DESIGN & ANALYSIS OF WIDE-BAND MULTIPLE FREQUENCY PATCH ANTENNAS FOR WLAN/WiMAX APPLICATIONS

MAIN PROJECT

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As a partial fulfilment of the curriculum

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Thankfully,

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Abstract

In the past few years, new designs based on the microstrip antennas have been used for handheld wireless devices because these antennas have low-profile geometry and can be embedded into the devices. Here a new technique for enhancing bandwidth that improves the performance of a conventional microstrip patch antenna is proposed. It presents a novel wideband probe fed inverted slotted microstrip patch antenna. The design adopts contemporary techniques: coaxial probe feeding, inverted patch structure and slotted patch. The composite effect of integrating these techniques and by introducing the patch, offer a low profile, broadband, high gain, and low cross-polarization level. The results for the VSWR, gain and co-and cross-polarization patterns are presented. The antenna operating the band of 1.925-2.925 GHz. Good radiation characteristics has been obtained. We also present a novel antenna operates in multiple frequencies which satisfies the IEEE 802.11 WLAN standards in the 2.4 GHz (2400-2484 MHz)specified by IEEE 802.11b/g/5.2 GHz (5150-5350 MHz)/5.8 GHz (5725-5825 MHz)specified by IEEE 802.11a operating bands and the worldwide interoperability for microwave access (WiMAX) 2.5/3.5/5.5 GHz(2500-2690/3400-3690/5250-5850 MHz) bands. E-plane and H-plane radiation patterns for the dual operation frequencies is satisfactory within this bandwidth.
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Chapter 1

Introduction

Wireless communications have been developed widely and rapidly in the modern world especially during the last decade. In the near future, the development of the personal communication devices will aim to provide image, DMB (Digital Multimedia Broadcasting), video telephony, speech and data communications at any time-any where around the world using the WLANs (Wireless Local Area Networks). Rapid advances of various WLAN protocols have sparked the requirements for miniaturized multiband antennas with suitable frequency bands appropriate for the Wi-Fi (IEEE 802.11 standard) and mobile WiMAX (IEEE 802.16e-2005 standard) applications. The demand for compact size, light weight and low cost antennas has increased in the recent years with the widespread deployment of wireless communications, like the wireless local area networks (WLAN). In order to satisfy the IEEE 802.11 WLAN standards in the 2.4 GHz (2400-2484 MHz)specified by IEEE 802.11b/g /5.2 GHz (5150-5350 MHz)/5.8 GHz (5725-5825 MHz)specified by IEEE 802.11a operating bands and the worldwide interoperability for microwave access (WiMAX) 2.5/3.5/5.5 GHz(2500-2690/3400-3690/5250-5850 MHz) bands, multi-band antennas with low cost, compact size, easy fabrication and higher performance are required.

We investigated two antenna structures suitable for WLAN standards. The first is a wide band probe fed inverted slotted microstrip patch antenna, which provides a enhancement in bandwidth. We tried out various structures including a trapezoidal structure, e-slot structure, U shaped structure and E shaped structure. Among these, E shaped structure provides an enhanced bandwidth. A detailed parameter study of the structure by varying its physical dimension are also doneto optimize the dimensions for maximum bandwidth covering WLAN stamndards. The next structure is a E-shape and U-shape Patch Antenna, which resonates at multiple frequencies which satisfies both WLAN and Wi-Max standars. The structure we used here is a connected E & U geometry with a notch and triangular cut on each edge. Both structures provided good performance.

The software we used to simulate these antenna structures is High Frequency Structure Simulator (HFSS) version-11. HFSS is an interactive software package for calculating the electromagnetic behavior of a structure. The software includes post-processing commands for analyzing this behavior in detail. Using HFSS, we can compute:

- Basic electromagnetic field quantities and, for open boundary problems, radiated near and far fields.
- Characteristic port impedances and propagation constants.
• Generalized S-parameters and S-parameters renormalized to specific port impedances.
• The eigenmodes, or resonances, of a structure.

The report is organized into four sections. The first section provides a detailed survey of the wide band antennas and the double frequency antennas and is reported in the literature. The next chapter has two sections each part discussing the structures and their performance. Then results and discussions of each structure is presented as third chapter. Last chapter presents the conclusion of our study.
Chapter 2

Literature Survey

The use of ISM band is becoming an important means of wireless communication. The design of antennas for these wireless applications is important. The antenna used must be handy, must have reasonable bandwidth, affordable cost, high efficiency and they must be flexible.

