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# Genetic algorithm and particle swarm optimization approach for prediction of physical parameters of rectangular-shaped microstrip antenna

# *Dikdörtgen şekilli mikroşerit antenin fiziksel parametrelerinin tahmini için genetik algoritma ve parçacık sürüsü optimizasyon yaklaşımı*

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# Genetic Algorithm and Particle Swarm Optimization Approach for Prediction of Physical Parameters of Rectangular-Shaped Microstrip Antenna

## *Highlights*

- *Genetic Algorithms (GA) and Particle Swarm Optimization (PSO) algorithms implemented for Rectangular-shaped microstrip antenna parameter estimation.*
- *Estimation accuracy has been compared for Closed-Form Empiric formulations, Artificial intelligence (ANN &SVM etc.), and optimization methods.*
- *Optimization methods save time and cost while having accuracy besides the proposed model no data set requirement.*

## *Graphical Abstract*

*Antenna parameter estimation via genetic algorithms and particle swarm optimization*.

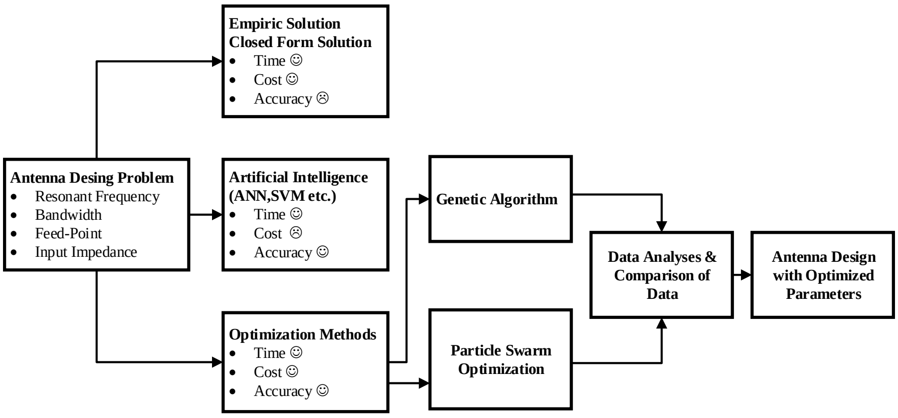

**Figure.** Flowchart of the proposed study

## *Aim*

*The aim of this paper is to estimate the of antenna parameters with optimization methods to reduce time and costs. It also aims to improve the accuracy of the estimation..*

## *Design & Methodology*

*Resonant frequency, bandwidth, feed point and input impedance were determined as design parameters. The above antenna design parameters were calculated using genetic algorithms and particle swarm optimization.*

## *Originality*

*Light-profile antennas are attracting much attention in fields such as missile systems, aircraft, spacecraft, and satellite systems due to their characteristics such as size, weight, production cost, ease of installation, and compatibility.*

## *Findings*

*The calculation results were compared with other studies in open literature and experimental data. The computational results agree well with the experimental results.*

## *Conclusion*

*The designed antenna was tested and verified, and the results are presented through the analyses performed using the 3D full wave solver CST Studio Suite® software.*

## *Declaration of Ethical Standards*

*The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.*

# Genetic Algorithm and Particle Swarm Optimization Approach for Prediction of Physical Parameters of Rectangular-Shaped Microstrip Antenna

***Research Article/Araştırma Makalesi***

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## ABSTRACT

This study presents the results of two optimization algorithms for estimating the resonant frequency, bandwidth, feed point, and input impedance of a rectangular-shaped microstrip antenna. To minimize the design cost and design time, genetic algorithms and particle swarm optimization methods have been applied and compared. The antenna design parameters were considered by using a genetic algorithm (GA) and particle swarm optimization (PSO) is implemented in the MATLAB® environment. The calculation results were assimilated with other studies in the literature in terms of accuracy. The computational results of the optimized parameters are having a good agreement with the experimental results. The optimized antenna was modeled and verified by the analyses performed using the CST Studio Suite® software.

**Keywords: Bandwidth, genetic algorithm, particle swarm optimization, rectangular-shaped microstrip antenna, resonant frequency.**

# Dikdörtgen Şekilli Mikroşerit Antenin Fiziksel Parametrelerinin Tahmini İçin Genetik Algoritma ve Parçacık Sürüsü Optimizasyon Yaklaşımı

## ÖZ

Bu çalışmada, bir dikdörtgen şekilli mikroşerit antenin çalışma frekansı, bant genişliği, besleme noktası ve giriş empedansını tahmin etmek için iki optimizasyon algoritması sonuçları sunulmaktadır. Tasarım maliyetini ve tasarım süresini en aza indirmek için genetik algoritma ve parçacık sürü optimizasyonu yöntemleri uygulanmış ve karşılaştırılmıştır. Anten tasarım parametrelerinin hesaplanması genetik algoritma ve parçacık sürü optimizasyonunu kullanılarak MATLAB® ortamında gerçekleştirilmiştir. Hesaplama sonuçları doğruluk açısından literatürdeki diğer çalışmalarla karşılaştırılmıştır. Optimize edilmiş parametrelerin hesaplama sonuçları, deneysel sonuçlarla iyi bir uyum içindedir. Optimize edilen anten, CST Studio Suite® yazılımı kullanılarak yapılan analizlerle modellenmiş ve doğrulanmıştır.

**Anahtar Kelimeler: Bant genişliği, çalışma frekansı, dikdörtgen şekilli mikroşerit anten, genetik algoritma, parçacık sürü optimizasyonu.**

## 1. INTRODUCTION

Over the last several decades our lives have been revolutionized due to the usage of wireless systems which cause a significant change in our daily life. The demand for efficient communication systems forced the designers to propose efficient antenna designs. With several advantages such as low-cost and low-profile structures, microstrip antennas became one of the most favorite antenna types among the 2D antenna family. Low-profile antennas are attracting attention in areas such as missile systems, aircraft, spacecraft, and satellite systems due to their characteristics such as structure size, weight, production cost, ease of installation, and compatibility with the physical structure of the aircraft [1]. The required properties of the antenna structures for military applications are having small size and light. Ease of integration is another important requirement. This requirement aims to integrate the antennas with active and passive circuits and aims to control the design parameters independently. To meet these requirements features such as integrability on flat and non-flat surfaces, simplicity, and reducing the cost of the manufacturing process with modern printed circuits must be satisfied [2].

In order to satisfy those requirements, the design of microstrip antennas attracted significant attention from many researchers over the course of the years [3]. Calculating the resonant frequency and impedance, estimating the bandwidth, and the feed point for those antennas studied by using empirical formulations and artificial intelligence [4]. It is a well-known fact that especially in calculating the parameters above, the literature is lack closed-form mathematical expression.

