A Dual-Band U-Slot PIFA Antenna with Ground Slit for RFID Applications

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ABSTRACT

In this paper, a Planar Inverted-F Antenna (PIFA) with U-Slot (U-PIFA) and slit in ground is introduced. The proposed PIFA is compact with single coaxial feed, single short strip, and single short pin. The main achievement of this research was the design of ISM Microwave bands 2.45/5.8 GHz dual band PIFA antenna by using slit in ground to control the selection of lower resonance frequency without any mutual effect on the upper resonance frequency which determined from U-slot in the patch. The dielectric constant of the substrate is 4.3 and loss tangent of 0.013, FR-4 substrate. The characteristics (input impedance, and the far field radiation pattern) of the U-PIFA were analyzed by a CST (Computer Simulation technology) Microwave Studio package. The maximum impedance bandwidths achieved are ~8.44% centered at 2.45 GHz and ~ 6.78% centered at 5.8 GHz for a return loss less than 10 dB with nearly omnidirectional pattern suitable for RFID applications. The antenna gains for frequency 2.45 GHz and 5.8 GHz are 2.2 dB and 6.55 dB, respectively.

Keywords: Antenna, Dual-band, U-slot, PIFA

1. INTRODUCTION

Radio frequency identification (RFID) systems have been developed rapidly and found application in identification, distribution, logistical, and security monitoring systems [1]. In RFID system, the reader antenna is an important component; it transmits signal to tags and receives backscatter signals from tags [2]. Several frequency bands have been assigned to RFID applications: LF band: 125 kHz, HF band: 13.56 MHz, UHF band: 869 MHz, 902– 928 MHz, Microwave ISM band: 2.450 (2.400–2.483) GHz and 5.800 (5.725–5.875) GHz [3]. The advantage of operating in higher frequencies is a higher range with high data transfer rate. However, as the operating frequency of RFID systems rises to the microwave region (2.45/5.8 GHz), the reader antenna design becomes more acute and critical. Since these two standards (2.45/5.8 GHz) may be used simultaneously in one system, a single antenna covering these two bands can eliminate the use of two single-band antennas [4].

Due to its low profile and ability to cover the existing wireless communication frequency bands, the planar inverted-F antenna (PIFA) has been widely adopted in portable wireless units ([5–8]). Also, due to the limited space available on the printed circuit board (PCB) of a wireless device, antenna miniaturization is crucial to keep the size of this type of antenna small and appropriate for portable wireless units, without degradation of performance in terms of bandwidth and radiation patterns. Studies of ground plane effects [9] and bandwidth enhancement methods [10], of such antennas have been reported.

PIFA as internal antenna has desirable features like compact, moderate range bandwidth, less prone and less power absorption than external antenna. The researches about PIFA shows that by adding the capacitive circuit [11] and replacing the coax feed with capacitive feed [12] can reduce the \( \lambda/4 \) size of PIFA up to \( \lambda/8 \).

Different methods are used to increase the bandwidth of PIFA, varying radiating element size [13], changing the width of the short wall [11], adding slots at the ground plane [14], or embedded U-slot in the patch [15]. In addition, by changing and adjusting the position of feed point and short wall, the impedance matching can be achieved. In [16], a practical methodology is proposed for robust optimization of a U-slot based PIFA structure with triple bands of 433 MHz, 912 MHz and 2.45 GHz. Reference [17] presents the design of a dual-frequency U, and Y slotted rectangular PIFA antenna at 2.4/5.2 GHz WLAN applications. In [18] 2.4/5.2 dual-band planar inverted-F antenna using novel plate geometry was introduced, for this antenna the U-shaped slot PIFA both the lower and upper resonant frequency can be determined independently.

In this paper dual band U-Slot PIFA has been presented. This is done by etching U-slot in the rectangular patch printed on a thin dielectric substrate excited by coaxial probe-feed. The U-slot in the patch was introduced to independently control the upper resonance frequency, whereas the slit in ground was introduced to independently control the lower resonance frequency. The input impedance, return loss, and the far field radiation pattern of the proposed wide-band antenna will be analyzed by using CST Microwave Studio. An input impedance bandwidth of (2.340 to 2.546) GHz and (5.644 to 6.037) GHz for a return loss less than 10 dB have been achieved.

