Design Study of Dual-Band Microstrip Antennas using U-Slot for S-Band Applications

Shweta Saini¹, Vipin Kaushik², A. K. Arya³

¹Dept. of Electronics and Communication Engg. Graphic Era University Dehradun, India
²Dept. of Electronics and Communication Engg. Korean Advanced Institute of Science and Technology (KAIST), South Korea

Abstract—In this paper, a complete design study of Dual-Band microstrip antennas (MSAs) using U-shape slotted patch with different feeding techniques is given and various methods of frequency control are also demonstrated. Investigations show that all the new designs are working in S-Band with satisfactory radiation characteristics and impedance bandwidths.

Keywords—MSA, Dual- band antenna, Frequency control, U-slot patch.

I. INTRODUCTION

In the recent years, microstrip antenna technology gained a significant progress due to its low cost, ease of fabrication, light weight, small size and wide range of applications [1]. The microstrip antenna provides feed line flexibility [2], circular polarization [3] and broad bandwidth [4]. But in some applications it is desired to have a dual-band or multi-band characteristics. These characteristics can be obtained by coupling multiple radiating elements or by using tuning devices [5][6]. However, these methods make antenna more complicated and bulky in size [7]. So, it is always a challenge to the researchers to make a simple design of microstrip antenna having dual frequency operations.

Many designs are reported to make a MSA dual-band, such as stacked patches [8][9], using two patches [10], slotted patch [11] like circular arc slot [12] or U-shaped slot [13].

Here one of the slotted patch MSA is proposed i.e.; U-shape slotted patch MSA. In this work, U-shape slotted patch microstrip antenna are designed with four popular feeding techniques (Edge feed, Proximity feed, Co-axial feed using L-probe and aperture coupled) [14] and simulated using CST Microwave Studio [15].

II. ANTENNA DESIGN AND CONFIGURATION

The design approach and proposed antenna configurations are described in this section. At the outset, four single square patch antennas are designed for resonating frequency (f1) 2.4 GHz in S-band with different feeding techniques namely edge feed, coxial feed, proximity feed and aperture coupled. Simple transmission line models were used for the antenna size calculations for which the formulas are given below.

\[ W = \frac{c}{2f} \left( \frac{1}{\epsilon_r + 1} \right)^{1/2} \]  
\[ L = \frac{c}{2f} \sqrt{\epsilon_{eff} - 2\Delta L} \]

Where \( \epsilon_{eff} \) and \( \Delta L \) can be calculated from [2]. The initial calculated value of the basic parameters of the initial antenna is given as, size of the substrates (LxWxlh) = 50x50x1.524mm³ with dielectric constant (\( \epsilon_r \)) = 3.38, size of patches (Lp×Wp×t) = 30x30x0.007mm³, size of ground plane 50x50x0.007mm³ and the operating frequency for the required design is 2.4GHz.

Then all the designs are simulated for operating frequency 2.4 GHz using the CST Microwave Studio[15].

After that a U-shaped slot is introduced in the radiating patch of all the models. The dimensions of the U-shaped slot is so adjusted that it gives a second current path ‘L2’ and so responsible for the second operating frequency ‘f2’.

The second operating frequency also lies in S-band and vary around 3.4 GHz for all the models. All the proposed designs are clearly shown with their top view and side view in figure 1(a-d) and figure 2(a-d) respectively.

From figure 1(d) it is clear that in the design of the aperture coupled MSA the slot in the ground plane(X×Y) is parallel to the feeding line and in another case of coaxial feed, to realize a broadband characteristics in feeding an L-shape probe is used as shown in figure 2(b). This feeding structure is known as broadband electromagnetic coupling probe [14].
Table 1: Design parameters of proposed antennas (all in millimeter)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Edge fed</th>
<th>Coaxial fed</th>
<th>Proximity fed</th>
<th>Aperture coupled</th>
</tr>
</thead>
<tbody>
<tr>
<td>L, W, h</td>
<td>50, 50, 1.524</td>
<td>50, 50, 1.524</td>
<td>50, 50, 1.524</td>
<td>50, 50, 1.524</td>
</tr>
<tr>
<td>Lp, Wp, t</td>
<td>35, 35, 0.007</td>
<td>30, 30, 0.007</td>
<td>30, 30, 0.007</td>
<td>30, 30, 0.007</td>
</tr>
<tr>
<td>Lc, Wc</td>
<td>17, 3.5</td>
<td>14, 2.5</td>
<td>20, 4</td>
<td>18, 4</td>
</tr>
<tr>
<td>Ul, Uw</td>
<td>7.5, 12</td>
<td>12, 12</td>
<td>11, 12</td>
<td>13, 15</td>
</tr>
<tr>
<td>d, d1, d2</td>
<td>15, 1, 1</td>
<td>7, 1, 1</td>
<td>-5, 1, 1</td>
<td>9, 1, 1</td>
</tr>
<tr>
<td>J1, J2, J3</td>
<td>11, 10.5, 11</td>
<td>9, 9, 9</td>
<td>9, 9, 9</td>
<td>9, 9, 9</td>
</tr>
<tr>
<td>X, Y</td>
<td>-</td>
<td>-</td>
<td>1.2, 10.5</td>
<td>7.5</td>
</tr>
<tr>
<td>S</td>
<td>10</td>
<td>10.8</td>
<td>-</td>
<td>7.5</td>
</tr>
</tbody>
</table>

