CHAPTER- 5

GAIN ENHANCEMENT BY MODIFIED RADIATING / GROUND PLANE

5.1 INTRODUCTION

Along with wideband, gain of microstrip antenna is another important parameter for wireless applications. The inherent gain limitation of microstrip patch antennas restricted it from many commercial applications. There are so many reported techniques we have discussed so far for enhancement of gain of microstrip antennas. This chapter focuses on the development of compact, low cost and high gain novel microstrip antennas by modifying radiating plane as well as ground plane.

5.2 A COMPACT AND HIGH GAIN MICROSTRIP ANTENNA

5.2.1 Introduction

Microstrip antennas are widely used in a broad range of military and commercial applications mainly because of their advantageous features like low profile, low cost, lightweight, and easy manufacturability. However, two major disadvantages associated with microstrip antennas are low gain and narrow bandwidth. Most works have been intended to improve the bandwidth, but few in enhancing the antenna gain. There are several methods which can be used to improve the gain of a patch antenna. The resonance gain method [1, 2] involves the addition of a superstrate or cover layer over the substrate. Alternatively, one can use an air gap to reduce the effective permittivity of the cavity under the patch [3, 4]. The gain of a patch antenna can also be increased using a parasitic element or a reduced surface-wave antenna [5-7], cavity backed slot antenna [8] and double layer array antenna [9]. All of them compel to increase the antenna height at the same time presence of superstrate above an antenna may adversely affect the antenna’s basic characteristics such as radiation pattern, radiation resistance and efficiency. An electromagnetic band-gap (EBG) structure can also be used to improve the antenna performance. Use of costly substrate like an electromagnetic crystal substrate [10] is also reported. Different kinds of
design techniques like removal of substrate [11] and slotted ground plane [12] are also reported but most of them provide gain of around 5-7 dBi.

This section introduces a new compact hexagonal patch antenna for high gain and multi frequency applications. A defective ground surface (DGS) is used to increase the gain of a conventional hexagonal patch antenna. The proposed DGS hexagonal microstrip patch antenna [13] is simple and different from that reported in [1–10]. Higher gain along with multi-frequency and compactness are achieved by cutting six triangular slots on the ground plane just below the six corners of hexagonal radiating patch. Antenna is circularly polarized and it has the measured peak gain of 7.2 dBi. The antenna shows multi frequency behavior and more than 57% compactness compare to the conventional hexagonal patch antenna. These characteristics suggest that the embedded triangular slots in the ground plane are more effective than the techniques reported in [1–10]. The proposed antenna is prototyped and measured. A good agreement is observed between the simulations and measurements for the antenna’s input impedance ($S_{11}$), gain and radiation pattern performances. The simulations are carried out using a method of moment (MOM) based ANSOFT designer software version 2.2. Experiments are done using standard microwave test bench and vector network analyzer.

5.2.2 Structure of the Novel Antenna Developed

A conventional hexagonal patch antenna “A” is designed as a reference antenna for parametric study purpose. Figure 5.1 shows the geometry of reference hexagonal patch antenna “A” which is printed on a finite unmodified rectangular ground plane of size 60 mm x 50 mm. Now to achieve higher gain along with multi frequency and compactness six triangular slots have been cut on the ground plane, just below the six corners of the hexagonal radiating patch and that leads to the proposed antenna “B”. The configuration of proposed antenna “B” is exactly same with the reference antenna “A” apart from the modified ground plane. Figure 5.2 shows the geometry of proposed high gain antenna “B” with a defective ground surface. Antennas “A” and “B” are printed on a less costly microwave substrate glass-PTFE of thickness $h = 1.6$ mm and relative permittivity $\varepsilon_r = 2.4$. Six (1, 2, 3, 4, 5 and 6) triangular slots having different side lengths are properly placed in the rectangular ground plane just below the six corners of hexagonal patch. Triangular slots 1, 2, 4 and 5 are with same dimensions and triangular slots 3 and 6 are with same dimensions.
The detailed dimensions of the reference and proposed antennas are mentioned in the Table 5.1. These dimensions are finalized after a good number of simulations. The patch
was fed by a 50 Ω coaxial probe of outer diameter 0.5 mm. The feed location was optimized at 35 mm x 30 mm position from the lower left most corner of ground plane to provide good impedance matching. The proposed antenna as well as the reference antenna is prototyped. Photographs of the fabricated proposed antenna are shown in Figure 5.3.

