CHAPTER 3

DESIGN OF MICROSTRIP PATCH ANTENNA USING GENETIC ALGORITHM
3.1 Introduction

Microstrip antenna inherently has very low bandwidth. Hence it is very important to find accurate dimension and its feed position to efficiently operate such antenna. There are many empirical formulae[1-4] for different regular structure microstrip patch antenna for calculating the resonant frequency. However, resonant frequency being a non-linear function of parameters like the physical dimensions and material property of the antenna, it is quite difficult to adjust all these parameters simultaneously to design a microstrip patch antenna for a particular operating frequency. Therefore, optimization tool like GA may lead an important role in such problems. GA performs its searching process through population to population instead of point-to-point search. The most favorite advantage of GA is its parallel architecture. They use probabilistic and deterministic rules[5-7]. In this chapter, GA has been efficiently used to design rectangular, circular and triangular microstrip patch antennae.

3.2 Design of Rectangular Microstrip Patch Antenna Using GA

The length (L), width (W), height (h) and the feed point location (a) for a rectangular microstrip antenna are shown in the figure 3.1.
The resonant frequency of the rectangular microstrip antenna[8] is expressed as,

$$f_r = \frac{c_0}{2(L + \Delta W) \sqrt{\varepsilon_r(W)}}$$  \hspace{1cm} (3.1)

where, $c_0$ is the velocity of the electromagnetic waves in free space and $\varepsilon_r(W)$ is the effective dielectric constant, which is given by

$$\varepsilon_r(W) = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2\sqrt{1+10\frac{h}{W}}}$$ \hspace{1cm} (3.2)

$\Delta W$ is the line extension and is given by

$$\Delta W = 0.412 \ h \left[ \frac{\varepsilon_r(W) + 0.300}{\varepsilon_r(W) - 0.258} \right] (W/h + 0.264) \left( W/h + 0.813 \right)$$ \hspace{1cm} (3.3)

Equation (3.1) is used as the fitness function of GA. The two independent variables are the length (L) and width (W). The population size is taken as 20 individuals and 200 generations are produced. The
probability of crossover is set at 0.7, while the probability of mutation is equal to 0.01. Thus, it is suitable for the calculation of the resonant frequencies for antenna elements with \( h \leq 0.0815\lambda_d \). Resonant frequency \((f_r)\), dielectric constant \((\varepsilon_r)\) and thickness of the substrate \((h)\) are given as inputs to GA, which gives the optimized values for the length and width of the antennae[9]. The optimized lengths \((L)\) obtained using GA are in good agreement with the experimental results as listed in column ‘VII’ of Table 3.1. Using these calculated parameters, i.e. ‘L’, ‘W’, ‘h’ and ‘\( \varepsilon_r \)’ in IE3D simulation software, resonant frequencies are calculated which almost match with the input resonant frequencies considered, thus, validating the results of GA. The theoretical results obtained by GA and IE3D software are listed in table 3.1 for 7 different rectangular microstrip antennae.

### Table 3.1 Resonant Frequency Results and Dimensions for Rectangular Microstrip Antennae

<table>
<thead>
<tr>
<th>Antenna No.</th>
<th>( f_r ) In GHz (Expt.)</th>
<th>( \varepsilon_r )</th>
<th>( h ) In mm</th>
<th>( L ) In mm (GA)</th>
<th>( W ) In mm (GA)</th>
<th>( L_{\text{exp}} ) In mm [3]</th>
<th>( f_{13.5} ) In GHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6.2</td>
<td>2.55</td>
<td>2.0</td>
<td>14.382</td>
<td>8.975</td>
<td>14.12</td>
<td>6.13</td>
</tr>
<tr>
<td>2</td>
<td>8.45</td>
<td>2.22</td>
<td>0.17</td>
<td>11.867</td>
<td>9.456</td>
<td>11.85</td>
<td>8.32</td>
</tr>
<tr>
<td>3</td>
<td>7.74</td>
<td>2.22</td>
<td>12.9</td>
<td>19.337</td>
<td>12.9</td>
<td>12.9</td>
<td>7.6</td>
</tr>
<tr>
<td>4</td>
<td>3.97</td>
<td>2.22</td>
<td>0.79</td>
<td>25.306</td>
<td>13.007</td>
<td>25</td>
<td>3.92</td>
</tr>
<tr>
<td>5</td>
<td>5.06</td>
<td>2.33</td>
<td>1.57</td>
<td>18.6</td>
<td>18.4</td>
<td>18.6</td>
<td>4.98</td>
</tr>
<tr>
<td>6</td>
<td>5.6</td>
<td>2.55</td>
<td>1.63</td>
<td>16.07</td>
<td>13.34</td>
<td>16.21</td>
<td>5.3</td>
</tr>
<tr>
<td>7</td>
<td>4.805</td>
<td>2.33</td>
<td>1.57</td>
<td>19.573</td>
<td>21.696</td>
<td>19.6</td>
<td>4.6</td>
</tr>
</tbody>
</table>

