INVESTIGATIONS ON MICROSTRIP ANTENNAS FOR SIZE REDUCTION, ENHANCEMENT OF BANDWIDTH AND TO OPERATE AT MULTI-FREQUENCIES

ABSTRACT OF THE THESIS SUBMITTED BY

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of

DOCTOR OF PHILOSOPHY (ENGINEERING)

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• **INTRODUCTION**

Conventional microstrip antennas in general have a conducting patch printed on a grounded microwave substrate, and have the attractive features of low profile, light weight, easy fabrication, and conformability to mounting hosts. For achieving microstrip antennas with a reduced size at a fixed operating frequency, the use of a high permittivity substrate is an effective method; Recently, it has been demonstrated that loading the microstrip patch with a shorting pin can very effectively reduce the required patch size for a fixed operating frequency [1]. There are numerous substrates that can be used for the design of microstrip antennas, and their dielectric constants are usually in the range of $2.2 \leq \varepsilon_r \leq 12$ [2-4]. Thick substrates whose dielectric constants are in the lower end of the range provide better efficiency, larger bandwidth, loosely bound fields for radiation into space, but only disadvantage of larger element size. Linear and circular polarizations can be achieved with either single elements or arrays of microstrip antennas. Arrays of microstrip elements, with single or multiple feeds may also be used to introduce scanning capabilities and to achieve greater directivities [5]. In recent years demand for small antennas on wireless communication has increased interest in compact microstrip antenna design among microwaves and wireless engineers [6-7]. To meet up high mobility for a wireless telecommunication device, a small and light weight antenna is likely to be preferred. Other than slotted antenna there are antennas like DRA (Dielectric Resonator Antenna), Fractal Antenna etc. which are also used to reduce the size of the antenna. Fractal antennas are difficult to design and DRA requires high dielectric constant substrates which are not readily available [8-13].

In the last 15-20 years research on compact microstrip antenna has progressed considerably. Some works based on microstrip antenna are discussed below:

- Lotfollah L. Shafai, Walid A. Chamma, Mohamed Barakat, Peter C. Strickland, and Guy Seguin investigated Dual-Band Dual-Polarized Perforated Microstrip Antennas for SAR Applications in the year 2000. For dual-band dual-polarized synthetic aperture radar (SAR) applications a compact low-profile design is investigated by the authors [14]. Stacked-patch configurations were used to meet up the bandwidth requirements, especially in the L-band [14].

- Sean C. Ortiz, Tony Ivanov, and Amir Mortazawi designed Quasi-Optical Amplifier Array with the help of CPW-Fed Microstrip Patch in the year 2000. A quasi-optical power-combining amplifier array based on coplanar waveguide (CPW)-fed microstrip patch antennas was designed by them. Both the transmit and receive antennas employ CPW-fed patches. [15].

- In the year 2007, R. Nilavalan, I.J. Craddock, A. Preece, J. Leendertz and R. Benjamin designed wideband microstrip patch antenna for breast cancer tumour detection. A patch antenna is presented which has been designed to radiate frequencies in the range 4–9.5 GHz into human breast tissue. The antenna is shown by means of previously unpublished simulation and practical measurements to possess a wide input bandwidth, radiation patterns that remain largely consistent over the band of interest and a good front-to-back ratio [16].

- In the year 2010, David Gibbins, Maciej Klemm, Ian J. Craddock, Jack A. Leendertz, Alan Preece, and Ralph Benjamin discussed a comparison of a wide-slot and a stacked patch antenna for the purpose of breast cancer detection. A wide-slot UWB antenna is presented for intended use in the detection scheme being developed at the University of Bristol, based on the principle of synthetically focused UWB radar using a fully populated static array [17].