Table 5.1 Specifications of antennas

<table>
<thead>
<tr>
<th>PATCH DIMENSIONS</th>
<th>W₁</th>
<th>W₂</th>
<th>W₃</th>
<th>L₁</th>
<th>L₂</th>
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<tr>
<td></td>
<td>10</td>
<td>10</td>
<td>20</td>
<td>10</td>
<td>15</td>
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<tr>
<td>SLOT DIMENSIONS</td>
<td>d</td>
<td>d₁</td>
<td>d₂</td>
<td>d₃</td>
<td>d₄</td>
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<tr>
<td></td>
<td>6</td>
<td>4.5</td>
<td>4</td>
<td>3</td>
<td>7</td>
</tr>
</tbody>
</table>

*All dimensions are in mm.

Figure 5.3 Photograph of the proposed antenna (a) radiating side and (b) ground side

5.2.3 Results and Discussion

The hexagonal patch antenna “A” serves the purpose of reference antenna of “B” and is used to study the effect of modified ground plane on the antenna performances. Simulated as well as measured $S_{11}$ and peak gain of antenna “A” and “B” are presented. The corresponding simulated and measured results for antenna “A” and “B” are summarized in Table 5.2 for comparative study.
Figure 5.4 shows the plots of simulated and measured input impedance $S_{11}$ for different kinds of antenna structures. Antenna “A” provides a single resonant frequency at 5.2 GHz (simulated) and 5 GHz (measured). In case of antenna “B” an additional resonance occurs at 3 GHz (simulated) but higher operating frequency (5.2 GHz) remains unchanged. This may be due to the capacitive and inductive effects caused by the electromagnetic coupling effects between the patch and slotted ground plane. The measured counterpart for antenna “B” shows three resonant frequencies 2.8 GHz, 3.2 GHz and 5 GHz. It shows that the measured $S_{11}$ validates its simulated counterparts for both of the antennas.

![Figure 5.4 Simulated and measured $S_{11}$ plots. (a) Reference antenna “A” and (b) Proposed antenna “B”](image)

**Table 5.2 Simulated and measured results**

<table>
<thead>
<tr>
<th>Antenna</th>
<th>Resonant Frequency (GHz)</th>
<th>Peak Gain (dBi)</th>
<th>Bandwidth (MHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Simulated</td>
<td>Measured</td>
<td>Simulated</td>
</tr>
<tr>
<td>A</td>
<td>5.2</td>
<td>5</td>
<td>5.1</td>
</tr>
<tr>
<td>B</td>
<td>3.0; 5.2</td>
<td>2.8; 3.2; 5.0</td>
<td>7.06</td>
</tr>
</tbody>
</table>

Figure 5.5 represents the measured $S_{11}$ plot of antennas “A” and “B” for comparative study purpose. The proposed antenna “B” shows multi resonating (2.8, 3.2 and 5 GHz) behavior compare to the single resonant (5 GHz) reference antenna “A”. After
ground plane modification the first resonance frequency of the proposed antenna is at 2.8 GHz. We observe a significant decrease in first resonant frequency from 5 GHz to 2.8 GHz. In order to resonate the reference antenna at 2.8 GHz without ground modification, the size of the antenna will be much more and this provides a size reduction of around 57%.

**Figure 5.5** Measured $S_{11}$ plot for reference antenna “A” and proposed antenna “B”

Figure 5.6 shows the plots of simulated and measured peak gain for different kinds of antenna structures. The maximum peak gain is 5.1 dBi (simulated) at 3.4 GHz and 5 dBi (measured) at 3.2 GHz for antenna “A”. For the proposed antenna “B” the maximum peak gain is 7.06 dBi (simulated) at 3.4 GHz and 7.2 dBi (measured) at 3.2 GHz. The little disagreement between simulated and measured gain may be attributed to the loss of the connectors and the measurement process.

**Figure 5.6** Simulated and measured peak gain plot. (a) Reference antenna “A” and (b) Proposed antenna “B”
Figure 5.7 Measured peak gain plot for reference antenna “A” and proposed antenna “B”

Measured gain of antennas “A” and “B” is presented in Figure 5.7 for comparative study purpose. Over a wide frequency band, gain of the antenna is positive as well as high. From the figure, it is seen that the antennas “A” and “B” have average measured peak gain of 2.74 dBi and 4.51 dBi respectively over the entire frequency band. This study confirms the high gain performance of the proposed antenna. Maximum measured gain for antennas “A” and “B” are 5 dBi and 7.2 dBi respectively. Thus the proposed antenna “B” exhibits enhancement of peak gain by 44% compare to the conventional hexagonal patch antenna “A”. Embedded triangular slots on the ground plane reduce the surface wave excitation resulting in higher gain performance of the proposed antenna.

Figure 5.8 Surface current distributions beneath the patch at the center frequencies 3 GHz and 5.2 GHz
The surface current distributions beneath the patch at the center frequencies 3 GHz and 5.2 GHz are drawn in Figure 5.8. It may be observed that the currents have perpendicular components to the edges of the patch.