Department of Computer Science and Engineering, Tezpur University
The return loss and VSWR plots calculated using IE3D simulation software for antenna number 1 (L=14.382 mm, W=8.975 mm, h=2 mm and $\varepsilon_r=2.55$) are shown in figure 3.2 and figure 3.3 respectively whereas figure 3.4 and figure 3.5 show that of antenna number 5 (L=18.6 mm, W=18.4 mm, h=1.57 mm and $\varepsilon_r=2.33$).

![Graph showing return loss plot for antenna No. 1](image)

**Figure 3.2 Return Loss Plot for Antenna No. 1**

(L=14.382 mm, W=8.975 mm, h=2 mm and $\varepsilon_r=2.55$)
Fig. 3.3 VSWR Plot for Antenna No. 1

(L=14.382 mm, W=8.975 mm, h=2 mm and \( \varepsilon_r = 2.55 \))

Fig. 3.4 Return Loss Plot for Antenna No. 5

(L=18.6 mm, W=18.4 mm, h=1.57 mm and \( \varepsilon_r = 2.33 \))
Simultaneous variation of length and width of a microstrip antenna to obtain optimized length and width for calculating the resonant frequency of a said antenna that matches with the experimental resonant frequency is a computationally tedious and time consuming process. As seen from the table, using GA this can be achieved without much computational time. The return loss plot and VSWR plot obtained using IE3D Simulation package for two antennae are also presented. These results have good agreement with that of experimental results. Thus, application of GA to calculate optimized length and width of microstrip antenna seems to be an accurate and simple method. This will go a long way in helping antenna designs especially for small pack antenna system where due to space limitation both length and width
are to be adjusted simultaneously to achieve the required resonant frequency. This is a forced situation in the present scenario of miniaturization.

3.3 Design of Circular Microstrip Patch Antenna

Using GA

Circular microstrip antenna, due to its simple design features is still popular in industrial and commercial applications[10-12]. However, due to inherent narrow bandwidth, the resonant frequency or the dimension of the patch antenna is to be predicted accurately.

Genetic Algorithm (GA) has been applied to calculate the optimized radius of Circular Microstrip Antennae. Resonant frequency (f) in the dominant TM_{11} mode, dielectric constant (\varepsilon_r) and thickness of the substrate (h) are taken as inputs to GA, which gives the optimized radii (a) of the antennae. Method of Moment (MOM) based IE3D software of the Zealand Inc., USA, and experimental results are used to validate the GA based code. It is seen that the GA results are more accurate while taking less computational time. The results are in good agreement with experimental findings[13].

The circular patch antenna with its design parameters i.e. thickness of substrate ‘h’ and radius of circular patch ‘a’, is shown in figure 3.6.
The resonant frequency of circular microstrip antenna\cite{13} is expressed as

\[
f_r = \frac{1.84118 \: \varepsilon_0}{2 \pi a \left[ \varepsilon_{\text{eff}} \left( 1 + \frac{2h}{\pi \varepsilon_r a} \left( \ln \left( \frac{a}{2h} \right) + (1.44 \: \varepsilon_r + 1.77) + \frac{h}{a} \left( 0.268 \: \varepsilon_r + 1.65 \right) \right) \right) \right]^{1/2}}
\]

(3.4)

Where, the effective dielectric constant ($\varepsilon_{\text{eff}}$), is given by

\[
\varepsilon_{\text{eff}} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \left[ 1 + \frac{12 \: h}{a \sqrt{\pi}} \right]^{-1/2}
\]

(3.5)

And $c_0$ is the velocity of light.

