DESIGN, FABRICATION AND ANALYSIS OF KEY-SHAPED MICROSTRIP PATCH ANTENNA FOR ULTRA-WIDE BAND APPLICATIONS

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ABSTRACT

This work presents the design, fabrication and analysis of microstrip patch antenna for ultra-wide band applications. The proposed key shape resembled antenna consists of two asymmetric hexagonal cuts on the ground plane. The defected ground structure and partial substrate removal techniques as well as coplanar waveguide feeding techniques are used to enhance the gain of the designed antenna. An efficient microstrip patch antenna with ultra-wide bandwidth has been proposed in this paper. The antenna dimensions are 50 x 50 x 1.6 mm$^3$. The FR4 substrate material with dielectric constant of 4.4 is used for the proposed antenna. The proposed antenna is simulated using high-frequency structural simulator (HFSS) software. The initial designed antenna is found to exhibit wide band characteristics with a gain of 6.26 dB and bandwidth of 6.48 GHz. The decreased ground area (modified design) antenna shows wide band characteristics with an enhanced gain of 6.45 dB and bandwidth of 6.83 GHz. Fabricated MPA from modified design is also wide band characteristics with a gain of 6.55 dB and band width of 7.71 GHz. These values are showing a good agreement between results of theoretical and practical.

Key words: High Frequency structure simulator software; Microstrip patch Antenna; Co-planar waveguide feed technique; Defected ground structure technique; Ultra-wide band.

http://www.iaeme.com/IJARET/issues.asp?JType=IJARET&VType=11&IType=6

1. INTRODUCTION

In recent years, the study of microstrip patch antennas (MPAs) has made great progress due to their advantages such as low cost, low weight, low profile, planar configuration, easy for fabrication and conformability with microwave integrated circuits [1], [2]. They have been extensively used in the civilian and military applications such as bio-imaging, television,
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mobile systems, satellite communications, radio-frequency identification (RFID), global positioning system (GPS), multiple-input multiple-output (MIMO) systems and vehicle collision avoidance system etc. [3], [4]. In spite of various advantages of typical MPAs, they also have three basic limitations such as narrow bandwidth, low gain, and relatively large size. A substrate thickness increasing method is available in the literature to improve the bandwidth of conventional MPA [3].

A various other techniques are reported to attribute the wide-impedance bandwidths of MPAs. For instance, the defected ground structures (DGSs) such as U, L, T, and inverted T are using in the MPAs [5-6]. Another limitation of MPAs is low gain which can be improved by an array antenna platform [7], [8], [9], [10], [11]. The last limitation of conventional MPA is the relatively large electrical size. Thus, these antennas are operated at lower microwave frequencies. A numerous efforts have been made to minimize the electrical size of antenna and attribute the miniaturized wireless devices [12],[13], [14]. In View of the above facts, we can say that many methods are developed to improve the properties of MPAs. Nevertheless, there is a relationship among bandwidth, gain, and size of the MPAs. Many of researchers in the field of antenna have observed that the improvement in one antenna property is frequently accompanied by decline in its other performances [3]. Traditionally, if gain increases bandwidth decreases and vice versa. Therefore, there is a great demand to develop the MPAs that hold the potential properties such as wider bandwidth, high gain and small size.

Herein, we present the design, fabrication and analysis of key shaped microstrip patch antenna for ultrawide band applications. The proposed antenna consists of two asymmetric hexagonal cuts on the ground plane. The performance of the proposed antenna is enhanced by considering the defected ground structure in the ground structure of antenna. The proposed antenna is inspired from the key shape with compact in structure.