- Other than above list there are so many works to motivate myself to work in the above field [18-38].
Investigations on Microstrip Antennas for Size Reduction, Enhancement of Bandwidth and to operate at Multi-Frequencies

- **Microstrip Antenna**

In its most basic form, a Microstrip patch antenna consists of a radiating patch on one side of a dielectric substrate which has a ground plane on the other side as shown in Figure 1. The patch is generally made of conducting material such as copper or gold and can take any possible shape. The radiating patch and the feed lines are usually photo etched on the dielectric substrate [2]. In order to simplify analysis and performance prediction, the patch is generally square, rectangular, circular, triangular, and elliptical or some other common shapes as shown in Figure 2.

For a rectangular patch, [3]

| Length (L) | 0.3333λ₀ < L < 0.5λ₀ |
| Height (h) | 0.003λ₀ ≤ h ≤ 0.05λ₀ |
| Thickness (t) | t << λ₀ |
| Dielectric constant (ε₉) | 2.2 ≤ εₓ ≤ 12 |

Where λ₀ is the free-space wavelength.

- **Advantages and Disadvantages**

Microstrip patch antennas are increasing in popularity for use in wireless applications due to their low-profile structure. Some of their principal advantages discussed by Kumar and Ray are given below [39]:

- Light weight and low volume, Low fabrication cost, hence can be manufactured in large quantities.
- Supports both, linear as well as circular polarization.
- Can be easily integrated with microwave integrated circuits (MICs).
- Capable of dual and triple frequency operations.

Microstrip patch antennas suffer from a number of disadvantages as compared to conventional antennas. Some of their major disadvantages discussed by Garg et al [40] are given below:

- Narrow bandwidth, Low efficiency and Low Gain
- Low power handling capacity and Surface wave excitation

- The objective of my work is to obtain small size, broadband & multiple resonance frequency by patch antennas. This has been achieved by cutting various types of slots are cut at the top as well as bottom layer. These various types of microstrip antennas are designed with the help of IE3D [50], software based on Method-of-Moment (MoM). Experimental investigations are done by using standard microwave test bench i.e. VNA (Vector Network Analyzer). The presentation of my thesis listed below:

  - **The first chapter** includes the introduction of microstrip antenna with dielectric substrate of PTFE (Polytetrafluoroethylene) and brief description of several previous works related to microstrip antenna operating at multi frequency band, reduced size and enhanced bandwidth.
  - **The second chapter** includes the process of size reduction i.e. how the size of conventional antenna is reduced by cutting slots. The brief idea about absolute gain, directivity and beam-width are also included in this section.
  - Compact Microstrip Antenna which was designed for the application of mobile communication is described in **the third chapter**. It will include the details regarding this antenna with a return loss and VSWR (Voltage Standing Wave Ratio) pattern [42].
Fourth chapter includes the design of printed patch antenna which are applicable for the microwave communication especially S-Band microwave frequency range. This section also includes the co-polarization and cross-polarization radiation patterns [43].

Design and analysis of a new UWB (Ultra Wide-Band) antenna is described in fifth chapter. In this chapter we describe the process of bandwidth enhancement and detailed observations which are obtained from the simulated results. This chapter includes a new observation i.e. the 3D view of E-Plane and H-Plane radiation pattern for the above mentioned antenna [44].

Different types of compact patch antenna and printed patch antenna which are applicable for the W-LAN communication, H-LAN Communication, different microwave frequency band communication especially for C-Band microwave frequency communication are discussed in the sixth chapter. All of the details regarding these antennas are discussed with the help of simulated data and measured data. [45-48].

The seventh chapter includes the design of printed patch antenna which is applicable for the satellite communication. In this section, we also describe the absolute gain and beam-width for the above mentioned antenna [49].

The eighth chapter concludes my thesis work. This section includes the detailed overall conclusion of the previous chapter.