There are many applications such as mobile radio and wireless communication where the features of microstrip antennas are suitable. These antennas are low profile, con- formable to planar and non planar surfaces, simple and inexpensive to manufacture using modern printed circuit technology, mechanically robust when mounted on rigid surfaces, compatible with MMIC designs, and when the particular patch shape and mode are se- lected they are very versatile in terms of resonant frequency, polarization, pattern and impedance. In addition, by adding loads between the patch and ground plane, such as pins and varactor diodes, adaptive elements with variable resonant frequency, impedance, polarization and pattern can be designed[1].

2.1 Wide Band Antenna

Many previous works were reported on microstrip patch antennas for wireless applications. There are numerous and well-known methods to increase the bandwidth of antennas, including increase of the substrate thickness, the use of a low dielectric substrate, the use of various impedance matching and feeding techniques, the use of multiple resonators, and the use of slot antenna geometry [2][3]. Slotted microstrip antennas are investigated for enhancing bandwidth [2][3]. Here a new design technique for enhancing bandwidth that improves the performance of a conventional microstrip patch antenna is proposed. The design adopts contemporary techniques; coaxial probe feeding, inverted patch structure and slotted patch. The composite effect of integrating these techniques and by introducing the patch, offer a low profile, broadband, high gain, and low cross-polarization level. An impedance bandwidth of 27% is achieved in this design with respect to the centre frequency of 2.08 GHz[2].

A L Slotted Rectangular Microstrip Patch Antenna is studied[14]. For obtaining better impedance bandwidth two dielectric materials Rohacell RO3003 in combination with foam is used here. The impedance bandwidth of 130MHz and 1.45GHz band is obtained in the proposed design. In this design two different dielectric material i.e. RO3003 ($\varepsilon_r=3$, h= 0.508mm, and foam material ($\varepsilon_r=1.06$, h= 3mm) was used. In this work,
co-axial or probe feed technique is used as its main advantage is that, the feed can be placed at any place in the patch to match with its input impedance (usually 50 ohm).

A Wideband Circularly Polarized Microstrip Patch Antenna is reported[23]. The antenna is designed to function in the 5-6 GHz wireless LAN bands. It achieves multi-band functionality through the addition of a slot to a square patch (21 mm by 21 mm by 2.6 mm). This antenna also generates circular polarization and has a 3 dB axial ratio bandwidth of 2.8%. The impedance bandwidth of the antenna is more than 14% within 2:1 VSWR. Here a much thinner (0.04 λ) slotted microstrip patch antenna is considered and the design is also capable of generating circular polarization (CP) with a 3 dB axial ratio bandwidth of 2.8%.

2.2 Double Frequency Antenna

An e-slot geometry inorder to make the structure a dual band one is reported in [4][5]. The structure also improves bandwidth. The antenna is designed for dual frequency band 2.4-2.52 GHz and 4.82-6.32 GHz, which support WLAN communications. The bandwidth at low resonant frequency and high resonant frequency are about 0.12 GHz and 1.5 GHz, respectively. This antenna was designed on RT/Duroid 5880 with 1.575mm of thickness, h, and 2.2 of dielectric constant $\varepsilon_r$.

Wideband Low Profile Double Inverted-F Antenna for 5.2/5.8 GHz WLAN and 5.5 GHz WiMAX Applications was also studied. The antenna has compact size of 920 mm$^2$ and provides a wide bandwidth of 2.1 GHz (4675 MHz 6775 MHz) which covers the 5.2/5.8 GHz WLAN and 5.5 GHz WiMAX applications. Moreover it has very high peak gain and lower gain variation within the 10 dB return loss bandwidth. The VSWR of DIFA varies from 1.0412 to 1.1960 within the antenna return loss bandwidth. Also the antenna provides peak return loss of -39.0732, -21.6220 and -21.7404 dB at 5.2, 5.5 and 5.8 GHz respectively.