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So, it is not possible to obtain accurate results by analytical expressions. The most accurate way for obtaining those is using full-wave EM solvers which cause loss of time- and have high budget license-cost. To obtain the desired antenna structure, it is important to calculate the design parameters effectively and accurately in a time and money cost-effective way. Therefore, different solution methods are needed. Another method is artificial intelligence applications [4]. Artificial intelligence applications such as neural networks require huge data sets, and it is not always easy to obtain such sets without manufacturing multiple designs which will be again a burden in terms of cost. As a promising alternative, the Genetic Algorithm and Particle Swarm Optimization are also applied in the determination of antenna parameters, which are optimization algorithms that are commonly applied in the solution of engineering problems. Optimization algorithms basically aim to achieve the optimal values in the specified search space in a short time by using heuristic or deterministic methods to solve a design problem in the most appropriate way.

The most important antenna performance parameter in rectangular-shaped microstrip antennas is the resonant frequency [5]. Predicting this parameter with high accuracy during the design phase has significant importance in avoiding possible parasitic effects [6]. Another performance parameter that must be predicted before the design is bandwidth since the microstrip antennas have low bandwidth compared to other antennas [7]. For this reason, it is even more important that the bandwidth of the designed antenna can be predicted with high accuracy, especially for microstrip antennas. In addition, the input impedance, which affects the radiation efficiency and return loss of microstrip antennas, must also be considered during the design. In order for the antenna to yield the desired input impedance value, the appropriate feed point must be accurately calculated. For all microstrip antennas, performance parameters such as resonant frequency, bandwidth, and input impedance rely on the width and length of the radiating patch and the position of the feed point, besides the electrical properties of the material used as the dielectric substrate [8].

In this paper, rectangular-shaped microstrip (RSM) antennas are considered and studied for the estimation of resonant frequency, bandwidth, feed point location, and input impedance parameters by optimization algorithms in a cost-effective way. GA and PSO are applied for obtaining the parameters with no data set requirement and with less memory requirement. This paper is the first research that studies all those parameters simultaneously. The antenna performance parameters resulting from the optimization were verified with a full wave simulator CST Studio Suite®.

## 2. MATERIAL and METHOD

### 2.1. Microstrip Antennas

The structure of microstrip antennas conforms to a dielectric layer on top of a ground plane and a conducting radiator above the dielectric layer as shown in Figure 1 which presents the most widely used antenna geometry [9,10]. To achieve actual antenna performance, a thick substrate with a low dielectric constant is preferred, resulting in better efficiency, wider bandwidth, and better radiation [1]. However, such a configuration leads to a larger antenna size. To design a small microstrip antenna, a material with a higher dielectric constant should be used, resulting in lower efficiency and bandwidth.

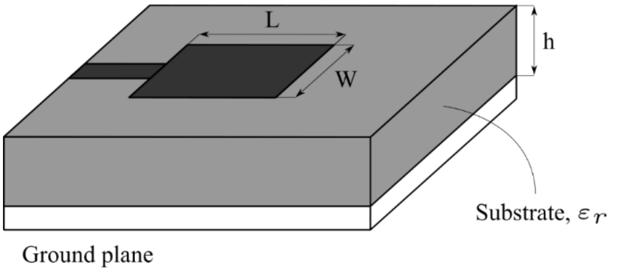


**Figure 1.** Rectangular microstrip antenna

In this paper, the physical parameters of the RSM antenna are optimized to have length $L$, width $W$, and height $h$. There are many experimental expressions for computing the resonant frequency of RSM antennas in recent studies [5]. Experimental expression in [8] with resonant frequency $f_r$, $\alpha$: correction factor, $c_0$: velocity of an electromagnetic wave in free space, $L$: patch length, $\Delta W$: a function of a conductive patch, $\varepsilon_{eW}$: the effective dielectric constant is given in equation (1).

$$f_r = \alpha \frac{c_0}{2(L+2\Delta W)\sqrt{\varepsilon_{eW}}} \tag{1}$$

$\varepsilon_{eW}$, $\varepsilon_r$: relative permittivity, $h$: height of substrate, $W$: width of conducting surface, with the expression given in equation (2).

$$\varepsilon_{eW}=\frac{(\varepsilon_r+1)}{2}+\frac{(\varepsilon_r-1)}{2}\left(1+\frac{10h}{W}\right)^{-1/2} \tag{2}$$

$\Delta W$, the thickness of the substrate $h$ is given in equation (3) as a function depending on the width of the conductive patch ($W$).

$$\Delta W=0.412h\frac{(\varepsilon_{eW}+0.300)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_{eW}-0.258)\left(\frac{W}{h}+0.813\right)} \tag{3}$$

$\alpha$ is given as the correction factor and $L_{eff}$: the effective length of the patch is given by the expression given in equation (4) as a function of the parameters $h$, $\varepsilon_r$.

$$\alpha=\frac{h}{L_{eff}}\pi\sqrt{\varepsilon_r} \tag{4}$$

$L_{eff}$ is defined as the effective length of the patch and the effective width is given in equation (5) as a function of the parameters $W_{eq}$, $\varepsilon_{eW}$, $L$, $W$.

$$L_{eff}=L+\left(\frac{W_{eq}-W}{2}\right)\left(\frac{\varepsilon_{eW}+0.300}{\varepsilon_{eW}-0.258}\right) \tag{5}$$

With $W_{eq}$ as the effective width, the vacuum medium resistance $R_0$, and the characteristic impedance of a strip line $Z_{cw}$, $h$, $\varepsilon_{eW}$ is given in equation (6).

$$W_{eq}=\frac{hR_0}{Z_{cW}\sqrt{\varepsilon_{eW}}} \tag{6}$$

The expression $Z_{cw}$ is given in parts in equation (7) and equation (8).

$$Z_{cW}=\frac{R_0}{2\sqrt{\varepsilon_r}}\left\{\begin{matrix}\frac{W}{2h}+0.4413+\frac{0.0823(\varepsilon_r-1)}{\varepsilon_r^2}+\frac{(\varepsilon_r+1)}{\varepsilon_r} \\ \left[-0.231+0.1592ln\left(\frac{W}{2h}+0.94\right)\right]\end{matrix}\right\}^{-1} \tag{7}$$

$$W/h\geq 3.3$$

$$Z_{cW}=\frac{R_0}{2\sqrt{\varepsilon_r}}\left\{\begin{matrix}\frac{W}{2h}+0.4413+\frac{0.0823(\varepsilon_r-1)}{\varepsilon_r^2}+ \\ \frac{(\varepsilon_r+1)}{\varepsilon_r}\left[-0.231+0.1592ln\left(\frac{W}{2h}+0.94\right)\right]\end{matrix}\right\}^{-1} \tag{8}$$

$$W/h<3.3$$

The expressions $R_o$, $c_0$ are given in equation (9) and equation (10).

$$R_o=120\pi\,\Omega \tag{9}$$

$$c_0=3\times 10^8\ m/s \tag{10}$$

The expression for bandwidth given in [11] is presented in equation (11). Bandwidth is expressed by the tolerable value of the voltage standing wave ratio (VSWR). $BW$; $Q_r$ is defined as the total quality factor of the radiation, $\eta$ is the radiation efficiency and $P$ is defined in relation to the correction coefficient.

