ABSTRACT

OF THE THESIS
ENTITLED

SOME STUDIES ON ENHANCEMENT OF BANDWIDTH AND GAIN OF A MICROSTRIP ANTENNA BY MODIFYING RADIATING & GROUND PLANE

For the Degree of
DOCTOR OF PHILOSOPHY (ENGINEERING)
UNDER THE FACULTY OF ENGINEERING, TECHNOLOGY & MANAGEMENT

Submitted by
Kaushik Mandal

UNDER THE SUPERVISION OF
Dr. Partha Pratim Sarkar
D.E.T.S, KALYANI UNIVERSITY

DEPARTMENT OF ENGINEERING & TECHNOLOGICAL STUDIES
KALYANI UNIVERSITY
KALYANI
NADIA, WEST BENGAL
INDIA

2014
Microstrip patch antenna elements are the most common form of printed antennas. They are popular for their low profile and low cost. A microstrip device in its simplest form is a layered structure with two parallel conducting planes separated by a thin dielectric substrate as shown in Figure 1. The metallic patch is generally fabricated using a photolithographic process and mounted on a dielectric substrate of thickness \( h \) much smaller than the free space wavelength \( h \ll \lambda_0 \), usually \( 0.003\lambda_0 \leq h \leq 0.05\lambda_0 \), with relative permittivity \( \varepsilon_r \) and permeability \( \mu_r \) with a metallic ground plane underneath.

The metallic patch is normally made of thin copper foil or is copper-foil-plated with a corrosion resistive metal, such as gold, tin, or nickel. Each patch can be designed with a variety of shapes with the most popular shapes being rectangular or circular. For a rectangular patch, the length \( L \) of the patch is usually \( 0.3333\lambda_0 < L < 0.5\lambda_0 \). The patch is selected to be very thin such that \( t \ll \lambda_0 \) (where \( t \) is the patch thickness).

Microstrip patch antennas radiate primarily because of the fringing fields between the patch edge and the ground plane. For good antenna performance, a thick dielectric substrate having a low dielectric constant is desirable since this provides larger bandwidth and better radiation. However, such a configuration affects the antenna efficiency and leads to a larger antenna size. A main challenge of microstrip antenna design includes its commercialization that requires wide bandwidth and high gain along with compactness and low cost. Over last two decades researchers and scientists have developed several methods to increase the bandwidth and gain of patch antenna. Some of the well established methods for bandwidth enhancement, gain enhancement and size reduction have been highlighted.

The bandwidth of microstrip antenna increases with an increase in the substrate thickness \( h \) or with a decrease in the dielectric constant \( \varepsilon_r \). However, there is a practical limit on increasing the \( h \), and if increased beyond \( 0.1\lambda_0 \), surface-wave propagation takes place, resulting in degradation in antenna performance. Also, with an increase in \( h \), the probe inductance
increases and probe compensation techniques have to be employed to obtain impedance matching. Using both directly coupled and gap-coupled coplanar microstrip resonators [1, 2] a maximum bandwidth reported is about 25.8%. However in this process antenna size increases. Using stacked configuration, thick air or foam [3, 4] as dielectric a maximum bandwidth reported is about 67.5%. In these process overall height of the antenna increases that restricts its use in some applications. Microstrip antennas using different shaped slot, slit and patch have been reported in [5, 6]. The antennas become more compact and a maximum bandwidth demanded there is about 31%.

Along with wide band, gain of microstrip antenna is another important parameter for wireless applications. In this section, some recently reported gain enhancement techniques have been reviewed. Using air gap under the patch [7] a maximum gain reported is about 6.5dBi but overall height of the antenna increases. Using electromagnetic band gap (EBG) substrate [8, 9] a maximum gain reported is about 9.33dBi. Use of EBG substrate makes the antenna more costly. Using double-layer microstrip array [10] a maximum gain reported is about 19.5dBi but overall size of the antenna increases.

Compactness of the microstrip antenna is another important parameter to make it suitable for portable wireless devices. Some recently reported miniaturization techniques have been discussed. Inserting slots and slits [11, 12] overall antenna size reduction is about 75% and also provides multi-frequency operation. Using Koch and Sierpinski fractal-shapes [13, 14] the antenna performance has been enhanced in terms of size, gain and multi-frequency behavior. These designs provide a maximum antenna size reduction of about 77.1%. Another very effective size reduction method is the use of shorting post. The design [15] using shorting post technique provides a size reduction of around 75%.