Dual Band U- shaped microstrip antenna presents novel coaxial feed[6]. The antenna gives wide bandwidth. It is also a simple structure. It offers a dual band and suggests an alternative approach in enhancing the band width, operating at a frequency of 2.5 GHz. A bandwidth enhancement of more than 7% was achieved. This technique has its advantages such as it does not increase the lateral size of the microstrip antenna and disadvantages such as it increases the height of the microstrip antenna. Therefore, tradeoff issues need to be considered in this design.

An another structure explains a Connected E-Shape and U-Shape Dual- Band Patch Antenna. A dual operation E-shape and U-shape Patch. Antenna feed by transmission line was analyzed there. The antenna is designed on two-layer (FR4 & Air) substrate. The dual operation frequencies are 4.7 GHz and 5.4 GHz[7]. The main advantage of using transmission line feeding is very easy to fabricate and Simple to match by controlling the inset position and relatively simple to model. Inorder to increase bandwidth methods such as increasing patch height over ground plane, using a lower substrate permittivity, multilayer structure consisting of several parasitic radiating elements with different size above the driven element can be employed. A stacked patch antenna resulting in a thicker antenna structure. Also there has been many active research on printed anten-
nas in different shapes. Many designs of single and dual band microstrip patch antenna with triangular, square and circular using E-slots and U-slots have been reported. Also H-shaped Patch antenna has been reported.

A New Dual Band E-shaped Slot Antenna using a trapezoidal structure is also studied[8]. It uses proximity fed technique. This antenna offers good return loss response (for S11 less than 10 dB) at the two bands. The ratio of the two resonating frequencies $f_{02}/f_{01}$ could be varied in a considerable range, without changing the antenna external dimensions, making the antenna suitable for other dual band wireless applications. Various E-shaped patch antennas with tapered, corrugated, and trapezoidal slots have been reported in the literature [9][10]. Many variants of the E-shaped patch structure have been considered to produce reduced size and wide band antennas [10][11]. Patch antennas with half E-shaped and folded E-shaped structures have been also reported [9][10][11]. Moreover, the E-shaped structures have been used together with other slot structures to produce antennas with enhanced bandwidths [11][12]. For dual band antenna applications E Shaped Patch Antenna Structures are suitable.

A Novel Microstrip-Fed Dual-Band Slot Antenna For Wlan Applications is also analysed[25]. The antenna, fed by a 50 microstrip line, has size of 32mm × 28mm × 1.6mm. By introducing a pair of U-shaped strips, this antenna can generate two separate impedance bandwidths. The prototype of this antenna has been successfully constructed and tested. The low-band resonant frequency is located at about 2.4 GHz, with 10 dB impedance bandwidth from about 2.3 to 2.5 GHz. The high-band resonant frequency is located at about 5.7 GHz, with 10 dB impedance bandwidth from about 4.9 to 6.0 GHz. In addition, the measured results show good radiation characteristics at the two operating bands, proving the dual-band operation of the considered antenna.
Chapter 3
Design

3.1 Design equations

A Rectangular patch of Width \( W \) and Length \( L \) over grounded substrates with the thickness \( h \) and relative permittivity \( \varepsilon_r \) the width is given by

\[
W = \frac{c}{2f[\varepsilon_r + 1]^1/2} \quad (3.1)
\]

Since some of the wave travel in the substrate and some in the air, an effective dielectric constant \( \varepsilon_{\text{eff}} \) is introduced to account for fringing and the wave propagation in the line and is given by

\[
\varepsilon_{\text{eff}} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \left[ (1 + \frac{12h}{w})^{1/2} \right] \quad \frac{w}{h} \geq 1 \quad (3.2)
\]

The fields slightly overlap the edges of the patch making the electrical length of the patch slightly larger than its physical length. Thus a correction term \( \Delta L \) also called Edge extension is introduced in account for the fringe capacitance. This edge extension \( \Delta L \) is given by

\[
\Delta L = 0.412h\left[ \left( \frac{\varepsilon_{\text{eff}} + 0.5}{\varepsilon_{\text{eff}} - 0.258} \right) \left( \frac{w}{h} + 0.264 \frac{w}{h} + 0.813 \right) \right] \quad (3.3)
\]

Because of the fringing effect, the dimension of the patch along its length have been extended on each end by a distance \( L \), so the effective length of the patch is given by

\[
L_{\text{eff}} = L + 2\Delta L \quad (3.4)
\]