$$BW=\frac{(S-1)}{\sqrt{S}}\frac{\eta}{Q_r}P \tag{11}$$

$Q_r$; $c_0$, $\varepsilon_r$, $h$, $f_r$ parameters are given in equation (12).

$$Q_r=\frac{c_0\sqrt{\varepsilon_r}}{4hf_r} \tag{12}$$

$\eta$; The power value radiated by $P_r$ space waves are given in equation (13) in relation to the power value parameters propagated by $P_s$ surface waves.

$$\eta=\frac{P_r}{P_r+P_s}100 \tag{13}$$

$Pr$ and $Ps$ associated with parameters $k_0$, $R_0$, $h$ and $\varepsilon_r$ are given in equation (14) and equation (15), respectively.

$$P_r\approx\frac{R_0k_0^2(k_0h)^2}{3\pi}\left(1-\frac{1}{\varepsilon_r}+\frac{2}{5\varepsilon_r^2}\right) \tag{14}$$

$$P_s=\frac{R_0k_0^2}{4}\frac{(\varepsilon_r-1)^3(k_0h)^3}{\varepsilon_r^3} \tag{15}$$

The expression $k_0$ is given in equation (16) depending on the parameters $f_r$ and $c_0$.

$$k_0=\frac{2\pi f_r}{c_0} \tag{16}$$

The expression P is given in equation (17) depending on the $Z_{cW}$ and $Z_{OW}$ parameters.

$$P=\frac{Z_{0W}}{Z_{cW}} \tag{17}$$

$Z_{0W}$ is the characteristic impedance of microstrip line of width $W$ and in relation to the parameters $R_0$, $h$, $W$ it is calculated in parts in equation (18) and equation (19).

$$Z_{0W}=\frac{R_0}{2\pi}ln\left(\frac{4h}{W}+\sqrt{\frac{16h^2}{W^2}+2}\right)\quad W/h\geq 3.3 \tag{18}$$

$$Z_{0W}=60\pi\left[\frac{W}{2h}+0.9033+\frac{1}{\pi}ln\left(\frac{W}{2h}+0.94\right)\right]^{-1} \tag{19}$$

$$W/h<3.3$$

The input impedance of an antenna directly affects the efficiency of power transmission within the antenna. The resonant frequency relies on the antenna parameters, such as the permittivity and thickness of the substrate, the length and width of the patch, and the position of the feed point. Because of its influence on power transmission efficiency, the feed point must be accurately determined to ensure a perfect match between the patch and the feed. Various analytical and theoretical methods for calculating the input impedance for RSM antenna elements with substrates having a dielectric material thickness from $0.005\lambda_d$ to $0.166\lambda_d$ can be found in the literature.

The necessary expression for the input impedance is given in (20) [12].

$$R_{in}=\frac{Q_T}{\pi\varepsilon_0\varepsilon_r f_r}\frac{h}{WL}cos^2\left(\frac{a\pi}{L}\right) \tag{20}$$

The total quality factor associated with the losses of the antenna element is $Q_T$, and the quality factor associated with the radiation, $Q_r$, the loss due to heating in the conducting element $Q_c$, and the losses due to heating in the ground plane and dielectric substrate can be calculated as $Q_d$ and $Q_T$, respectively, using the expression given in (21).

$$Q_T=(Q_r^{-1}+Q_c^{-1}+Q_d^{-1}) \tag{21}$$

The quality factor associated with the radiation $Q_r$ is given in equation (22).

$$Q_r=\frac{c_0\sqrt{\varepsilon_{eW}}}{4f_rh} \tag{22}$$

The dielectric loss tangent of the substrate $Q_d$ is given in equation (23).

$$Q_d=tan^{-1}\delta \tag{23}$$

The conductor loss $Q_c$ is given in equation (24).

$$Q_c=7.86h\frac{Z_{0w}}{P_w}Q_d=tan^{-1}\delta \tag{24}$$

The expression $P_w$ is given in equation (25) depending on the parameters $P_{w1}$ and $P_{w2}$.

$$P_w=\frac{P_{w1}}{P_{w2}^2} \tag{25}$$

The expressions $P_{w1}$ and $P_{w2}$ are given in equation (26) and equation (27), respectively, depending on the parameters $W$ and $h$.

$$P_{w1}=2\pi\left[\frac{W}{h}+\frac{W}{\pi h}\left(0.94+\frac{W}{2h}\right)^{-1}\right]\left[1+\frac{h}{W}\right] \tag{26}$$

$$P_{w2}=\left[1-\left(\frac{W}{h}\right)^2\right]\left[1+\frac{h}{W}\right] \tag{27}$$

$Z_{0W}$ is the characteristic impedance of an air-filled strip line and $R_0$, $h$, $W$ parameters are given separately in equation (28) and equation (29).

$$Z_{0W}=\frac{R_0}{2\pi}ln\left(\frac{4h}{W}+\sqrt{\frac{16h^2}{W^2}+2}\right)\quad W/h\geq 3.3 \qquad (28)$$

$$Z_{0W}=60\pi\left[\frac{W}{2h}+0.9033+\frac{1}{\pi}ln\left(\frac{W}{2h}+0.94\right)\right]^{-1} \quad W/h<3.3 \qquad (29)$$

To evaluate the optimization algorithms to the problem, the objective functions are defined at the first step. The physical dimensions of the patch are evaluated using the function defined for the computation of $f_r$. It is defined as two independent variables, length $L$ and width $W$. $f_r$, $\varepsilon_r$ and $h$ are used as input parameters for the GA and PSO, which calculate the optimization results for the patch dimensions $L$ and $W$. The population size for the GA was assumed to be 50 individuals and calculated over 100 generations. The crossover probability was assumed to be 0.1 and the mutation probability was assumed to be 0.1. For PSO, the population size was set at 50 individuals and calculated over 100 generations. While the inertia coefficient was set to 0.1, the acceleration coefficients (personal-social, acceleration coefficient) were chosen to be 2. The search space is assumed to be $0 < L < 50$mm and $0 < W < 50$ mm in both algorithms.