The goal of this dissertation is to design better performed antennas

- That should be simpler in structure
- That should provide better bandwidth
- That should provide better gain
- That should provide more stable radiation pattern
- That should be more compact
To fulfill these goals, bandwidth enhancement techniques like use of gap coupled configuration, use of inverted U-shape patch, U-shape patch and defected ground surface (DGS) have been proposed. Some enhanced gain microstrip antennas have been designed using DGS and narrow parasitic patches. Slot loading technique has been used to design a reduced size i.e. compact microstrip patch antenna along with dual-frequency operation. Single layer thin substrate with co-axial feed mode is used for all proposed designs. All these investigations have been performed both theoretically and experimentally. Theoretical investigations are carried out with the method of moment (MOM) based ANSOFT designer software. Realized antennas are experimented using Vector Network Analyzer and standard microwave test bench.

This dissertation has been distributed over seven chapters as follows.

Chapter one describes the introduction to subject matter, basic features and applications of microstrip patch antenna. Several recently published related literatures have been surveyed and discussed. Motivation, objective of this dissertation and thesis outlines have also been given in this chapter.

The second chapter presents the basic theory of the microstrip patch antennas i.e. radiation mechanism and feeding techniques. Then the different methods of analyses used for the microstrip patch antenna design and different characteristics of microstrip patch antenna have been discussed.

The third chapter mainly deals with the design of a wideband microstrip patch antenna using staggering effect. A novel single layer wide band microstrip patch antenna with three rectangular patches of different sizes has been proposed. Three patches are gap-coupled by their radiating edges and leads to enhancement of bandwidth.

In chapter four the radiating and ground plane are modified to design wideband microstrip patch antennas. A novel single layer wideband microstrip patch antenna with an inverted U-shape slot on a rectangular patch has been proposed. Another wideband antenna with U-shape patch and inverted U-slotted ground plane has been also designed.

In chapter five the radiating and ground plane are modified to design high gain microstrip patch antennas. A compact single layer high gain hexagonal patch antenna with slotted ground plane has been proposed. Another high gain antenna with a square patch surrounded by patch strips has been also designed.
The sixth chapter presents a compact microstrip patch antenna developed by introducing slits on rectangular microstrip patch so as to operate mainly in L & S bands.

Chapter seven includes the conclusive remarks on the present dissertation. The accomplishments and the limitations are mentioned. Potentials for further research are also discussed.

A single layer, microstrip patch antenna [16] with three different rectangular patches with slightly different dimensions on a glass PTFE substrate with \( h = 1.6 \text{ mm} \) and \( \varepsilon_r = 2.4 \) is proposed. Structure of the antenna is shown in Figure 2. The dimensions are \( W_1 = 38 \text{ mm, } L_1 = 46 \text{ mm; } W_2 = 33 \text{ mm, } L_2 = 40 \text{ mm and } W_3 = 29 \text{ mm, } L_3 = 35 \text{ mm} \). The antenna is fed using a 50\( \Omega \) coaxial probe at \( \frac{W_2}{2} \times \frac{L_2}{2} \) to provide good impedance matching.

Spacing between two patch is \( W_s = 2 \text{ mm} \) and difference in length are \( L_{s1} = 3 \text{ mm} \) and \( L_{s2} = 2.5 \text{ mm} \). The proposed antenna is prototyped on a finite ground plane of dimensions 150 mm x 116 mm.

The staggering effect between three patches provides a wide bandwidth of 1.33 GHz (4.30-5.63 GHz) i.e. 27%. The proposed antenna provides a stable radiation pattern along with average peak gain of 2.97 dBi and maximum peak gain for the antenna is 5.72 dBi at 5.5 GHz.

![Figure 2 Geometry of the proposed gap coupled microstrip patch antenna](image)

Single layer wideband microstrip patch antenna with an inverted U-shape slot on a rectangular patch is designed and shown in the Figure 3. A rectangular patch of dimension 21mm X 22 mm is printed on one side of FR4_epoxy substrate with \( h = 1.6 \text{ mm} \) and dielectric constant \( \varepsilon_r = 4.4 \). On the other side of the substrate a finite ground plane of dimension (50mm X 60mm) is printed. An inverted U-shaped slot with symmetrical arm length is inserted close to the radiating edge of the rectangular patch. Detailed dimensions are as follows.
Another wideband and high gain U-shape patch antenna [18] is proposed with circular shape as well as with square shape ground plane.

The proposed design [17] exhibits a wider bandwidth of 2.37 GHz (5.93 – 8.30 GHz) with a percentage B.W of 33.31% along with a stable radiation pattern. Three resonant frequencies 6.23 GHz, 6.80 GHz and 7.91 GHz unify to provide a wide bandwidth. So after insertion of slot the bandwidth has been enhanced.