2. ANTENNA DESIGN

The proposed MPA initial design (resembled to key shape) of this work is shown in the Figure 1a. The patch is placed on FR4-epoxy substrate with thickness of 1.6 mm to increase the gain; detected ground structure is used, which is fed by a technique called coplanar waveguide feed. The patch is a flat sheet of metal mounted over a ground plane which is generally made of conductive material such as copper or gold and it can be assembled in any possible shape. The radiating patch and the feed lines are usually photo etched on the dielectric substrate.
Table 1 Antenna dimensions for the initial proposed structure

<table>
<thead>
<tr>
<th>Position</th>
<th>Ground</th>
<th>Substrate</th>
<th>Radiation box</th>
<th>Port</th>
<th>Rectangle</th>
</tr>
</thead>
<tbody>
<tr>
<td>x-size</td>
<td>50</td>
<td>50</td>
<td>75</td>
<td>1.9</td>
<td>13.9</td>
</tr>
<tr>
<td>y-size</td>
<td>50</td>
<td>50</td>
<td>75</td>
<td>-0.5</td>
<td>9.4</td>
</tr>
<tr>
<td>z-size</td>
<td>-</td>
<td>1.6</td>
<td>75</td>
<td>-</td>
<td>--</td>
</tr>
</tbody>
</table>

The patch of the proposed antenna is different from the conventional rectangular patch as those two rectangular patches of different sizes were joined over using poly-lines to achieve improved performance. The dimensions of the initial proposed antenna structure are shown in the Table 1.

Table 2 Parameters of the modified MPA design

<table>
<thead>
<tr>
<th>S.No</th>
<th>Parameter</th>
<th>Values (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>Ground Width (Wg)</td>
<td>50</td>
</tr>
<tr>
<td>02</td>
<td>Ground Length (Lg1 + Lg2)</td>
<td>22.9</td>
</tr>
<tr>
<td>03</td>
<td>Substrate Length (Ls)</td>
<td>50</td>
</tr>
<tr>
<td>04</td>
<td>Substrate Width (Ws)</td>
<td>50</td>
</tr>
<tr>
<td>05</td>
<td>Feed Length (Lf)</td>
<td>0.5</td>
</tr>
<tr>
<td>06</td>
<td>Feed Width (Wf)</td>
<td>1.9</td>
</tr>
<tr>
<td>07</td>
<td>Patch Width (Wp)</td>
<td>13.9</td>
</tr>
<tr>
<td>08</td>
<td>patch length (Lp)</td>
<td>9.4</td>
</tr>
</tbody>
</table>

After optimization (parameter) studies of the initial proposed design, the two asymmetric hexagonal cuts on the ground plane are introduced in the final design (modified design) of antenna which is shown in Figure 1b-c. The Schematic illustration of modified designed MPA, modified simulated antenna and the fabricated antenna from the modified design are presented in the Figure 1b, Figure 1c and Figure 1d, respectively. The parameters of the modified design MPA are shown in the Table 2.

3. MESUREMENT SETUP

![Figure 2](image)

Figure 2 The measurement setup for testing the fabricated antenna

Only the initial, introductory paragraph has a drop cap. The fabricated antenna from the proposed designed is also tested from vector network analyzer ANRITSU Combinational Analyzer (Model No. MS2037C). Figure 2 represents the measurement setup of the fabricated antenna. For the measurement, we have used two antennas: (i) fabricated antenna and (ii) HORN antenna. The fabricated and HORN antennas are acted as a transmitter and a receiver, respectively.
4. RESULTS AND DISCUSSIONS

4.1. Initial Design

In the proposed work, we have used the “high-frequency structural simulator” (Anyss HFSS software) for the simulated results. The numerical analysis of Anyss HFSS software is based on the finite element method [15]. The Return loss, Bandwidth, Voltage Standing Wave Ratio (VSWR), Gain and Radiation pattern for initial proposed MPA are obtained from Anyss HFSS software.