Now, I describe some of my works which are related to my thesis discussed below:

1. **Compact Microstrip Antenna for mobile communication [42]:**

   A single layer, single feed compact rectangular microstrip antenna is proposed (Fig. 4). Resonant frequency has been reduced drastically by cutting unequal rectangular slots at the edge of the patch. Two rectangular slots are introduced at the left and right side of the patch to reduce the resonant frequency. The antenna size has been reduced by 73.9% when compared to a conventional rectangular microstrip patch antenna. The configuration of the conventional printed antenna is shown in Figure 3 with L=24 mm, W=30 mm. Figure 4 shows the configuration of proposed antenna designed with similar PTFE substrate. All the results are summarized in Table I and Table II.
2. Compact Microstrip Patch Antenna for Microwave Communication [43]:

A single layer, single feed compact rectangular microstrip antenna is proposed & resonant frequency has been reduced drastically by cutting three unequal rectangular slots at the edge of the patch. Antenna size has been reduced by 47.4% with an increased frequency ratio when compared to a conventional square microstrip patch antenna. The configuration of the conventional printed antenna is shown in Fig. 8 with $L=20$ mm, $W=20$ mm, Poly tetra fluro ethylene (PTFE) substrate thickness $h = 1.5875$ mm, dielectric constant $\varepsilon_r = 4.4$. Figure 9 shows the configuration of proposed antenna designed with similar PTFE substrate. The 3dB beam-width of the radiation pattern is $152.3^\circ$ which is sufficiently broad beam for the applications for which it is intended. All the results are summarized in Table III and Table IV.
3. Comparison Between Two CPW-FED UWB Antennas Based on Dielectric Constant of Substrate [44]:

Design and analysis of two compact coplanar waveguide (CPW) fed Ultra Wideband (UWB) slot antenna is presented in this work. The antenna consists of a Y-shaped slot. The CPW feed is designed for 50Ω impedance. The characteristics of the designed structure are investigated by using MoM based electromagnetic solver, IE3D [50]. An extensive analysis of the proposed antenna is presented. The simulation of the proposed antenna was fabricated with FR4 substrate. A better impedance bandwidth is obtained from 2.85 GHz to 5 GHz that constitutes a fractional bandwidth of 58% with return loss of about -10 dB in proposed antenna is greater than the impedance bandwidth which is obtained from 7.70 GHz to 12 GHz that constitutes a fractional bandwidth of 49% with return loss of about -10 dB in reference antenna [41]. Also the proposed antenna have a return loss of about -27.75 at 8.51 GHz and obtained a impedance bandwidth from 9.9 GHz to 11.5 GHz that constitutes a fractional bandwidth of 14.73% with return loss of about -10 dB. The simple configuration and low profile nature of the proposed antenna leads to easy fabrication that may be built for any wireless UWB device applications. All the results are summarized in Table V.

### Table -III

<table>
<thead>
<tr>
<th>Antenna structure</th>
<th>Resonant freq. (GHz)</th>
<th>Freq. ratio</th>
<th>3 DB beamwidth (°)</th>
<th>Absolute gain (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>f₁= 3.41</td>
<td>171.06</td>
<td>5.43</td>
<td></td>
</tr>
<tr>
<td></td>
<td>f₂= 6.77</td>
<td>170.40</td>
<td>3.23</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>f₁= 2.95</td>
<td>152.3</td>
<td>4.79</td>
<td></td>
</tr>
<tr>
<td></td>
<td>f₂= 3.48</td>
<td>156.9</td>
<td>5.44</td>
<td></td>
</tr>
<tr>
<td></td>
<td>f₃= 6.68</td>
<td>171.2</td>
<td>4.09</td>
<td></td>
</tr>
</tbody>
</table>