The objective function for determining $f_r$ is shown in equation (30).

$$F=\frac{F_{r_{disared}}-F_{r_{calculated}}}{F_{r_{disared}}} \qquad (30)$$

The objective function for determining the BW is shown in equation (31). The position of the feed point was calculated using equation (32). The total objective function is shown in equation (33).

$$BW=\frac{BW_{disared}-BW_{calculated}}{BW_{disared}} \qquad (31)$$

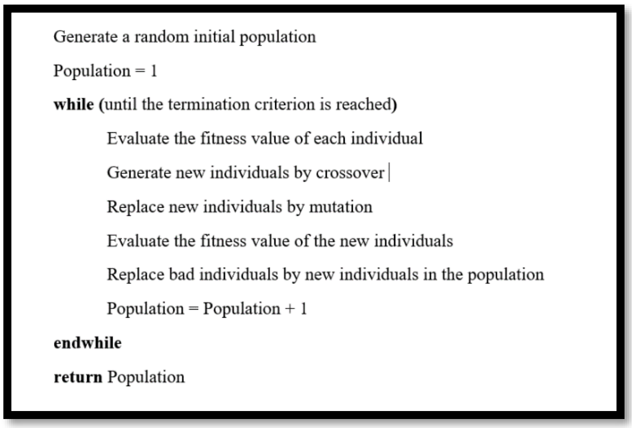
$$a=\frac{a_{disared}-a_{calculated}}{a_{disared}} \qquad (32)$$

$$Total\ Objective\ Function=F+BW+a \qquad (33)$$

The results obtained by calculating the best coefficients by GA and PSO using the above formulas are measured up the experimental results of the current studies.

## 2.2. Genetic Algorithm and Particle Swarm Optimization

GAs are search algorithms based on the concepts of natural selection and genetics. GAs involves creating a population of possible solutions to a given problem. These solutions then crossover and mutate (as in genetics), creating new offspring, and this process repeats over several generations [13,14]. Each individual (or candidate solution) is assigned a fitness value (based on the objective function), and the fitter individuals are given the chance to mate and produce more "fit" individuals. In this way, better and better individuals or solutions are produced over generations until a stopping criterion is reached. After the algorithm is started, the initial population is randomly generated, and parents are selected from this population to generate the next generation. Crossover and mutation operators are applied to the parents to generate new individuals. These individuals eventually replace the existing individuals in the population, and the process repeats. In a way, GAs attempt to imitate the natural evolutionary process to some degree. The pseudocode describing this process is shown in Figure 2. The general flowchart of GA is shown in Figure 3.



```
Generate a random initial population
Population = 1
while (until the termination criterion is reached)
        Evaluate the fitness value of each individual
        Generate new individuals by crossover
        Replace new individuals by mutation
        Evaluate the fitness value of the new individuals
        Replace bad individuals by new individuals in the population
        Population = Population + 1
endwhile
return Population
```

**Figure 2.** Pseudocode of a typical GA

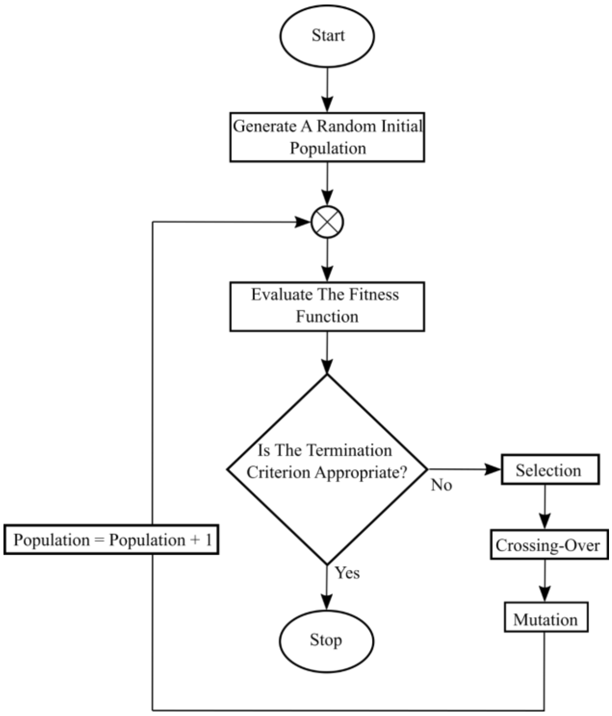


**Figure 3.** General flow chart of GA

The second optimization algorithm applied in this study is PSO which is a powerful search algorithm that is a subset of swarm intelligence, collective intelligence, and computational intelligence. This optimization method was developed based on the behavior of creatures that move collectively in nature [15]. For example, if the behavior of a swarm of bees is examined, it is found that bee’s aim is to find the place where the density of flowers is highest. Since the bees have no information about the area with the highest density of flowers, they begin to search for flowers in random places at random frequencies. Each swarm remembers the places where it finds the most flowers and can somehow learn from other bees where they also find many flowers. Figure 4 shows the behavior of bees collecting pollen. Each bee decides for itself whether to return to the place where it finds the most flowers or to go to the areas designated by other bees that are known to have the most flowers.

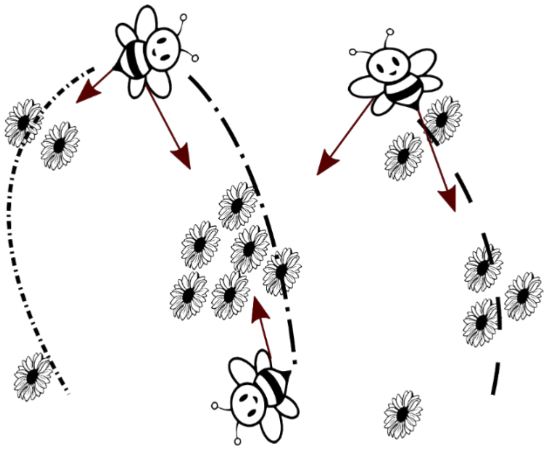


**Figure 4.** Bees moving toward the high-density ground

Hereby, a bee may find a place with a higher density of flowers than before. This new place, rich in flowers, is then the bee's new personal best. Sometimes a bee will fly over a place with more flowers than any other bee in the swarm. The entire swarm is then attracted to that place to some degree, in addition to its own exploration. In this way, the bees explore the area and fly over the busiest spots, which they then make their hotspots. They constantly check the area and fly to the places with the highest density of flowers that they have found before, hoping to find the absolute highest density of flowers. Eventually, the bees' flight leads them to the spot in the field with the highest flower density, and all the bees congregate at that point [16]. If no location with a higher flower density is found, they fly steadily to the highest known flower density, as shown in Figure 5.

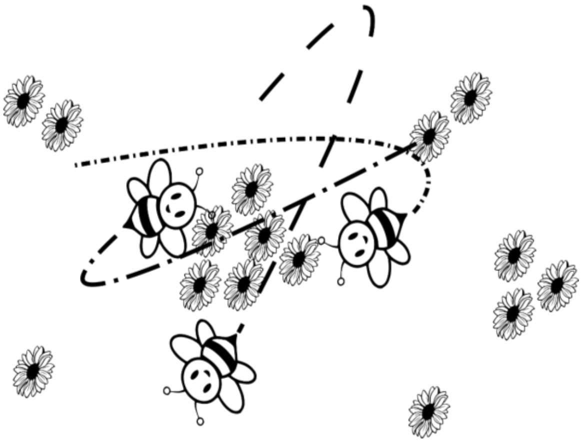


**Figure 5.** Bees collected at the highest density

**Particle/agent:** Each individual in the swarm (e.g., bees, fish) is called a particle or agent.

**Position:** As explained above, the position of a particle is comparable to the position of a bee in a field. In a two-dimensional optimization problem, the position of the particle can be thought of as coordinates in the x-y plane.