Figure 5.9 illustrates the measured and simulated axial ratio (AR) plotted against frequency. It is found that the suitable circular polarized (CP) performances at two bands have been achieved.

![Figure 5.9 Measured and simulated axial ratio](image)

![Figure 5.10 E-plane radiation patterns of the two antennas “A” & “B” measured at 3.2 GHz](image)
Radiation pattern curves with co- and cross-polarization in one principle plane (E-plane); measured at the frequency of 3.2 GHz are shown in the Figure 5.10. The figures show that the maximum radiation occurs in the broad side direction ($\theta = 0^\circ$); the front-to-back ratio of the antenna “B” was the best. Good front to back radiation ratio leads to higher gain of the proposed antenna. The proposed antenna provides a favorable radiation pattern along with the high gain. Here co- result is always 5dB higher than cross result and front to back radiation ratio is greater than 2.

5.2.4 Conclusions

So without any additional layer and costly substrate the proposed antenna successfully achieves higher gain, compare to the corresponding regular hexagonal microstrip patch antenna. Along with the enhanced gain the proposed antenna shows a reasonable compactness as well as multi resonant characteristics. Thus the defective ground plane plays an important role to fulfill all of the desired goals. This is the uniqueness of this design.
5.3 **SQUARE SHAPED HIGH GAIN MICROSTRIP ANTENNA**

5.3.1 **Introduction**

Microstrip antennas are the most common form of printed antennas and are used in a broad range of applications owing to their simplicity, conformal structure and low manufacturing cost. However it has also some major shortcomings, such as narrow impedance bandwidth and low gain, which seriously limit their applications. Many broadband techniques for microstrip antennas have been reported [14, 15]. Several techniques have been previously demonstrated to enhance the gain of patch antenna, including the use of parasitic patch [16, 17], using superstrate layers [2, 18], cavity backed slot antenna [8] and double layer array antenna [9]. All of them compel to increase the antenna height at the same time presence of superstrates above an antenna may adversely affect the antenna’s basic characteristics such as radiation pattern, resistance and efficiency. Use of costly substrate like photonic band gap [19, 20] and electromagnetic crystal substrate [10] are also reported. Different kinds of design techniques like removal of substrate [11] and slotted ground plane [12] are also reported but most of them provide gain around 5-7 dBi. Unfortunately a single layer microstrip-fed slot antenna naturally radiates bi-directionally and has a low gain level. In this article we proposed a new design variety of single layer patch, which is simple and different from that have been discussed so far, but able to achieve higher gain.

This section introduces a new technique for gain enhancement of microstrip antennas. The proposed microstrip antenna [21] consists of a main square shaped radiating patch surrounded by four narrow side patches. The radiating elements are printed on an electrically thin glass PTFE substrate and fed by a co-axial probe. The effects of different side patches on absolute antenna gain are studied. A maximum antenna gain of 7.85 dBi is achieved and the proposed antenna shows 48.39% enhancement of gain compare to the conventional square patch antenna. We have analyzed the proposed high gain microstrip antenna structure theoretically by ASOFT designer version 2.2 software which works on the Method of Moments. The simulated results obtained have been compared with the experimental results. It is interesting to note that the simulated and experimental results are in close agreement.
5.3.2 Structure of the Novel Antenna Developed

The geometry and dimensions of the proposed high gain antenna are shown in Figure 5.11 where all the dimensions are in mm. Since the novelty of this reported article is the simplicity so it is fabricated on planer glass PTFE substrate having dielectric constant ($\varepsilon_r$) = 2.4, thickness (h) = 1.6 mm and loss tangent = 0.00022.

![Diagram of the proposed gain enhanced antenna](image)

**Figure 5.11** Illustration of the proposed gain enhanced antenna

A very small square shaped 20 mm x 20 mm radiating patch is printed on the upper side of the microwave glass PTFE substrate of dimensions 100 mm x 100 mm. The square-shaped radiating patch is surrounded by four narrow side patches “a”, “a’”, “b” and “b’”. The side patches “a” and “a’” are with same dimensions 20 mm x 5 mm, similarly “b” and “b’” are with same dimensions 5 mm x 34 mm. All the side patches are separated from the main square radiating patch by 2 mm. The antenna is fed by co-axial probe at the upper corner of main radiating patch as shown in Figure 5.11.