### Table -IV

<table>
<thead>
<tr>
<th>Antenna structure</th>
<th>Resonant freq. (GHz)</th>
<th>Return loss (dB)</th>
<th>10 DB bandwidth (MHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>f₁= 3.41</td>
<td>-17.7</td>
<td>53.7</td>
</tr>
<tr>
<td></td>
<td>f₂= 6.77</td>
<td>-21.7</td>
<td>202.1</td>
</tr>
<tr>
<td>2</td>
<td>f₁= 2.95</td>
<td>-15.02</td>
<td>18.14</td>
</tr>
<tr>
<td></td>
<td>f₂= 3.48</td>
<td>-18.13</td>
<td>56.72</td>
</tr>
<tr>
<td></td>
<td>f₃= 6.68</td>
<td>-11.04</td>
<td>57.9</td>
</tr>
</tbody>
</table>

**Figure 13: Reference Antenna Structure**

**Figure 14: Proposed Antenna Structure**

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**Table V**
4. **Compact Microstrip Antenna for WLAN and H-LAN communication [46]:**

A single layer, single feed compact rectangular antenna is proposed in this work. Resonant frequency has been reduced drastically by cutting unequal rectangular slots at the edge of the patch & a circle in the middle. The width of the rectangular slots is different to improve the gain bandwidth performance of the antenna. The antenna size has been reduced by 41.8% when compared to a conventional rectangular microstrip patch antenna with a maximum of 24.9 MHz bandwidth at –16.3 dB return loss at 3.41 GHz. The characteristics of the designed structure are investigated by using MoM based electromagnetic solver, IE3D [50]. All the results are summarized in Table VI and Table VII.

<table>
<thead>
<tr>
<th>ANTENNA STRUCTURE</th>
<th>RESONANT FREQUENCY</th>
<th>RETURN LOSS (dB)</th>
<th>10 dB BANDWIDTH (MHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>STARTING FREQ</td>
<td>ENDING FREQ</td>
<td>CENTRE FREQ</td>
</tr>
<tr>
<td>REFERENCE</td>
<td>5.70</td>
<td>12</td>
<td>8.79</td>
</tr>
<tr>
<td>PROPOSED</td>
<td>2.85</td>
<td>5</td>
<td>3.71</td>
</tr>
<tr>
<td></td>
<td>8.51</td>
<td>11.5</td>
<td>10.86</td>
</tr>
</tbody>
</table>

| **Figure 18: Conventional Antenna Structure** |
| **Figure 19: Proposed Antenna Structure** |

![Conventional Antenna Return Loss](image1)

**Conventional Antenna Return Loss**

![Proposed Antenna Return Loss](image2)

**Proposed Antenna Return Loss**

![2D E-plane radiation Pattern at 3.41 GHz](image3)

**2D E-plane radiation Pattern at 3.41 GHz**
5. **A Printed Patch Antenna for Mobile Communication [48]**

The work to be presented in this chapter is also a compact single layer, single feed printed antenna obtained by cutting unequal rectangular slots at the edge of the patch which gave a resonant frequency much lower than the resonant frequency of the conventional printed antenna with the same patch area. Antenna size has been reduced by 73.15% with an increased frequency ratio. All the results are summarized in Table VIII and Table IX.

<table>
<thead>
<tr>
<th>Table –VI</th>
<th>Table-VII</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Antenna Structure</strong></td>
<td><strong>Resonant Frequency (GHz)</strong></td>
</tr>
<tr>
<td>Conventional</td>
<td>f₁ = 4.17</td>
</tr>
<tr>
<td>Proposed</td>
<td>f₁ = 3.41</td>
</tr>
<tr>
<td></td>
<td>f₂ = 7.87</td>
</tr>
</tbody>
</table>