**Fitness function:** As in all optimization methods, there should be an objective function to evaluate the goodness of a solution.

**Personal best position ($p_{best}$):** Each bee notes where it personally encountered the most flowers. This position with the highest fitness value found by a bee is called $p_{best}$ position.

**Global best position ($g_{best}$):** Each bee knows its personal best position as well as the position with the highest density of flowers discovered by the swarm.

The pseudocode of the PSO algorithm is shown in Figure 6 and its flowchart is in Figure 7.

```
Generate a random initial swarm
Assignment the starting position of each particle as its own best ($p_{best}$)
Evaluate the global best ($g_{best}$) of the swarm
while (until the termination criterion is reached)
    for (i=1 to the number of particles)
        if (if the current location is better than $p_{best}$)
            Assignment as new $p_{best}$ of particle
        if (if the current location is better than $g_{best}$)
            Assignment as new $g_{best}$ of swarm
    endfor
endwhile
return $p_{best}$
```

**Figure 6.** Pseudocode of PSO

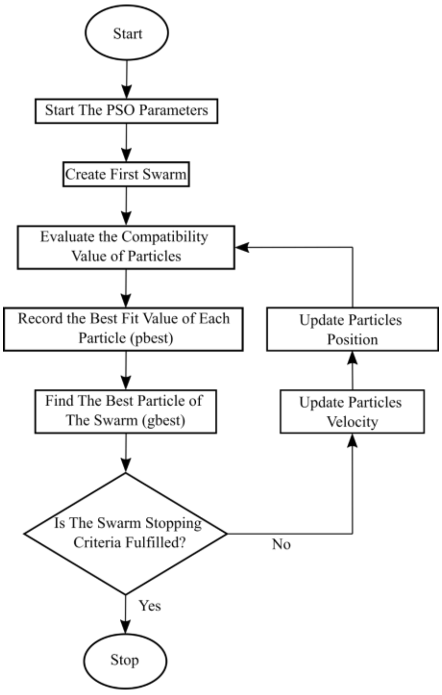


**Figure 7.** Flow chart of PSO

## 3. DATA ANALYSES

In this section, the computational results of the proposed algorithms (GA, PSO) are compared with the antennas presented in the literature, which have already been fabricated and have the experimental results. The optimization results of resonant frequency obtained with GA are shown in Table 1, and the optimization results obtained with PSO optimization are shown in Table 2.

As can be seen in Table 1, there are 17 different antennas whose optimization and production results are presented. The experimental and optimization results for different antenna lengths are presented as $F_{Experimental}$ and $F_{Calculated}$, respectively. As can be seen from the results, the accuracy rate is quite high, and the average error rate is less than 0.099%.

**Table 1.** Optimization results of resonant frequency with GA

| Antenna Number | Optimization Data | | |
|---|---|---|---|
| | L(mm) | $F_{EXP}$(GHz) | $F_{GA}$(GHz) |
| 1 | 10.514 | 8.000 | 8.000 |
| 2 | 12.135 | 7.134 | 7.134 |
| 3 | 14.005 | 6.070 | 6.069 |
| 4 | 14.674 | 5.820 | 5.820 |
| 5 | 13.807 | 6.380 | 6.380 |
| 6 | 15.088 | 5.990 | 5.989 |
| 7 | 18.603 | 4.660 | 4.659 |
| 8 | 23.749 | 4.600 | 4.600 |
| 9 | 26.296 | 3.580 | 3.580 |
| 10 | 27.073 | 3.980 | 3.980 |
| 11 | 27.696 | 3.900 | 3.900 |
| 12 | 29.905 | 3.980 | 3.980 |
| 13 | 30.442 | 3.900 | 3.900 |
| 14 | 34.605 | 3.470 | 3.470 |
| 15 | 34.607 | 3.200 | 3.200 |
| 16 | 39.040 | 2.980 | 2.980 |
| 17 | 36.649 | 3.150 | 3.150 |

**Table 2.** Optimization results of resonant frequency with PSO

| Antenna Number | Optimization Data | | |
|---|---|---|---|
| | L(mm) | $F_{EXP}$(GHz) | $F_{PSO}$(GHz) |
| 1 | 10.512 | 8.000 | 8.000 |
| 2 | 12.135 | 7.134 | 7.134 |
| 3$^{f}$ | 14.000 | 6.070 | 6.069 |
| 4 | 14.665 | 5.820 | 5.820 |
| 5 | 13.808 | 6.380 | 6.380 |
| 6 | 15.089 | 5.990 | 5.989 |
| 7 | 18.602 | 4.660 | 4.659 |
| 8 | 23.749 | 4.600 | 4.600 |
| 9 | 26.297 | 3.580 | 3.580 |
| 10 | 27.074 | 3.980 | 3.980 |
| 11 | 27.696 | 3.900 | 3.900 |
| 12 | 29.905 | 3.980 | 3.980 |
| 13 | 30.442 | 3.900 | 3.900 |
| 14 | 34.606 | 3.470 | 3.470 |
| 15 | 34.607 | 3.200 | 3.200 |
| 16 | 39.041 | 2.980 | 2.980 |
| 17 | 36.650 | 3.150 | 3.150 |

As can be seen from the results, the accuracy rate is quite high, and the average error rate is less than 0.099%, similar to the GA results.

In Table 3, the calculation results are compared with the values found in the literature.

The results of the optimization with the GA and the PSO, as well as the results of the optimization of the bandwidth, which are as important as the correct calculation of the resonant frequency, are presented in Tables 4 and 5.