In order to resonant, this effective length must be equal to half wavelength. Then

\[
L_{\text{eff}} = L + 2\Delta L = \frac{\lambda}{2g} = \frac{\lambda_o}{2\sqrt{\varepsilon_{\text{eff}}}} \quad (3.5)
\]

Where, \( \lambda_g \) = Guide wavelength and \( \lambda_o \) = free space Wavelength

The resonant frequency is derived in terms of effective permittivity and effective length as given below

\[
f_r = \frac{c}{2L_{\text{eff}}\sqrt{\varepsilon_{\text{eff}}}} \quad (3.6)
\]
For $TM_{mn}$ mode

$$f_r = \frac{c}{2\sqrt{\varepsilon_{eff}}} \left[ \left( \frac{m}{L} \right)^2 + \left( \frac{n}{W} \right)^2 \right]^{1/2}$$

These are the design equations for the Rectangular Microstrip Patch Antenna[1]

### 3.2 Structure for Wide Band Antenna

![Slotted microstrip antenna-Top view](image1)

Figure 3.1: Slotted microstrip antenna-Top view

![Slotted microstrip antenna-side view](image2)

Figure 3.2: Slotted microstrip antenna-side view
### Table 3.1: patch antenna design parameters in millimeters

<table>
<thead>
<tr>
<th>Dimension (mm)</th>
<th>W</th>
<th>L</th>
<th>w1</th>
<th>w2</th>
<th>l1</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>79</td>
<td>53</td>
<td>10</td>
<td>17</td>
<td>37</td>
</tr>
<tr>
<td>Dimension (mm)</td>
<td>l2</td>
<td>h0</td>
<td>h1</td>
<td>fp</td>
<td></td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>12.5</td>
<td>1.5748</td>
<td>12</td>
<td></td>
</tr>
</tbody>
</table>

The structure chosen was a slotted E-shaped antenna. Fig. 3.1 depicts the geometry of the patch antenna. The inverted rectangular patch, with width W and length L is supported by a low dielectric superstrate with dielectric permittivity $\varepsilon_1$ and thickness $h_1$. An air-filled substrate with dielectric permittivity $\varepsilon_0$ and thickness $h_0$ is sandwiched between the superstrate and a ground plane. The patch integrates the double E shaped patch on the same radiating element. For the main E-shaped, the slots are embedded in parallel on the radiating edge of the patch symmetrically with respect to the centerline (x-axis) of the patch and it is incorporated extra E shaped slot on the same radiating edge of opposite side. The patch is fed by a coaxial probe along the centerline (x-axis) at a distance $f_P$ from the edge of the patch as shown in Fig.3.2. A dielectric substrate with dielectric permittivity, $\varepsilon_1$ of 2.2 and thickness, $h_1$ of 1.5748mm has been used in this research. The thickness of the air-filled substrate, $h_0$ is 12.5 mm. An Aluminum plate with dimensions of 1.393 $\lambda_0$ -1.254 $\lambda_0$ (where $\lambda_0$ is the guided wavelength of the centre operating frequency) and thickness of 1 mm is used as the ground plane. The antenna is designed to operate at 2.25 GHz region.

This design employs contemporary techniques namely, the coaxial probe feeding, inverted patch, and slotted patch techniques to meet the design requirement. The use of probe feeding technique with a thick air-filled substrate provides the bandwidth enhancement, while the application of superstrate with inverted radiating patch offers a gain enhancement, and the use of parallel slots also reduce the size of the patch. The use of superstrate on the other hand would also provide the necessary protections for the patch from the environmental effects. By incorporating extra E shape slots in radiating edges, the gain and cross-polarization has been improved. These techniques offer easy patch fabrications, especially for array structures.

### 3.3 Structure of Dual Band Antenna

A connected microstrip E-shape and U-shape patch antenna is designed with over all dimensions 35 mm x 40 mm and height of 1.5 mm. A parametric study on the structure is made in-order to obtain the best possible size and position of the connector. Simulation results are also shown below.