Figure 3a shows the simulated return loss versus frequency for the initial design of the proposed MPA using Anyss HFSS software. A frequency range of 0 GHz to 12 GHz is chosen to obtain these results. From the Figure 3a, we observe that the initial structure of the proposed antenna on the FR-4 substrate is resonates with the frequency of 5.40 GHz at maximum return loss i.e -42.15 dB. The bandwidth value of this initial design of the proposed MPA is 6.48 GHz. The simulated VSWR plot of the initial design is shown in Figure 3b. Traditionally, the antenna theoretical value of VSWR is equal to 1. However, in practical cases often the value of VSWR is lie between 1 and 2 (1). The VSWR value of the proposed MPA is 1.04. Based on this result, we can say that the proposed antenna design has a good impedance match at 5.46 GHz because the VSWR value is 1.04. Therefore, the proposed design is an acceptable design. The polar gian of the initial design of proposed MPA at resonating frequency 5.40 GHz is shown in Figure 3c. The gain observed at 5.40 GHz is 6.26 dB. Figure 3d shows the Far-Filed radiation patterns of the proposed antenna. From the Figure 3d, we can say that the radiation pattern of the proposed antenna design is an omni directional at resonating frequency of 5.40 GHz.

![Figure 3](image3.png)

Figure 3 Simulated (a) Return loss vs Frequency, (b) VSWR, (c) Gain pot and (d) Radiation pattern of the proposed initial MPA design.

4.2. Parameter Study

The aim of the proposed work is to develop the MPA having the high bandwidth and the high gain. This leads to the function of antenna would be better in the condition of high signal strength of antenna at high number of users. In this context, to enhance the bandwidth and the gain of the proposed antenna, we have varied the initial design of the proposed antenna
ground structure lengths. We have chosen the initial design of the proposed MPA from high (60 mm) and low (40 mm) lengths of ground structure with respect to an initial design of the proposed MPA having 50 mm ground structure. The rest of parameters are remaining same.

4.2.1. Proposed MPA with ground length of 60

![Image](a) Return loss vs Frequency, (b) VSWR, (c) Gain pot and (d) Radiation pattern of the proposed MPA design with ground length of 60 mm.

The simulated results of the proposed MPA with the ground length of 60 mm like Return loss, Bandwidth, VSWR and Gain and radiation pattern are achieved by means of Ansys HFSS software. These results are shown in Figure 4a-c. The proposed MPA with ground structure 60 mm results are listed in the Table 3.

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Return loss ($S_{11}$)</th>
<th>Bandwidth</th>
<th>VSWR</th>
<th>Gain</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.61 GHz</td>
<td>-41.11 dB</td>
<td>5.34 GHz</td>
<td>0.22</td>
<td>5.91 dB</td>
</tr>
</tbody>
</table>

Figure 4d shows the Far-Filed radiation patterns of the proposed antenna with 60 mm ground length structure. The radiation pattern of this proposed antenna design having 60 mm ground length structure is an omni directional at resonating frequency of 5.61 GHz.

4.2.2. Proposed MPA with ground length of 40

The proposed MPA with ground length of 40 mm simulated results such as Return loss, Bandwidth, VSWR and Gain are achieved by means of Ansys HFSS software (Figure 5a-c). The proposed MPA design with ground structure 40 mm results are listed in the Table 4.
design, fabrication and analysis of key-shaped microstrip patch antenna for ultra-wide band applications.

Figure 5 Simulated (a) Return loss vs Frequency, (b) VSWR, (c) Gain pot and (d) Radiation pattern of the proposed MPA design with ground length of 40 mm

Figure 5d shows the Far Filed radiation patterns of the proposed antenna with 40 mm ground length structure. The radiation pattern of this proposed antenna design having 40 mm ground length structure is an omni directional at resonating frequency of 6.6 GHz.

Table 4 Results of MPA with 40 mm ground length

<table>
<thead>
<tr>
<th>Frequency (GHz)</th>
<th>Return loss (S11)</th>
<th>Bandwidth (GHz)</th>
<th>VSWR</th>
<th>Gain (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.6</td>
<td>-22.91</td>
<td>5.43</td>
<td>1.14</td>
<td>5.42</td>
</tr>
</tbody>
</table>

In conclusion, there is no considerable advantage in view of bandwidth and gain values of the proposed antenna design with ground lengths 60 and 40 mm compared to the proposed antenna design having ground length of 50 mm. Therefore, we future extended this work with modified design of antenna consisting hexagonal cuts in the ground to increase the bandwidth and gain values.