Equation (3.4) is used as the fitness function of GA to optimize radius of the patch of the antennae. The population size is taken 20 individuals, and 200 generations are produced. The probability of
crossover is set at 0.25, while the probability of mutation was equal to 0.01. Resonant frequency ($f_r$), dielectric constant ($\varepsilon_r$) and thickness of the substrate ($h$) are given as inputs to GA, which gives the optimized radii (a) of the antennae. The comparisons of GA and results obtained by IE3D software are listed in table 3.2 for nine different fabricated circular microstrip antennae. The optimized radii (a) obtained using GA are in good agreement with the experimental results as listed in column 'VII' of table 3.2.

Using these calculated radius (a) in IE3D simulation software, resonant frequencies are calculated which almost match with the input resonant frequencies used as input, thus, validating the results of GA. The percentage of error for calculation of radius using GA, are listed in column VI. Average error obtained using GA is only 0.65 for seven antennas.

<table>
<thead>
<tr>
<th>Antenna No.</th>
<th>$f_r$ (GHz)</th>
<th>$\varepsilon_r$</th>
<th>$h$ (mm)</th>
<th>a (mm)</th>
<th>Error (%)</th>
<th>$f_{IE3D}$ (GHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4.945</td>
<td>4.55</td>
<td>2.35</td>
<td>7.6742</td>
<td>0.306234</td>
<td>4.94</td>
</tr>
<tr>
<td>2</td>
<td>3.75</td>
<td>4.55</td>
<td>2.35</td>
<td>10.3837</td>
<td>0.156731</td>
<td>3.735</td>
</tr>
<tr>
<td>3</td>
<td>2.003</td>
<td>4.55</td>
<td>2.35</td>
<td>20.0659</td>
<td>0.3295</td>
<td>2.02</td>
</tr>
<tr>
<td>4</td>
<td>1.03</td>
<td>4.55</td>
<td>2.35</td>
<td>39.5602</td>
<td>0.477484</td>
<td>1.05</td>
</tr>
<tr>
<td>5</td>
<td>0.825</td>
<td>4.55</td>
<td>2.35</td>
<td>49.502</td>
<td>0.0040404</td>
<td>0.82</td>
</tr>
<tr>
<td>6</td>
<td>1.51</td>
<td>2.33</td>
<td>3.175</td>
<td>35.2043</td>
<td>0.785285</td>
<td>1.53</td>
</tr>
<tr>
<td>7</td>
<td>4.07</td>
<td>2.33</td>
<td>0.794</td>
<td>13.0196</td>
<td>2.51654</td>
<td>4.12</td>
</tr>
</tbody>
</table>

* Measured by Abboud et al [14], reminder measured by Howell [15].
Fig. 3.7 Return Loss Plot for Antenna No. 1

\(a=7.6742 \text{ mm, } h=2.35 \text{ mm and } \varepsilon_r = 4.55\)

Fig. 3.8 Return Loss Plot for Antenna No. 2

\(a=10.3837 \text{ mm, } h=2.35 \text{ mm and } \varepsilon_r = 4.55\)
The return loss plots calculated using IE3D simulation software for antenna number 1 (a=7.6742 mm, h=2.35 mm and $\varepsilon_r = 4.55$) and antenna number 2 (a=10.3837 mm, h=2.35 mm and $\varepsilon_r = 4.55$) are shown in figure 3.7 and figure 3.8 respectively.

Seven antennae are optimized to validate the developed code using GA. IE3D software and experimental results are used to compare and hence, to validate the obtained results by GA. Design parameter obtained using GA are used to simulate the antenna using IE3D. Return loss plots are presented for simulated antennas. As seen, the results obtained using GA are more close to experimental results. Thus, a highly selected fitness function in GA gives much accurate result. Application of GA to microstrip antenna design seems to be an accurate, computationally simple and cost effective method, which may go a long way in antenna design.

3.4 Design of Triangular Microstrip Patch Antenna

Using GA

Triangular microstrip antenna, due to its simple design features and patch area has gained much interest for investigation by researchers since last few decades[16-23]. Most importantly they are advantageous in arranging in such a way to reduce the coupling as well as the spacing between two adjacent elements when used as elements of a periodic array. Since they have very narrow bandwidth
the resonant frequency or design parameter has to be predicted accurately.