2. ANTENNA CONFIGURATION AND DESIGN CONSIDERATION

The geometry of the proposed dual band U-PIFA antenna with slit in ground is shown in Fig. 1. The U-PIFA with the total antenna size of 35x35 mm² is printed on an FR4 substrate (\( \varepsilon_r = 4.3 \), thickness, \( h = 0.8 \) mm, loss tangent = 0.013). The optimal dimensions of this proposed dual band antenna are listed in Table 1. The radiating square patch is set to be the dimension of 23x23 mm². We obtain the operating frequency...
2.45 GHz calculated by the standard design formula for PIFA [19, 20]

\[ f_{ol} = \frac{v_0}{4(L_p + W_p)} \]  \hspace{1cm} (1)

In (1), \( f_{ol} \) is the lower resonant frequency, \( v_0 \) is velocity of light. For the lower resonant frequency (2.45 GHz), \( W_p \) and \( L_p \) are the width and length of the radiating patch, respectively. For the higher resonant frequency \( f_{ol} \) (5.8 GHz), \( W_p \) and \( L_p \) are replaced by U-slot length and width, \( a \) and \( b \), respectively. A U-slot shaped is embedded at the centre of the square radiating patch-layer of the substrate and fed through a matching 50Ω probe feed. A square ground layer of 35x35 mm² is connected to patch through a shorting wall of height \( h_{sr} \) and width \( S_w \), and shorting pin of diameter \( D_{sc} \) placed at distance \( x_{sc} \) and \( y_{sc} \) from the lower left patch corner. The resonant length \((a + b)\) of the U-slot is 18.38 mm corresponding to approximately 0.35 wavelength of the resonant mode at 5.8 GHz.

The grounded slit-shaped is with the width \( W_{slit} \) and the length \( L_{slit} \) and placed at a distance \( d_{slit} \) from the lower side of the ground. In this study, by introducing the grounded slit-shaped inset into the ground, the lower resonance frequency can be tuned easily without any affect on the higher resonance frequency.

The effects of the geometrical parameters \((a, b, c, L_{slit} \text{ and } W_{slit})\) on the antenna performance have been extensively studied by simulating the antenna with the aid of CST Microwave Studio package. Confidence in the accuracy of the result obtained by the package was based on an extensive comparison of radiation patterns and input impedance obtained by the package with that reported in the literatures. Excellent agreement between our numerical results and data reported in the literature was found for all the considered test cases for the U-slot and feed position.

### 3. RESULTS AND DISCUSSIONS

Before starting the design and simulation of the proposed antenna, the results in [15] were reproduced using CST to check the accuracy of our simulation approach. In [15], a broad-band U-slot rectangular patch antenna printed on a microwave substrate is investigated. The published experimental data of this work including the impedance locus and radiation pattern were in good agreement with the theory. This work is re-simulated with the aid of CST Microwave Studio and with the same geometrical parameter dimensions except of changing the vertical feed position, \( y_f \) (2.7 mm and 3 mm below the center of original rectangular patch for antenna B antenna C, respectively, instead of 0 mm).

![Fig. 1: Geometry of the U-Slot PIFA. (a) 3D view. (b) Top view. (c) Bottom view.](image)

![Fig. 2: The input impedance for U-slot PIFA.](image)
Fig. 3: (a) Published radiation patterns (simulated and measured) of antenna B operated at 3.56 GHz [15].
(b) Simulation radiation patterns for E- and H-plane of antenna B operated at 3.56 GHz via CST package.

The proposed U-PIFA is designed to operate at the center frequencies 2.45 and 5.8 GHz in ISM bands for RFID application. Figure 4 shows the simulated results of the return loss $S_{11}$, input resistance $R_A$, and input reactance $X_A$ for the antenna of Fig. 1. The antenna performance results, return loss (RL), operating bandwidth ($RL \geq 10\,\text{dB}$), center frequency at each band are listed in Table 2. From these results, the operating bandwidth (RL $\geq 10\,\text{dB}$) can reach about 206 MHz (2.34-2.54 GHz) or 8.44% centered at 2.45 GHz, and 393 MHz (5.64-6.04 GHz) or 6.78% centered at 5.8 GHz which covers the entire ISM RFID band. Figure 4(b) and 4(c) show the simulated resistance and reactance part of antenna input impedance, respectively. It is shown from this figure that a good matching is achieved at these two bands.

