8, 9, 14, 15, 16, 18, 22]. The optimized slotted MSPA achieved all three design objectives: a wide bandwidth of 315 MHz, a minimum return loss of –54.84 dB, and exact resonance at the target frequency of 5 GHz. In contrast, previous works discussed in Section 4 demonstrated only partial success in meeting optimization objectives.

The fitness function in [8] optimized the antenna dimensions to bring the resonant frequency to 5 GHz. But the bandwidth and return loss achieved were very low when compared to the proposed fitness function. A bandwidth of 280 MHz at a minimum $\boldsymbol{S_{11}}$ of -24.16 dB could only be achieved. When compared to previous work in [14] under section 4.3, the proposed fitness function addresses the deviation from the desired resonant frequency and the subsequent shifting of bandwidth effectively. In [14], the MSPA dimensions were optimized for a desired resonance frequency of 5.8 GHz. The GA optimization returned an optimized antenna resonating at 5.7 GHz instead of 5.8 GHz. The optimized antenna deviated from the desired design requirement of 5.8 GHz and is having a minimum return loss of -37.41 dB at 5.7 GHz . Under section 4.4, the fitness function used in [18], when applied for GA optimization minimizes S_{11} at two different frequencies under constraints and returns a nominal bandwidth of 190 MHz and minimum return loss at -16 dB compared to 315 MHz and -54.84 dB in the proposed work. Genetic Algorithm optimizing antenna using fitness function in [22] under section 4.5, improves only the return loss from -4.25 dB to -20 dB when compared to the improvement achieved in three parameters – bandwidth, return loss, and resonant frequency - using the proposed novel fitness function. The fitness function discussed under section 4.6 in [16] deviated from the desired operating frequency of 2.4 GHz and returned only a modest value of nearly -13 dB for S_{11}. The performance of the proposed fitness function is also compared with the fitness function used in another previous work on antenna optimization using GA [15] discussed under section 4.7. The bandwidth alone is considered for optimization in [15] whereas, in the proposed the fitness function optimizes the patch antenna for return loss, bandwidth, and for an exact resonant frequency.

The optimization process iterated over 50 generations of 50 chromosomes each, and it took 16 hours for completion on a laptop with an I3 processor and 8 GB RAM. The maximum fitness value was set to 650 for the desired bandwidth of 300 MHz. However, the optimization exceeded this expectation by returning a bandwidth greater than 315 MHz. The relative dependency of fitness components in the fitness function prevents the optimization of a single parameter rather than all three target parameters. By setting higher fitness values and increasing the number of generations, the antenna design can be further improved. Other antenna design parameters, such as feed position and width, can also be included to improve the optimization of antenna designs using GA.

6. CONCLUSION

This research successfully demonstrates the effectiveness of a novel fitness function for optimizing Microstrip Patch Antennas (MSPAs) using Genetic Algorithms (GA). The proposed fitness function was specifically designed to simultaneously optimize three critical antenna parameters: return loss, bandwidth, and resonant frequency. Unlike prior approaches that typically focused on optimizing a single parameter or achieved limited success across multiple objectives, the proposed method achieved all targeted performance metrics. The optimized slotted MSPA achieved a return loss of -54.84 dB, a bandwidth of 315 MHz, and an exact resonant frequency of 5 GHz, surpassing the results reported in earlier works [8, 9, 14, 15, 16, 18, 22].

Through comparative analysis, the proposed approach consistently outperformed existing fitness functions in terms of convergence accuracy and overall antenna performance. This highlights the significance of a well-structured fitness function in guiding GA-based optimization processes. Furthermore, the implementation efficiency—achieving optimal results using modest computational resources—demonstrates the practical applicability of the method.

Future work may involve extending the fitness function to incorporate additional design parameters such as feed position and width, as well as exploring more complex objective functions to further enhance antenna performance. The promising outcomes of this study underline the potential of the proposed fitness function as a robust tool in MSPA optimization using evolutionary algorithms.

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