**Table 3.** Resonant Frequency Values (GHz) Calculated in Literature and Calculation Result [17]

| Antenna Number | Resonant Frequency Values (GHz) Calculated in Literature | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $f_{Howell}$ | $f_{Hammerstad}$ | $f_{Carver}$ | $f_{Bahl}$ | $f_{James}$ | $f_{Sengupta}$ | $f_{Garg}$ | $f_{Chew}$ | $f_{Kara1}$ | $f_{Kara2}$ | $f_{EXP}$ | $f_{GA}$ | $f_{PSO}$ |
| 1 | 8.698 | 6.845 | 7.546 | 7.519 | 6.464 | 8.447 | 6.889 | 7.160 | 8.089 | 8.067 | 8.00 | 8.000 | 8.000 |
| 2 | 7.485 | 5.870 | 6.601 | 6.484 | 5.525 | 7.342 | 5.904 | 6.179 | 7.241 | 7.242 | 7.134 | 7.134 | 7.134 |
| 3 | 6.478 | 5.092 | 5.660 | 5.606 | 4.784 | 6.453 | 5.122 | 5.396 | 6.529 | 6.549 | 6.070 | 6.069 | 6.069 |
| 4 | 6.180 | 4.855 | 5.423 | 5.352 | 4.576 | 6.042 | 4.886 | 5.100 | 5.881 | 5.875 | 5.820 | 5.820 | 5.820 |
| 5 | 6.523 | 5.101 | 5.823 | 5.660 | 4.784 | 6.453 | 5.122 | 5.396 | 6.529 | 6.546 | 6.380 | 6.380 | 6.380 |
| 6 | 5.798 | 4.539 | 5.264 | 5.063 | 4.239 | 5.804 | 4.550 | 4.830 | 5.950 | 5.979 | 5.990 | 5.989 | 5.989 |
| 7 | 4.768 | 3.746 | 4.227 | 4.141 | 3.526 | 4.689 | 3.770 | 3.949 | 4.600 | 4.60 | 4.660 | 4.659 | 4.659 |
| 8 | 4.084 | 3.201 | 3.824 | 3.615 | 2.938 | 4.209 | 3.168 | 3.446 | 4.556 | 4.603 | 4.600 | 4.600 | 4.600 |
| 9 | 3.408 | 2.668 | 3.115 | 2.983 | 2.485 | 3.430 | 2.670 | 2.845 | 3.554 | 3.574 | 3.580 | 3.580 | 3.580 |
| 10 | 3.585 | 2.808 | 3.335 | 3.162 | 2.590 | 3.668 | 2.790 | 3.015 | 3.920 | 3.955 | 3.980 | 3.980 | 3.980 |
| 11 | 3.558 | 2.785 | 3.299 | 3.133 | 2.573 | 3.629 | 2.771 | 2.987 | 3.863 | 3.895 | 3.900 | 3.900 | 3.900 |
| 12 | 3.510 | 2.753 | 3.294 | 3.112 | 2.522 | 3.626 | 2.721 | 2.966 | 3.940 | 3.988 | 3.980 | 3.980 | 3.980 |
| 13 | 3.313 | 2.608 | 3.147 | 2.964 | 2.364 | 3.473 | 2.554 | 2.823 | 3.852 | 3.903 | 3.900 | 3.900 | 3.900 |
| 14 | 3.001 | 2.358 | 2.838 | 2.675 | 2.146 | 3.129 | 2.317 | 2.549 | 3.450 | 3.493 | 3.470 | 3.470 | 3.470 |
| 15 | 2.779 | 2.183 | 2.623 | 2.474 | 1.992 | 2.889 | 2.151 | 2.357 | 3.160 | 3.197 | 3.200 | 3.200 | 3.200 |
| 16 | 2.684 | 2.102 | 2.502 | 2.370 | 1.936 | 2.752 | 2.086 | 2.259 | 2.954 | 2.982 | 2.980 | 2.980 | 2.980 |
| 17 | 2.779 | 2.183 | 2.623 | 2.474 | 1.992 | 2.889 | 2.151 | 2.357 | 3.125 | 3.160 | 3.150 | 3.150 | 3.150 |
| % Average Error | 8.486 | 25.329 | 13.170 | 16.491 | 30.722 | 6.253 | 25.583 | 20.354 | 1.492 | 1.039 | | 0.00032134 | 0.00032134 |

**Table 4.** Optimization of bandwidth with GA

| Antenna Number | Calculating Bandwidth with GA | | |
|---|---|---|---|
| | W(mm) | $BW_{EXP}$ | $BW_{GA}$ |
| 1 | 7.760 | 17.500 | 17.354 |
| 2 | 7.900 | 18.200 | 18.200 |
| 3 | 9.870 | 17.900 | 17.768 |
| 4 | 10.000 | 18.000 | 17.942 |
| 5 | 8.140 | 19.000 | 18.999 |
| 6 | 7.900 | 20.000 | 19.999 |
| 7 | 12.000 | 18.700 | 18.583 |
| 8 | 7.830 | 20.900 | 20.900 |
| 9 | 12.560 | 20.000 | 19.999 |
| 10 | 9.740 | 20.600 | 20.600 |
| 11 | 10.200 | 20.300 | 20.299 |
| 12 | 8.830 | 20.900 | 20.900 |
| 13 | 7.770 | 21.960 | 21.959 |
| 14 | 9.200 | 21.500 | 21.499 |
| 15 | 10.300 | 21.600 | 21.599 |
| 16 | 12.650 | 20.400 | 20.400 |
| 17 | 10.800 | 21.200 | 21.200 |
| **% Average Error** | 0.157 | | |

In Table 4, bandwidths corresponding to different bandwidth values for the same 17 antennas are presented as values calculated by experimental and GA. The % error ($\% \, Error = \frac{BW_{Experimental} - BW_{Calculated-GA}}{BW_{Experimental}} \times 100$) values for each antenna are given. In addition, the average error of the bandwidth calculation was obtained as 0.157%.

**Table 5.** Bandwidth optimization with PSO

| Antenna Number | Calculating Bandwidth with PSO | | |
|---|---|---|---|
| | W(mm) | $BW_{EXP}$ | $BW_{PSO}$ |
| 1 | 10.889 | 17.500 | 17.354 |
| 2 | 12.078 | 18.200 | 18.200 |
| 3 | 14.849 | 17.900 | 17.768 |
| 4 | 15.708 | 18.000 | 17.942 |
| 5 | 14.632 | 19.000 | 18.999 |
| 6 | 16.358 | 20.000 | 19.999 |
| 7 | 20.657 | 18.700 | 18.583 |
| 8 | 4.679 | 20.900 | 20.900 |
| 9 | 19.144 | 20.000 | 19.999 |
| 10 | 5.634 | 20.600 | 20.600 |
| 11 | 4.970 | 20.300 | 20.299 |
| 12 | 1.650 | 20.900 | 20.900 |
| 13 | 3.064 | 21.960 | 21.959 |
| 14 | 2.309 | 21.500 | 21.499 |
| 15 | 7.487 | 21.600 | 21.599 |
| 16 | 2.419 | 20.400 | 20.400 |
| 17 | 3.916 | 21.200 | 21.200 |
| **% Average Error** | 0.147 | | |

In Table 5, the bandwidths corresponding to different bandwidth values for the same 17 antennas are shown as values calculated by experimental and PSO. The % error ($\% \, Error = \frac{BW_{Experimental} - BW_{Calculated-PSO}}{BW_{Experimental}} \times 100$) values for each antenna are given. In addition, the average error of bandwidth calculation was found to be 0.147%.