The dielectric material selected for the design is FR4 which has dielectric constant of ($\varepsilon_r =4.4$) and height of dielectric substrate (h) = 1.5. The antenna is fed by 50 ohm microstrip line, through a quarter-wavelength transformer for impedance matching.
Table 3.2: Dimensions of the antenna (Unit: mm)

<table>
<thead>
<tr>
<th>L</th>
<th>W</th>
<th>$L_h$</th>
<th>$w_h$</th>
<th>$L_n$</th>
<th>$w_n$</th>
<th>$L_m$</th>
<th>$w_m$</th>
<th>$L_d$</th>
<th>$w_d$</th>
</tr>
</thead>
<tbody>
<tr>
<td>40</td>
<td>35</td>
<td>5</td>
<td>2.5</td>
<td>5</td>
<td>25</td>
<td>20</td>
<td>2</td>
<td>3.75</td>
<td>2</td>
</tr>
</tbody>
</table>

Figure 3.3: Connected E & U antenna
Chapter 4

Results and Discussions

4.1 Slotted microstrip antenna for improved bandwidth

The structure in 3.1 was analysed using the software HFSS. The objective was to design a single band antenna with improved bandwidth for a frequency range of 2-2.5GHz.

Figure 4.1: Slotted microstrip antenna
The fig.4.2 shows the S11 parameter of the slotted antenna. The antenna resonates at a frequency of 2.28GHz and provides a bandwidth from 1.93GHz to 2.45GHz(22.8%).

Figure 4.2: S11 parameter plot

4.2 Parameter study

Parameter study is also conducted for the antenna by varying the dimensions. The results are presented here.

4.2.1 Effect of changing \( w_1 \)

<table>
<thead>
<tr>
<th>W</th>
<th>L</th>
<th>( w_1 )</th>
<th>( w_2 )</th>
<th>( l_1 )</th>
<th>( l_2 )</th>
<th>Resonant frequency</th>
<th>Return loss</th>
<th>Bandwidth</th>
</tr>
</thead>
<tbody>
<tr>
<td>79</td>
<td>53</td>
<td>7</td>
<td>17</td>
<td>37</td>
<td>6</td>
<td>2.25</td>
<td>-22dB</td>
<td>20.6</td>
</tr>
<tr>
<td>79</td>
<td>53</td>
<td>8</td>
<td>17</td>
<td>37</td>
<td>6</td>
<td>2.25</td>
<td>-22dB</td>
<td>21.1</td>
</tr>
<tr>
<td>79</td>
<td>53</td>
<td>9</td>
<td>17</td>
<td>37</td>
<td>6</td>
<td>1.85,2.1</td>
<td>-16dB, 13dB</td>
<td>25.4</td>
</tr>
<tr>
<td>79</td>
<td>53</td>
<td>10</td>
<td>17</td>
<td>37</td>
<td>6</td>
<td>2.28</td>
<td>-22.1dB</td>
<td>22.8</td>
</tr>
<tr>
<td>79</td>
<td>53</td>
<td>11</td>
<td>17</td>
<td>37</td>
<td>6</td>
<td>2.28</td>
<td>-4.5dB</td>
<td>23.2</td>
</tr>
<tr>
<td>79</td>
<td>53</td>
<td>12</td>
<td>17</td>
<td>37</td>
<td>6</td>
<td>2.23</td>
<td>-25dB</td>
<td>24.6</td>
</tr>
<tr>
<td>79</td>
<td>53</td>
<td>13</td>
<td>17</td>
<td>37</td>
<td>6</td>
<td>2.35</td>
<td>-20dB</td>
<td>15.9</td>
</tr>
</tbody>
</table>

Table 4.1: Effect of changing the parameter \( w_1 \)

The table 4.1 shows the effect of varying the \( w_1 \) of the structure. As \( w_1 \) is increased from the designed dimension, an improvement in bandwidth can be observed. Similarly as \( w_1 \) is decreased, reduction in bandwidth can be observed. In addition variance in return loss can also be observed.
4.2.2 Effect of changing $w_2$

The above table shows the effect of changing $w_2$. The parameter $w_2$ has no effect on bandwidth. The bandwidth is almost constant here. The only change that can be
observed is on the return loss. With the increase in \( w2 \) return loss decreases and it increases with the decrease in \( w2 \). There is no apparent change in resonant frequency.