After that all the new designs with U-shape slotted patch are simulated for operating frequency around 3.4 GHz using the CST Microwave Studio [15] with thickness of ground plane (t)=0.007mm, height of each individual substrate(h)=1.524mm, dielectric constant of all the substrate (εr)=3.38 and thickness of all patches and feed lines = 0.007mm moreover optimized values of all other necessary parameters of all four designs are given in table 1.

Figure 1: Top view of proposed designs.
(a) Edge fed  (b) Coaxial fed  (c) Proximity fed  (d) Aperture coupled
III. FREQUENCY CONTROL

In this section, a method of resonant frequency control is illustrated. As the proposed MSA is a dual-band antenna so it has two frequencies of operation. The radiating patch has a U-shaped slot so it provides two current paths (L₁ and L₂) which leads to the two resonant frequencies (f₁ and f₂). The average current lengths is shown in figure 3(a, b) and approximated values can be given as:

\[ L_1 = \alpha_1 U_w + \alpha_2 U_l + \alpha_3 L_p \]  
\[ L_2 = \beta_1 d_2 + \beta_2 d_1 + \beta_3 U_w + \beta_4 L_p \]  

Where \( \alpha_i \) (i=1,2,3) and \( \beta_j \) (j=1,2,3,4) depend on the parameters of the MSA. The detailed calculations of \( \alpha_1, \alpha_2, \alpha_3, \beta_1, \beta_2, \beta_3, \beta_4 \) can be obtained from[13]. Now in accordance with the L₁ and L₂ the approximated values of resonant frequencies can be calculated from equations 3 and 4 [13].

\[ f_1 = \frac{c}{2\sqrt{\epsilon_{eff}} L_1} \]  
\[ f_2 = \frac{c}{2\sqrt{\epsilon_{eff}} L_2} \]  

Where \( L_1 \) and \( L_2 \) are the average lengths of the current paths of first and second resonant frequencies, \( c \) is the velocity of light in free space and the effective permittivity \( (\epsilon_{eff}) \) is given as
\[ \varepsilon_{\text{eff}} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \left( 1 + \frac{10 h}{W} \right)^{-0.555} \quad (7) \]

Where \( h \) (total height of the substrates) and \( W \) are height of the substrate and width of the patch respectively.

Now let us consider coaxial fed MSA with U-shaped slot as shown in figure (1(b), 2(b)). By performing various simulations it is investigated that the first resonant frequency \( f_1 \) can be controlled by adjusting the length ‘\( L_p \)’ of the initial radiating patch as shown in figure 4(a). This is due to the fact that as the patch length increases the first current path ‘\( L_1 \)’ increases and by the relation shown in equation 5 (i.e. \( f_1 \) is inversely proportional to the \( L_1 \)) the first radiating frequency \( f_1 \) decreases and vice-versa. But now the method of controlling the second radiating frequency \( f_2 \) is to be investigated, so variation in all the parameters are to be recorded that leads to the change in the second current path length ‘\( L_2 \)’ and it is quite clear from the figure 1(b) that all the appropriate parameters related to the U-shaped slot are \( U_L \) and \( d_2 \). Now a complete parametric study of \( L_p \), \( U_L \) and \( d_2 \) is shown in figure 4(a-c) while keeping all other parameters fixed.