**Table 6.** Optimization of feed point and input impedance with

| Antenna Number | Optimization of Feed Point and Input Impedance with GA | | | | |
|---|---|---|---|---|---|
| | $R_{Experimental}$ (Ω) | $R_{Calculated}$ (Ω) | % Error | $a_{Experimental}$ (mm) | $a_{Calculated}$ (mm) |
| 1 | 47.000 | 49.999 | 6.382 | 4.030 | 3.772 |
| 2 | 46.000 | 50.000 | 8.510 | 3.000 | 3.563 |
| 3 | 46.000 | 50.000 | 8.695 | 3.750 | 4.490 |
| 4 | 45.000 | 50.000 | 11.111 | 3.450 | 4.545 |
| 5 | 46.000 | 49.999 | 8.695 | 3.100 | 3.750 |
| 6 | 45.000 | 49.999 | 11.110 | 3.500 | 3.234 |
| 7 | 44.000 | 50.000 | 13.636 | 2.550 | 5.050 |
| 8 | 46.000 | 49.996 | 8.687 | 4.250 | 6.574 |
| 9 | 46.000 | 49.999 | 8.695 | 3.200 | 6.916 |
| 10 | 45.000 | 49.999 | 11.110 | 3.100 | 8.324 |
| 11 | 45.000 | 50.000 | 11.111 | 3.550 | 7.825 |
| 12 | 46.000 | 50.002 | 8.700 | 3.050 | 7.340 |
| 13 | 49.000 | 49.964 | 1.968 | 3.200 | 7.352 |
| 14 | 50.000 | 49.955 | 0.088 | 3.000 | 8.768 |
| 15 | 47.000 | 50.014 | 6.414 | 3.600 | 9.117 |
| 16 | 46.000 | 50.000 | 8.697 | 3.700 | 9.767 |
| 17 | 47.000 | 49.993 | 6.370 | 3.700 | 8.549 |
| **% Average Error** | 8.234 | | | | |

The matter of feed point in antennas is important for stimulating proper modes of operation, impedance

**Table 7.** Optimization of feed point and input impedance with PSO

| Antenna Number | Optimization of Feed Point and Input Impedance with PSO | | | | |
|---|---|---|---|---|---|
| | $\mathbf{R}_{Experimental}$ (Ω) | $\mathbf{R}_{Calculated}$ (Ω) | % Error | $\mathbf{a}_{Experimental}$ (mm) | $\mathbf{a}_{Calculated}$ (mm) |
| 1 | 47 | 50 | 6.382 | 4.03 | 3.289 |
| 2 | 46 | 50 | 8.695 | 3 | 3.562 |
| 3 | 46 | 50 | 8.695 | 3.75 | 4.174 |
| 4 | 45 | 50 | 11.111 | 3.45 | 4.274 |
| 5 | 46 | 50 | 8.695 | 3.1 | 3.492 |
| 6 | 45 | 50 | 11.111 | 3.5 | 3.035 |
| 7 | 44 | 50 | 13.636 | 2.55 | 4.906 |
| 8 | 46 | 50 | 8.695 | 4.25 | 7.263 |
| 9 | 46 | 50 | 8.695 | 3.2 | 6.916 |
| 10 | 45 | 50 | 11.111 | 3.1 | 8.647 |
| 11 | 45 | 50 | 11.111 | 3.55 | 9.379 |
| 12 | 46 | 50 | 8.695 | 3.05 | 9.619 |
| 13 | 49 | 50 | 2.040 | 3.2 | 8.096 |
| 14 | 50 | 50 | 0 | 3 | 10.119 |
| 15 | 47 | 50 | 6.382 | 3.6 | 9.165 |
| 16 | 46 | 50 | 8.695 | 3.7 | 13.619 |
| 17 | 47 | 50 | 6.382 | 3.7 | 11.092 |
| **% Average Error** | 8.234 | | | | |

matching, and developing high-performance antennas. For this reason, the feed point and input impedance were calculated using GA and PSO. The actual optimization results are shown in Table 6 for the GA and Table 7 for the PSO.

The results obtained with the GA were examined and the % error values $\% \, Error=\frac{R_{Experimental}\text{-}R_{Calculated-GA}}{R_{Experimental}}\times 100)$ were calculated for the feed points. The mean % error value was determined to be 8.234.

The results obtained by PSO were examined and the % error values $\% \, Error=\frac{R_{Experimental}\text{-}R_{Calculated-PSO}}{R_{Experimental}}\times 100)$ were calculated for the feeding points. The mean % error value was determined to be 8.234.

The graphs of the iteration number objective function values obtained by the GA are shown in Figure 8.a and Figure 8.b. To make the graphical resolution values readable, the first 9 antennas are shown in Figure 8.a, while the antennas numbered 10 - 17 are shown in Figure 8.b.

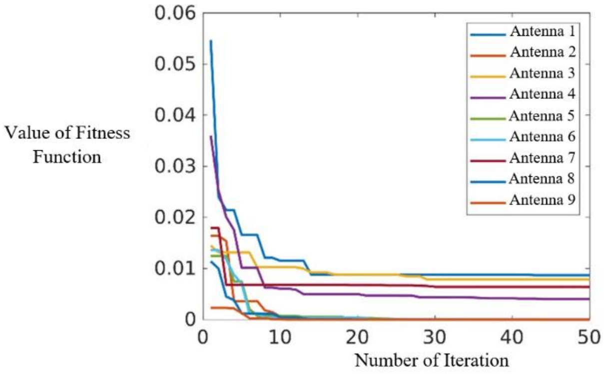


**Figure 8.a.** GA iteration graphs Antenna 1-9

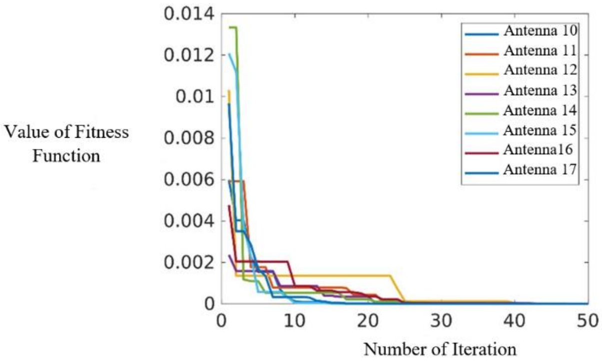


**Figure 8.b.** GA iteration graphs Antenna 10-17

The graphs of the iteration number objective function values obtained by PSO are shown in Figure 9.

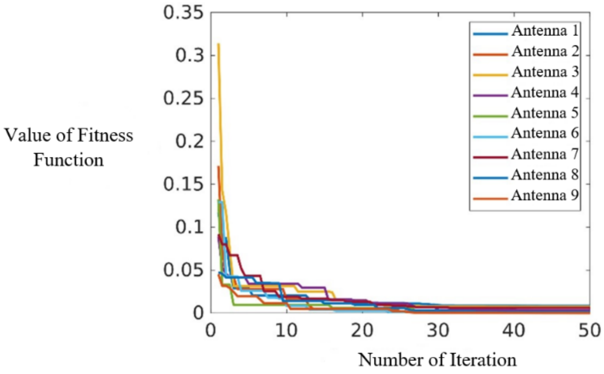


**Figure 9.a.** PSO iteration graphs Antenna 1-9

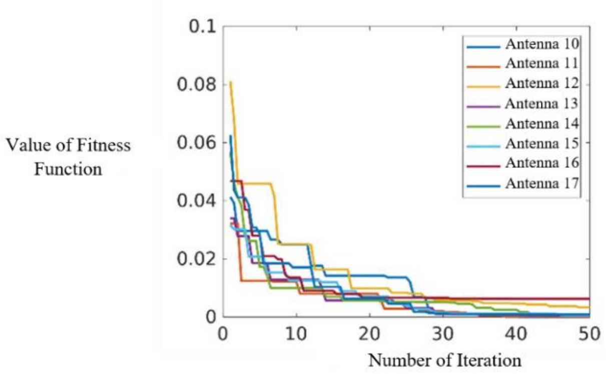


**Figure 9.b.** PSO iteration graphs Antenna 10-17

The resolution time for 17 different antennas is 12.004 seconds for the GA and 10.222 seconds for the PSO on a Windows PC laptop with Intel(R) Core (TM) i5-8265U CPU and 8.00GB RAM. Looking at the iteration curves and computation times, the PSO solves the problem in less time. From the average errors, both algorithms solve the problem and have the highest accuracy compared to the studies reported in the literature.