**Figure 23: Conventional Antenna Structure**

**Figure 24: Proposed Antenna Structure**

**Figure 25: Conventional Antenna Return Loss**

**Figure 26: Proposed Antenna Return Loss**

**Figure 27: 2D E-plane radiation Pattern at 3.07 GHz**
6. Compact Microstrip Antenna for C-Band Microwave Communication [47]:
Design and analysis of a single layer, dual feed rectangular patch antenna is presented in this work. The work to be presented here is also a printed antenna obtained by adding two similar patches on the same ground plane which gave a resonant frequency in the microwave frequency range when any one port of any patch is active and other act as a parasitic element. But when both the port is active then the proposed antenna works as a UWB Antenna (Band-Width of about 10 GHz). This proposed antenna is also applicable for satellite communications, radar, terrestrial broadband, space communications, and amateur radio. All the results are summarized in Table X and Table XI.
7. Bevel Microstrip Printed Antenna for Satellite Communication [49]:
A single feed, single layer compact bevel cut rectangular patch antenna rectangular antenna is proposed. The bevels are cut at the left-top corner and the right-bottom corner. The 1st resonant frequency (4.25 GHz) is applicable for short band radio wave communication and the other resonant frequency (6.93 GHz) is applicable for radar communication. We got ideas to design our proposed antenna from [51] which is shown in Figure 33. We are modified the structure to achieve a good return loss for our proposed antenna. The reference antenna is applicable for GPS application at 1575 MHz whereas the proposed antenna is applicable for satellite communication at 4.25 GHz. We modified the structure based on slot cutting, in reference antenna two bevels are cut at the left-bottom & right-top corner [Figure 33] whereas in proposed antenna bevels are cut at the left-top & right-bottom corner [Figure 32]. All the results are simulated by using IE3D [50], a MoM based software and the results are verified by the VNA network analyzer. Two bevels are cut at the left-top and right bottom corner whose dimensions and the location of coaxial probe-feed (radius=0.8 mm) are shown in the figure 32. All the results are summarized in Table XII and Table XIII.

**Figure 32: Proposed Antenna Structure**

**Figure 33: Reference Antenna Structure**

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**Table – X**

<table>
<thead>
<tr>
<th>ANTENNA STRUCTURE</th>
<th>Resonant Frequency (GHz)</th>
<th>Return Loss (dB)</th>
<th>-10 dB Bandwidth (MHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proposed (When only one port is active)</td>
<td>( f_1 = 4.15 )</td>
<td>-22.03</td>
<td>93.84</td>
</tr>
<tr>
<td></td>
<td>( f_2 = 4.81 )</td>
<td>-23.68</td>
<td>130.83</td>
</tr>
<tr>
<td></td>
<td>( f_3 = 6.47 )</td>
<td>-15.28</td>
<td>107.72</td>
</tr>
<tr>
<td></td>
<td>( f_4 = 9.64 )</td>
<td>-14.54</td>
<td>98.30</td>
</tr>
</tbody>
</table>

| Proposed (When both ports are active) | 10 GHz |

**Table- XI**

<table>
<thead>
<tr>
<th>Antenna Structure</th>
<th>Resonant Frequency (GHz)</th>
<th>Freq. Ratio</th>
<th>3-dB beam width (°)</th>
<th>Absolute Gain (dBi)</th>
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</thead>
<tbody>
<tr>
<td>Proposed (When only one port is active)</td>
<td>( f_1 = 4.15 )</td>
<td>( f_2 = 4.81 )</td>
<td>( f_3 = 2.41 )</td>
<td></td>
</tr>
<tr>
<td></td>
<td>( f_4 = 6.47 )</td>
<td>( f_5 = 2.81 )</td>
<td>( f_6 = 9.64 )</td>
<td></td>
</tr>
<tr>
<td></td>
<td>( f_7 = 7.20 )</td>
<td>( f_8 = 4.04 )</td>
<td>( f_9 = 6.93 )</td>
<td></td>
</tr>
</tbody>
</table>

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*Fig. 33: Proposed Antenna Return Loss  Fig. 34: Proposed Antenna VSWR Pattern  Fig. 35: 2D E-plane radiation Pattern at 4.25 GHz*
Investigations on Microstrip Antennas for Size Reduction, Enhancement of Bandwidth and to operate at Multi-Frequencies