To study the effects of side patches four kinds of antenna structures have been studied using simulated as well as measured results. All these four kinds of antenna structures have been fabricated and measured to verify the simulated results of different parameters. The antenna with all side patches provides the maximum gain and it is presented as the proposed antenna. Photographs of the four fabricated antennas are depicted in Figure 5.12.
5.3.3 Results and Discussion

A prototype of the proposed antenna i.e. the main radiating patch in presence of all the side patches is fabricated and shown in Figure 5.12 (d). The return loss, gain and radiation pattern of the antennas are measured. In order to understand the effect of side patches we consider three kinds of antenna structures: “A”, “B” and “C” for the parametric study purpose. Type “A” stands for the main square radiating patch in absence of all the side patches [Figure 5.12(a)]. Type “B” means main radiating patch along with the side patches “a” and “a’” only [Figure 5.12(b)]. Antenna “C” is the main radiating patch along with the side patches “b” and “b’” only [Figure 5.12(c)].

Figure 5.13 shows the plot of simulated and measured return loss for different kinds of antenna structures. It shows that depending on the side patches resonant frequency and return loss is varying. Measured return loss validates its simulated counterparts for all four antennas.
Figure 5.13 Plots of simulated and measured return loss for different antenna structures

Table 5.3 Simulated and measured results

<table>
<thead>
<tr>
<th>Antenna</th>
<th>Resonant frequency (GHz)</th>
<th>Gain (dBi)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Simulated</td>
<td>Measured</td>
</tr>
<tr>
<td>Type- “A”</td>
<td>4.6</td>
<td>4.8</td>
</tr>
<tr>
<td>Type- “B”</td>
<td>4.8</td>
<td>4.8</td>
</tr>
<tr>
<td>Type- “C”</td>
<td>4.5</td>
<td>4.5</td>
</tr>
<tr>
<td>Proposed Antenna</td>
<td>4.8</td>
<td>4.6</td>
</tr>
</tbody>
</table>
Figure 5.14 shows the plot of simulated and measured gain for different kinds of antenna structures. Antenna gain is varying from 5.49 dBi to 7.39 dBi (simulated) and 5.29 dBi to 7.85 dBi (measured). Measured gain confirms its simulated counterparts. Antennas “A”, “B” and “C” are studied with the help of their simulated as well as measured results to understand the effects of side patches on absolute gain and performances of the antenna. The results of parametric study carried out are presented in Table 5.3.

![Figure 5.14 Plots of simulated and measured gain for different antenna structures](image)

Figure 5.14 presents the measured return loss plot of all four antennas for comparative study purpose. The proposed antenna provides maximum bandwidth of around 350 MHz (4.41-4.76 GHz). Measured impedance bandwidth of antennas “A”, “B” and “C” are 250 MHz (4.65-4.90 GHz), 150 MHz (4.71-4.86 GHz) and 200 MHz (4.42-4.62 GHz) respectively. In all cases the impedance bandwidth is defined for return loss ≤ -10dB.
Figure 5.15 Measured return loss plot of antennas “A”, “B”, “C” and the proposed antenna for comparative study purpose

Measured gains of all four antennas are presented in Figure 5.16 for comparative study purpose. Antenna gains are varying from 5.29 dBi to 7.85 dBi. One more thing to observe is that over a wide frequency band gain of the antenna are positive as well as high. Presence of all side patches provides the maximum gain of 7.85 dBi. The proposed antenna exhibits enhancement of gain by 48.39% compare to the conventional square patch antenna “A”. Maximum measured gain for antennas “A”, “B” and “C” are 5.29 dBi, 6.61 dBi and 6.7 dBi respectively.

Figure 5.16 Measured gain plot of antennas “A”, “B”, “C” and the proposed antenna for comparative study purpose
Figure 5.17 shows the measured radiation patterns including the co-polarization and cross polarization in two principle planes namely, the E-plane (y-z plane) and H-plane (x-z). It can be seen that the radiation patterns in both planes are nearly directional for the resonant frequency at 4.6 GHz. More significantly the radiation patterns in both planes are with low cross-polarization values and there are no such back lobe portions. The proposed antenna provides a favorable radiation pattern along with the high gain. It can be noted that the little disagreement between measured and simulated results may be due to the fabrication tolerances, loss of the connectors or the measurement process.

![Figure 5.17](image.png)

**Figure 5.17** Measured radiation patterns of the proposed antenna at 4.6 GHz. (a) E-plane and (b) H-plane

### 5.3.4 Conclusions

A coaxial probe fed square shaped patch antenna with enhanced gain is presented. The presence of side patches appears as critical parameters. Without any additional layers and costly substrate the proposed antenna successfully achieves higher gain. By using the side patches surrounding the main square patch, the gain of conventional square patch antenna can be enhanced by more than 48.39%. Also, these results suggest that planar antenna structure may offer new design opportunities for higher gain applications of microstrip patch antenna.
5.4 REFERENCES