Genetic Algorithm (GA) has been applied to calculate the optimized side length of Triangular Microstrip Antennae. The inputs to the problem are the desired resonant frequency, dielectric constant and thickness of the substrate. And output is the optimized side length. Method of Moment (MOM) based IE3D software of the Zealand Inc., USA, and experimental results are used to validate the GA based code. The basic formula developed in [24] is used to determine the resonant frequency of Triangular microstrip antenna.

The side length (r), height (h) and the feed point location (a) for a Triangular microstrip antenna are shown in the figure 3.9.

![Fig. 3.9 Triangular Patch Antenna](image-url)
The fitness function used in GA to optimize the Triangular patch antenna is the resonant frequency expression [24], given as

\[ f_{n,m,l} = \frac{2c}{3r_{\text{eff}} \sqrt{\varepsilon_{\text{eff}}}} \left( \frac{n^2 + nm + m^2}{4} \right)^\frac{1}{2} \]  \hspace{1cm} (3.6)

Where \( c \) is the velocity of the electromagnetic waves in free, and \( \varepsilon_{\text{eff}} \) is given by

\[ r_{\text{eff}} = \frac{2\pi}{3} a \sqrt{\frac{1}{1+g}} \]  \hspace{1cm} (3.7)

Equation (3.6) is used as the fitness function since it is more accurate as compared to earlier empirical formulae. The variable to be optimized is \( r \). The population size is taken as 20 individuals, and 200 generations are produced. The probability of crossover is set at 0.25, while the probability of mutation is set equal to 0.01.

Resonant frequency \( f_i \), dielectric constant \( \varepsilon_r \) and thickness of the substrate \( h \) are given as inputs to GA, which gives the optimized side length of the antennae. The optimized side lengths \( r \) obtained using GA are in good agreement with the experimental results as listed in column 'VI' of the Table. Using these calculated parameters, i.e. \( r \), \( h \) and \( \varepsilon_r \) in IE3D simulation software, resonant frequencies are calculated which almost match with the input resonant frequencies considered, thus, validating the results of GA. The theoretical results obtained by GA and results obtained by IE3D software are listed in table 3.3 for 5 different Triangular Microstrip Antennas.
Table 3.3 Resonant Frequency Results and Dimensions for
Triangular Microstrip Antennae

<table>
<thead>
<tr>
<th>Antenna No.</th>
<th>$f_r$ (in GHz)</th>
<th>$\varepsilon_r$</th>
<th>$h$ (in cm)</th>
<th>$R_{GA}$ (in cm)</th>
<th>$R_{EXPT}$ (in cm)</th>
<th>From[23]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4.1</td>
<td>10.5</td>
<td>0.07</td>
<td>4.086</td>
<td>4.1</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>8.7</td>
<td>2.32</td>
<td>0.078</td>
<td>8.876</td>
<td>8.7</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>10.0</td>
<td>2.32</td>
<td>0.159</td>
<td>10.158</td>
<td>10.0</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>6.65</td>
<td>4.3</td>
<td>0.159</td>
<td>6.73</td>
<td>6.65</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>4.33</td>
<td>2.33</td>
<td>0.159</td>
<td>4.648</td>
<td>4.33</td>
<td></td>
</tr>
</tbody>
</table>

The mathematical expressions available for determination of resonant frequency of Triangular Microstrip Antenna show that for higher accuracy the effective permittivity of the dielectric substrate must be considered. Hence, in such situation, it is difficult to calculate the side length of the Triangular microstrip antenna. As seen from the table, using GA this can be achieved without much computational time. In proposed approach, five antennae are optimized to validate the developed code using GA. IE3D software and experimental results are used to compare and hence to validate the obtained results by GA. The return loss plot and VSWR plot obtained using IE3D Simulation package for two antennae are also presented.
3.5 Conclusion

This chapter presents design of different regular structure microstrip antenna using GA. The results obtained are close to experimental results. This method can be applied for other irregular structures which are having empirical formulae to find the resonant frequency. The technique can be further improved by choosing proper selection of fitness function or, by developing new better empirical formula where it is not available. This is a simple and efficient technique for design a microstrip antenna.
References


22. W. Chen, K. F. Lee and J. S. Dahele, "Theoretical and experimental studies of the resonant frequencies of equilateral

23. K. Guney, “Resonant frequency of a triangular microstrip
July 1993.

24. D. Guha and J. Y. Siddiqui, "CAD Formulas for the Triangular
Microstrip Patch Antennas," proc. Nat. Sym. on Antennas and
Propagation, Cochin University of Science and Technology,