4.3. Modified MPA Design
The simulated results (Return loss, Bandwidth, VSWR, and Gain) of modified MPA design are shown in Figure 6a-c. All the results of proposed designs are summarized in the Table 5.
Figure 6 Simulated (a) Return loss vs Frequency, (b) VSWR, (c) Gain pot and (d) Radiation pattern of the modified MPA design.

Figure 6d shows the Far-Filed radiation patterns of the modified design. The radiation pattern of this proposed modified antenna design is an omni directional at maximum resonating frequency of 5.6 GHz.

Table 5 Summarized results of all the proposed MPA designs

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Initial design</th>
<th>Initial design with 60 mm ground length</th>
<th>Initial design with 40 mm ground length</th>
<th>Modified Design</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency (GHz)</td>
<td>5.40</td>
<td>5.61</td>
<td>6.60</td>
<td>5.60</td>
</tr>
<tr>
<td>Bandwidth (GHz)</td>
<td>6.48</td>
<td>5.34</td>
<td>5.43</td>
<td>6.83</td>
</tr>
<tr>
<td>Return loss (dB)</td>
<td>-42.15</td>
<td>-41.11</td>
<td>-22.91</td>
<td>-43.23</td>
</tr>
<tr>
<td>Gain (dB)</td>
<td>6.26</td>
<td>5.91</td>
<td>5.42</td>
<td>6.45</td>
</tr>
<tr>
<td>VSWR</td>
<td>1.04</td>
<td>0.22</td>
<td>1.14</td>
<td>1.5</td>
</tr>
</tbody>
</table>

From the Table 5, we can observe that the hexagonal slots on the ground of modified design is enhanced the bandwidth and gain values from 6.48 GHz to 6.83 GHz and 6.26 dB to 6.45 dB, respectively. Therefore, the modified MPA design is the best designed in comparison with the initial design of MPA and its varied lengths of ground.

To further strengthen of this present work, we have fabricated MPA from the modified design and also tested.

4.4. Fabricated Antenna

The Return loss, Bandwidth, VSWR and Gain results of fabricated MPA are measured from the vector network analyzer. Figure 7a shows the return loss vs frequency for the fabricated MPA. It can be seen that the fabricated MPA resonates with frequency of 4.3 GHz at maximum return loss i.e. 30.5 dB. The bandwidth value of fabricated MPA is 7.71 GHz. The VSWR plot of the fabricated MPA is shown in Figure 7b. The VSWR value of the fabricated...
MPA is between 1 and 2 i.e. 1.15. Therefore, we can say that the fabricated antenna is worthy. The value of gain for the fabricated MPA is 6.55.

![Figure 7](image)

**Figure 7 Return loss vs Frequency and VSWR of the fabricated MPA**

The simulated results of the final design and its fabricated model results are summarized in the Table 6. These results are showing a good agreement between with theoretical (simulated) and practical (fabricated) results.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Simulated result of modified MPA</th>
<th>Tested results of fabricated MPA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency (GHz)</td>
<td>5.60</td>
<td>6.3</td>
</tr>
<tr>
<td>Return Loss (dB)</td>
<td>-43.23</td>
<td>-31.1</td>
</tr>
<tr>
<td>VSWR</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>Bandwidth (GHz)</td>
<td>6.83</td>
<td>7.71</td>
</tr>
<tr>
<td>Gain (dB)</td>
<td>6.45</td>
<td>6.55</td>
</tr>
</tbody>
</table>

5. CONCLUSIONS

We have designed and fabricated the wide band MPA for UWB applications. The proposed antenna achieved the high bandwidth and high gain by placing two asymmetric hexagonal cuts on the ground plane. The fabricated antenna results are showing a good agreement with the simulated results of the proposed antenna. We strongly believe that the proposed MPA is a good candidate for multi-mode terminals for integrated wireless devices.

AKNOWLEDGEMENTS

The authors wish to thank the management of DNR Engineering College for providing infrastructural facilities to accomplish this work.

REFERENCES


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