## 4. ANTENNA DESIGN

In this section, antenna designs were modeled with CST Studio Suite® software using the physical parameters optimized by PSO. The 3D image of the antenna corresponding to antenna number 3 given in the tables is shown in Figure 10 (a). The location of the feed point from the top view is shown in Figure 10 (b), and the side view of the feed point is shown in Figure 10 (c).

The width and length of antenna 3 are 14.85 and 14.00 mm, respectively. In the design, the substrate with electrical conductivity value $\varepsilon_r = 2.55$ was used. The thickness of the substrate and radiating patch part of the antennas optimized in the work and presented in the literature is hs=17 μm and h=35 μm, respectively.

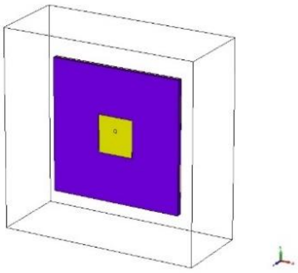


**Figure 10.a.** Antenna # 3 design view

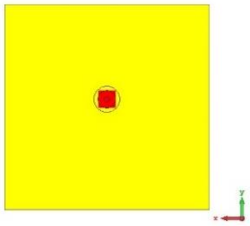


**Figure 10.b.** Antenna # 3 location of feed point top view

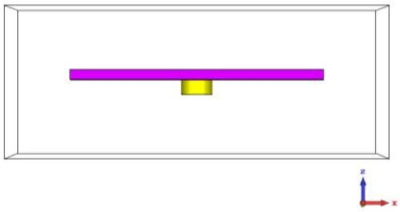


**Figure 10.c.** Antenna # 3 feed point side view

The resonant frequency and $S_{11}$ graph of the designed Antenna 3 is given in Figure 11 (a) and the far field graph of the designed Antenna 3 is given in Figure 11 (b).

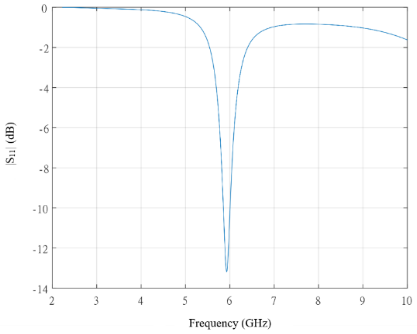


**Figure 11.a.** Antenna 3 S11 characteristics

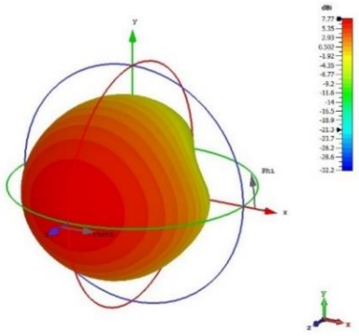


**Figure 11.b.** Antenna 3 Far-field directivity

As can be seen in the graph above, the resonant frequency of the antenna is 5.9826 GHz, while the fractional bandwidth is 16%, with a bandwidth threshold of -10 dB, a lower cutoff frequency of 5.75, and an upper cutoff frequency of 6 GHz.

The surface currents graph of the designed Antenna 3 is given in Figure 12.

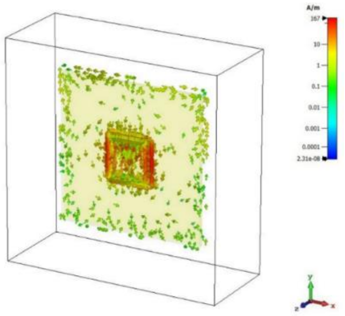


**Figure 12.** Surface currents graph of the designed Antenna 3

The optimized antenna achieved to have a gain of 13 dB, a directivity value of 7.77, and the VSWR value of 1.5648 at the desired frequency.

## 5. CONCLUSION

In this paper, GA and PSO methods were investigated, and the corresponding algorithms were developed for estimating the resonant frequency, bandwidth, impedance, and feed point for RSM antennas. In accordance with the implementation and comparison of these two algorithms the following conclusions are obtained;

- Both of those two methods optimize the problems without the need for derived information. In addition to optimizing continuous and discontinuous functions, they are also applied to optimize multi-objective problems. It provides effective solutions for problems with large search spaces and many parameters. Thanks to these advantages offered by the algorithms, the closed-form expressions determined as the estimation problem could be easily solved and more than one parameter could be optimized. The disadvantages of the algorithms can be expressed in terms of the computational time incurred by the repeated calculation of the fitness value for each individual.
- The primary motivation of this work is to develop an algorithm for pre- and high-accuracy estimation of parameters such as resonant frequency, bandwidth, impedance value, and feed point of narrowband resonant frequency microstrip antennas to reduce antenna design and manufacturing costs. GA and PSO algorithms have been proposed as a low-cost and fast solution for 3-dimensional full-wave electromagnetic simulation programs, which currently have very high development costs. These algorithms are applied to design antennas with the desired frequency by optimizing the antenna width, length, and feed point position.
- GA and PSO algorithms implemented in MATLAB® environment. The calculation time is 12.004 seconds with the GA and 10.222 seconds with the PSO with the same computer.
- It can be seen that the calculation results converge to the experimental data with the least error compared to other studies in the literature. According to the obtained results, the average error values for the antennas, the details of which are presented in the research results section, can be summarized as follows:
    - According to the GA results, the average error value of the resonant frequency is 0.00032%, while the average error value of the PSO has a similar percentage.
    - The impedance calculation errors were on the order of 8% for both algorithms, while the GA results had an average bandwidth estimation error value of 0.1578%, while this value was 0.1478% for PSO.

## DECLARATION OF ETHICAL STANDARDS

The authors of this article declare that the materials and methods used in their studies do not require ethical committee approval and legal-specific permission.

## AUTHORS' CONTRIBUTIONS

**Zeynep Sıdıka SEVEN:** Responsible for the investigation, visualization, methodology, writing.

**Sultan CAN:** Responsible for the idea, investigation, validation, resources, writing original draft, review editing, and supervision.

## CONFLICT OF INTEREST

There is no conflict of interest in this study.

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