![Graphs showing the effect of changing \( w2 \)](image)

**Figure 4.4: Effect of changing \( w2 \)**

### 4.2.3 Effect of changing \( l1 \)

<table>
<thead>
<tr>
<th>W</th>
<th>L</th>
<th>w1</th>
<th>w2</th>
<th>l1</th>
<th>l2</th>
<th>Resonant frequency (GHz)</th>
<th>Return loss (dB)</th>
<th>Bandwidth (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>79</td>
<td>53</td>
<td>10</td>
<td>17</td>
<td>34</td>
<td>6</td>
<td>2.35</td>
<td>-19.99 dB</td>
<td>14.1</td>
</tr>
<tr>
<td>79</td>
<td>53</td>
<td>10</td>
<td>17</td>
<td>35</td>
<td>6</td>
<td>2.33</td>
<td>-20.9 dB</td>
<td>16.3</td>
</tr>
<tr>
<td>79</td>
<td>53</td>
<td>10</td>
<td>17</td>
<td>36</td>
<td>6</td>
<td>2.30</td>
<td>-21.3 dB</td>
<td>21.3</td>
</tr>
<tr>
<td>79</td>
<td>53</td>
<td>10</td>
<td>17</td>
<td>37</td>
<td>6</td>
<td>2.28</td>
<td>-22.1 dB</td>
<td>22.8</td>
</tr>
<tr>
<td>79</td>
<td>53</td>
<td>10</td>
<td>17</td>
<td>38</td>
<td>6</td>
<td>2.27</td>
<td>-24.9 dB, 13 dB</td>
<td>23.3</td>
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<td>10</td>
<td>17</td>
<td>39</td>
<td>6</td>
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<td>24.1</td>
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<td>10</td>
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<td>40</td>
<td>6</td>
<td>2.23, 1.95</td>
<td>-32 dB, 19 dB</td>
<td>24.6</td>
</tr>
</tbody>
</table>
Table 4.3: Effect of changing the parameter l1

The effect of changing l1 is shown in table 4.3. With the decrease in l1 bandwidth decreases and bandwidth increases with the increase in l1. There is a slight shift in resonant frequency also. Resonant frequency increases with decrease in l1 and decreases with the increase in l1.

![Figure 4.5: Effect of changing l1](image)

Figure 4.5: Effect of changing l1
4.2.4 Effect of changing l2

<table>
<thead>
<tr>
<th>W</th>
<th>L</th>
<th>w1</th>
<th>w2</th>
<th>l1</th>
<th>l2</th>
<th>Resonant frequency</th>
<th>Return loss</th>
<th>Bandwidth</th>
</tr>
</thead>
<tbody>
<tr>
<td>79</td>
<td>53</td>
<td>10</td>
<td>17</td>
<td>37</td>
<td>3</td>
<td>2.28</td>
<td>22.5dB</td>
<td>24.1</td>
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<td>53</td>
<td>10</td>
<td>17</td>
<td>37</td>
<td>4</td>
<td>2.28</td>
<td>-22dB</td>
<td>23.7</td>
</tr>
<tr>
<td>79</td>
<td>53</td>
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<td>17</td>
<td>37</td>
<td>5</td>
<td>2.28</td>
<td>-22.5dB</td>
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<td>53</td>
<td>10</td>
<td>17</td>
<td>37</td>
<td>6</td>
<td>2.28</td>
<td>-22.1dB</td>
<td>22.8</td>
</tr>
<tr>
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<td>53</td>
<td>10</td>
<td>17</td>
<td>37</td>
<td>7</td>
<td>2.75</td>
<td>-24dB</td>
<td>17.8</td>
</tr>
<tr>
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<td>53</td>
<td>10</td>
<td>17</td>
<td>37</td>
<td>8</td>
<td>2.28</td>
<td>-25dB</td>
<td>16.6</td>
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<tr>
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<td>53</td>
<td>10</td>
<td>17</td>
<td>37</td>
<td>9</td>
<td>2.29</td>
<td>-24.5dB</td>
<td>14.4</td>
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</table>

Table 4.4: Effect of changing the parameter l2

The effect of changing l2 is shown in table 4.4. As l2 increases, there is a decrease in bandwidth and bandwidth increases with the decrease in l2. There is no effective change in resonant frequency by varying l2.

Figure 4.6: Effect of changing l2
It is concluded from parameter study that with \( w_1=9 \) and \( w_2=20 \), we get a bandwidth of 25.4% with returnloss of -24.9 dB. \( l_1=37 \) and \( l_2=3 \) gives the designed resonant frequency of 2.28 GHz.