<table>
<thead>
<tr>
<th>W</th>
<th>W_1</th>
<th>W_2</th>
<th>W_3</th>
<th>W_4</th>
<th>L_1</th>
<th>L_2</th>
<th>L_3</th>
<th>L_4</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>9</td>
<td>5</td>
<td>2.8</td>
<td>7.3</td>
<td>6</td>
<td>4</td>
<td>4.9</td>
<td>6.3</td>
</tr>
</tbody>
</table>

Another wideband and high gain U-shape patch antenna [18] is proposed with circular shape as well as with square shape ground plane.
Four U-shape patch antennas ("A", "B", "C" and "D") on modified circular shaped ground plane and two U-shape patch antennas ("E" and "F") on modified square shape ground plane are investigated. The dimensions of different parameters for all these six antennas are given in Table 1.

**Table 1** Specifications of proposed antenna

<table>
<thead>
<tr>
<th>GROUND PLANE’S SHAPE</th>
<th>ANTENNA- A</th>
<th>ANTENNA- B</th>
<th>ANTENNA- C</th>
<th>ANTENNA- D</th>
<th>ANTENNA- E</th>
<th>ANTENNA- F</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>D or L</strong></td>
<td>32</td>
<td>36</td>
<td>40</td>
<td>36</td>
<td>32</td>
<td>36</td>
</tr>
<tr>
<td><strong>S</strong></td>
<td>6</td>
<td>8</td>
<td>10</td>
<td>8</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td><strong>L_p</strong></td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td><strong>d_p</strong></td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>7</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td><strong>G_p</strong></td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>6</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td><strong>Δ_p</strong></td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td><strong>L_s</strong></td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td><strong>d_s</strong></td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>7</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td><strong>G_s</strong></td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>6</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td><strong>Δ_s</strong></td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>3</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

*All the parameters are in mm.

Effects of different parameters like shape and size of the ground plane and effect of patch width (d_p) and slot width (d_s) have been studied. Impedance bandwidth is varying inversely with variation of size of ground plane. Antenna with circular ground plane provides more impedance bandwidth compare to same sized square ground plane antenna. Antenna “D” among circular ground plane antennas and antenna “E” among square ground plane antennas provides better bandwidth. Antenna “D” provides a maximum bandwidth of 86.79% (4.5-11.4 GHz) and maximum peak gain of 4.1 dBi along with stable radiation pattern. Antenna “E” provides a maximum bandwidth of 75.94% (4.9-10.9 GHz) and maximum peak gain of 2.39 dBi. So the proposed design on a thin substrate and without using any air gap or foam exhibits wideband and high gain performance.
Higher gain along with multi frequency and compactness is achieved by modifying a conventional hexagonal patch antenna as shown in Figure 5.

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 high gain compact antenna [19].

**Figure 5** Geometry of the proposed gain enhanced hexagonal antenna

Due to defective ground surface (DGS) the proposed antenna shows multi resonating behavior at 2.8 GHz, 3.2GHz and 5.0 GHz. After ground plane modification the first resonance frequency decreases from 5 GHz to 2.8 GHz. This provides a reasonable size reduction of around 57%, average measured peak gain of 4.51 dBi and maximum gain of 7.2 dBi. So it exhibits enhancement of peak gain by 44% compare to the conventional hexagonal patch antenna.

A very simple square shape (20 mm x 20 mm) radiating patch is surrounded by four narrow parasitic patches as shown in Figure 6. All the side patches are separated from the main square radiating patch by 2 mm. A thin glass PTFE substrate is used for the design [20] purpose.

In order to understand the effect of side patches three kinds of antenna structures have been considered, studied and summarized. The proposed antenna provides maximum bandwidth of around 350 MHz (4.41-4.76 GHz) and maximum peak gain of 7.85 dBi along with a favorable radiation pattern.

**Figure 6** Illustration of the proposed gain enhanced antenna
A novel compact single probe-feed rectangular microstrip patch antenna [21] for operation in dual frequency band is investigated. Finger like slits are inserted on the radiating edges of the patch as shown in Figure 7.

The proposed antenna resonates at two different frequencies of 3.0 GHz and 5.4 GHz compared to the single resonating (4.3 GHz) reference antenna and provides a size reduction of around 73.07%. First frequency band 3.05 to 3.15 GHz and second frequency band 5.37 to 5.5 GHz produced by the proposed antenna, are within Wi-MAX (3.1 to 3.6 GHz) and WLAN (4.9 to 5.9 GHz) bands respectively.

Figure 7 Geometry of the proposed antenna
REFERENCES


[NOTE: References 16 to 21 are our own publications]