From the above figure 4(b) it is seen that by varying \( U_L \) the second resonant frequency varies while the first resonant frequency is remain constant. Also by figure 4(c) it is observed that the second resonant frequency changes with change in \( d_2 \) while there is only little variation in the first resonant frequency. So above parametric study demonstrated that the first resonant frequency \( f_1 \) is associated with the parameter \( L_p \) while the second resonant frequency \( f_2 \) is associated with the parameters \( U_L \) and \( d_2 \). Similar study can be carried out for the case of other feeding techniques.

IV. RESULT AND DISCUSSIONS

\([S_{11}]\) in db parameter and radiation patterns for the proposed dual-band microstrip antennas with U-shape slotted patch are proposed in this section. \([S_{11}]\) in db the parameters of all the four designs, namely edge fed, coaxial fed, proximity fed and aperture coupled, are given in figure 5 (a-d). It can be seen in the figure 5 (a) that edge fed MSA has two resonant frequencies ‘\( f_1 \)’ and ‘\( f_2 \)’ as 2.2 GHz and 3.4 GHz respectively. Similarly from figure 5 (b) coaxial fed MSA has its resonating frequencies at 2.2 GHz and 3.4 GHz. Also for the proximity fed MSA resonant frequencies are 2.3 GHz and 3.5 GHz as shown in figure 5 (c). And in the last the resonant frequencies for the aperture coupled MSA are 2.4 GHz and 3.6 GHz and shown in figure 5 (d). The detail study shows the dual-band characteristics of the MSAs using U-shape slotted patches.
The radiation patterns for all the proposed designs are given in figure 6-9. For better understanding of the results the radiation patterns at $\Theta=90^\circ$ and $\Theta=0^\circ$ are given for all the designs in figure (6-9) for both the resonant frequencies, $f_1$ and $f_2$. 

Figure 5: The $|S_{11}|$ parameter in db
(a) Edge fed  (b) Coaxial fed   (c) Proximity fed  (d) Aperture coupled

Figure 6. Radiation pattern for Edge fed MSA
at $f_1=2.2GHz$  a) $\Theta=90^\circ$  b) $\Theta=0^\circ$  
at $f_1=3.4GHz$  c) $\Theta=90^\circ$  d) $\Theta=0^\circ$
Design and simulation of dual-band Microstrip patch antenna is carried out in this work and methods of resonant frequency control are also studied. A U-shape slot in the radiating patch makes an antenna operating at two resonant frequencies. All the new designs with U-shape slotted patch are suitable for S-band applications.
REFERENCES


AUTHOR’S PROFILE

Shweta Saini was born in Uttar Pradesh, India in 1987. She received the B.Tech degree in Electronics and Communication engineering from U.T.U Dehradun, India in 2011. Currently, she is working towards her M.Tech (Communication System) thesis at Research and Development Lab. In Graphic Era University, Dehradun, India.

Her area of research includes Patch antenna, Printed antenna, Dual band MSAs, Slotted Patch MSAs and other compact antennas.

Vipin Kaushik was born in New Delhi, India in 1989. He received the B.Tech degree in electronics and communication engineering from U.T.U Dehradun, India in 2011. Currently, he is working towards his M.Tech (RF and Microwave) thesis at Research and Development Lab. In Graphic Era University, Dehradun, India.

He worked as a Lecturer in the Department of Electronics and Communication Engineering, Tula’s Institute, Dehradun during 2011-2012. His area of research includes Patch antennas, Printed antennas and other compact antennas. He has published several research papers in national and international journals on microstrip antenna designs of various specifications.

Dr. A. K. Arya was born in uttrakhand, India in 1985. He received the B.E degree in electronics and communication engineering from G.B. Pant Engineering College, Uttrakhand, India in 2005, M.Tech. degree in electronics and communication engineering from G. B. Pant University of Agriculture and Technology, Uttrakhand, India in 2007 and Ph.D. degree in RF and Microwave Engineering from Indian Institute of Technology, Roorkee, India in 2012. Currently he is pursuing post-doctoral fellowship at Korean Advanced Institute of Science and Technology (KAIST), South Korea.

He worked as assistant professor in department of Electronics and communication Engineering, Graphic Era University, Dehradun, India from june 2012 to jan 2014. His Area of research includes Microstrip Antennas, RFID, Matamaterials and RF Circuit Design and High frequency techniques.

He has published a number of research papers on Microstrip antennas and in other microwave techniques. Also he is member and reviewer of IEEE Antenna and Wireless Propagation Letters, Progress in Electromagnetic Research and International Association of Engineers (IAENG), Hong-Kong.