### 4.2.5 Radiation Pattern

![Radiation Pattern](image)

Figure 4.7: Radiation Pattern

The radiation characteristics are also investigated. Fig.4.7 presents the measured far-field radiation patterns for both co- and cross polarizations for the designed antenna at 2.28 GHz. The pattern is suitable for the designed applications.

### 4.2.6 Impedance plot

![Impedance plot](image)

Figure 4.8: Impedance plot

The simulated impedance on a smith chart for frequency range 2.28GHz. Impedance loci using smith chart shows perfect matching.
4.3 Dual Band Combined E and U antenna

We designed a dual band combined E & U antenna which resonates at multiple frequencies. Figure 4.9 shows the analysed Structure using HFSS. It not only provides a better S11 characteristics, but also gives considerable gain and good radiation pattern. The structure resonates at multiple frequencies (1.75 GHz, 2.25 GHz, 3.25 GHz, 4.5 GHz, 4.8 GHz, 8.35 GHz).

![Connected E & U antenna Without notch and with two coupling](image)

Figure 4.9: Connected E & U antenna Without notch and with two coupling

![S11 Parameter for 2.5GHz](image)

Figure 4.10: S11 Parameter for 2.5GHz

Antenna shows a wideband operation from 4.25 GHz to 10.5 GHz covering both WLAN and Wi-Max frequencies. The radiation characteristics are also investigated. Fig.4.11,fig.4.12 presents the measured far-field radiation patterns for both co- and cross- polarizations for the designed antenna at 2.5GHz and 4.6GHz.

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4.4 Parameter study

4.4.1 Effect of changing $w_h$

Parameter study is performed in this structure also. The change in dimensions other than $w_h$ resulted in no considerable difference in the resonant frequency and bandwidth. The results for varying $w_h$ is presented in 4.5.

<table>
<thead>
<tr>
<th>L</th>
<th>W</th>
<th>$L_h$</th>
<th>$w_h$</th>
<th>$L_m$</th>
<th>$w_m$</th>
<th>$L_d$</th>
<th>$w_d$</th>
<th>Resonance (GHz)</th>
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<td>5</td>
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<td>12</td>
<td>5</td>
<td>25</td>
<td>20</td>
<td>2</td>
<td>3.75</td>
</tr>
</tbody>
</table>

Table 4.5: Effect of changing $w_h$ (Unit: mm)
By increasing the value of $w_h$, frequency tuning is possible. Then we will get a maximum resonance at higher frequencies. The resonant frequencies are 2.2/ 2.5/3.5/5.5 GHz(2500-2690/3400-3690/5250-5850 MHz) and from WiMAX band, a wideband of frequencies can be used for several applications. This effect makes the antenna as a candidate for frequency reconfigurable antenna. We can observe the variations from the figure 4.13.
Chapter 5

Conclusion

A double E shaped patch for enhancing bandwidth of microstrip patch antenna is successfully designed. By employing the slotted patch shaped design, inverted patch, and coaxial probe feeding techniques, an impedance bandwidth of 22.83% is achieved in this design with respect to the centre frequency of 2.28 GHz. In addition, good antenna gain and radiation characteristics have also been obtained. The patch has a simple structure with dimension of $0.516\lambda_o \times 0.383\lambda_o$. The design is suitable for array applications with respect to a given frequency of 1.80-2.36 GHz.

Connected E-shape and U-shape patch antenna is investigated and successfully simulated. The simulated return loss and the radiation pattern showed well performance in multiple frequencies which satisfies the IEEE 802.11 WLAN standards in the 2.4 GHz (2400-2484 MHz)specified by IEEE 802.11b/g /5.2 GHz (5150-5350 MHz)/5.8 GHz (5725-5825 MHz)specified by IEEE 802.11a operating bands and the worldwide interoperability for microwave access (WiMAX) 2.5/3.5/5.5 GHz(2500-2690/3400-3690/5250-5850 MHz) bands and also over a wideband from the WiMAX band. The design shows suitable characteristic for wide-band multiple frequency for wlan/wimax applications.
References

[1] Constantine A. Balanis "Antenna Theory Analysis and Design"