<table>
<thead>
<tr>
<th>Table – XII</th>
<th>Table- XIII</th>
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<td><strong>ANTENA</strong></td>
<td><strong>ANTENA</strong></td>
</tr>
<tr>
<td>RESONANT</td>
<td>RESONANT</td>
</tr>
<tr>
<td>FREQ.</td>
<td>FREQUENCY</td>
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<tr>
<td>FREQ.(GHz)</td>
<td>(GHz)</td>
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<tr>
<td><strong>STRUCTURE</strong></td>
<td><strong>STRUCTURE</strong></td>
</tr>
<tr>
<td>FREQ.</td>
<td>FREQ.</td>
</tr>
<tr>
<td><strong>FREQ.</strong></td>
<td><strong>FREQ.</strong></td>
</tr>
<tr>
<td>RATIO</td>
<td>RATIO</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>BEAM</strong></td>
<td><strong>BEAM</strong></td>
</tr>
<tr>
<td>WIDTH</td>
<td>WIDTH</td>
</tr>
<tr>
<td>(%)</td>
<td>(%)</td>
</tr>
<tr>
<td><strong>LUTE</strong></td>
<td><strong>LUTE</strong></td>
</tr>
<tr>
<td>GAIN</td>
<td>GAIN</td>
</tr>
<tr>
<td>(DB)</td>
<td>(DB)</td>
</tr>
<tr>
<td><strong>10 DB</strong></td>
<td><strong>RETURN</strong></td>
</tr>
<tr>
<td>BANDWIDTH</td>
<td>BANDWIDTH</td>
</tr>
<tr>
<td>(MHZ)</td>
<td>(MHz)</td>
</tr>
<tr>
<td><strong>PROPOSED</strong></td>
<td><strong>PROPOSED</strong></td>
</tr>
<tr>
<td>f1=4.25</td>
<td>f1=4.25</td>
</tr>
<tr>
<td>170.91</td>
<td>-31.32</td>
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<tr>
<td>5.51</td>
<td>95.63</td>
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<tr>
<td>f1=6.93</td>
<td>f2=6.93</td>
</tr>
<tr>
<td>170.62</td>
<td>-28.79</td>
</tr>
<tr>
<td>4.29</td>
<td>165.37</td>
</tr>
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</table>

**Conclusion and Future Scope of works:**

My work is to obtain small size, broadband & multiple resonance frequency by patch antennas. This has been achieved by cutting various types of rectangular slots like E-shaped rectangle, L type slit, inverted L type slit, both L type slit & inverted L type slit, triangular slit, H-type slit etc. These types of slots are cut at the top as well as bottom layer i.e. ground planes. These various types of microstrip antennas are designed with the help of IE3D software [50], based on Method-of-Moment (MoM). Experimental investigations are done by using standard microwave test bench i.e. VNA (Vector Network Analyzer). Here E-plane & H-Plane radiation patterns are also analyzed. We have also been able to design some microstrip antennas which are operating at multiple frequencies with size reduction. In addition, we designed some broadband antennas for operating at Ultra-Wide Band frequency range.

In future microstrip antennas for applications like RFID and several bio-medical uses are expected to be researched. Different types of microstrip antennas have been designed in this thesis. In future planar microstrip antennas on curved surface with variable radii of curvature may be investigated. They may be compared with the planar antennas. Successful design of curved surface MSA (Micro-Strip Antenna) may be helpful in Body-mounted applications. Researchers are also trying to develop microstrip antenna using semiconductor substrates.

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S.Chatterjee: ABSTRACT

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• Publications

Publications in International Journals:


5. Samiran Chatterjee, Santosh Kumar Chowdhury, Partha Pratim Sarkar and Debasree Chanda (Sarkar), “Comparison Between Two CPW-FED UWB Antennas Based on Dielectric Constant of Substrate”, INTERNATIONAL JOURNAL OF ELECTRONICS & COMMUNICATION TECHNOLOGY (IJECT), VOL IV, ISSUE I, VER. 1, JAN-MARCH 2013


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