Table 2: Simulated return loss and bandwidth against frequency of U-Slot PIFA

<table>
<thead>
<tr>
<th>Antenna performance</th>
<th>Lower band</th>
<th>Upper band</th>
</tr>
</thead>
<tbody>
<tr>
<td>$S_{11}$ (dB)</td>
<td>-40.17</td>
<td>-46.67</td>
</tr>
<tr>
<td>$f_c - f_L$ (MHz)</td>
<td>2.34 - 2.54</td>
<td>5.64 - 6.04</td>
</tr>
<tr>
<td>Center frequency (GHz)</td>
<td>2.44</td>
<td>5.80</td>
</tr>
<tr>
<td>BW (MHz)</td>
<td>206</td>
<td>393</td>
</tr>
</tbody>
</table>

4. GEOmetrical PARAMETERS STUDIES

In order to investigate the influences of geometrical antenna parameters of antenna performance, a geometrical parametric study are needed. Return loss performance is mainly affected by the dimensions of the U-slot and grounded
slit shaped to ensure a mutual coupling between the variation of U-slot parameters \((a, b, c)\) and grounded slit-shaped parameters \((L_{slit}, W_{slit})\) on resonance frequencies.

### 4.1. Effects of the U-Slot

The dual band characteristic as aforementioned is characterized by the U-slot at the center of the patch. Figure 5(a) presents the tuning effect of the length \(a\) for the U-slot with selected values from 7 to 10 mm on return-loss response. The upper resonance frequency is moved below 5.8 GHz when \(a\) increases, whereas that of lower resonance frequency is almost unchanged. Figure 5(b) illustrates the effect of length \(b\) for the U-slot with varying dimension from 9 to 12 mm on the frequency response of the return loss for the proposed antenna. The results show that the upper resonance frequency is shifted below 5.8 GHz when \(b\) increases, whereas the lower resonance mode is almost unaffected. Figure 5(c) shows the effect of U-slot position \(c\) with varying dimensions of 3, 5, 7, and 9 mm on the return-loss response is presented. Also, we noticed from this figure that the upper resonance frequency is changed, whereas the lower resonance frequency is almost unchanged. The main reason for \(a\), \(b\), and \(c\) to significantly affect the upper resonance frequency and do not change on lower resonance frequency is due to the lengths of U-slot parameters \((a, b, c)\), which appropriately provide the electric current paths for the higher resonance mode while do not provide this for lower resonance mode. Thus, the lower resonance frequency do not affected by changing the U-slot geometrical parameters \((a, b, c)\).

![Fig. 5: Simulated return loss against frequency for the dual-band U-slot PIFA.](a)

![Fig. 5: Simulated return loss against frequency for the dual-band U-slot PIFA.](b)

### 4.2. Effects of the Ground-Slit

In this section, effect of the ground-slit on the frequency response of the return loss for the proposed antenna is considered. In Fig. 6(a), we deduce that when ground-slit length \(L_{slit}\) is increased from 5 mm to 30 mm, the lower resonance frequency is decreased from 2.55 GHz for \(L_{slit} = 5\) mm to 2.13 GHz for \(L_{slit} = 30\) mm. The reason for this result is that when length of slit is increased, the path of current along the slit is also increased, so that the resonance frequency is decreased. We show that the changing of ground-slit length \(L_{slit}\) controls the location of lower resonance frequency but not alters the location of upper resonance frequency. Figure 6(b) presents the effect of ground-slit width \(W_{slit}\) with varying dimension from 0.5 to 1 mm on return-loss response. Thus, we conclude from Fig. 6 that the upper resonant frequency do not affected by changing the ground-slit geometrical parameters \((L_{slit}, W_{slit})\). The above study is very vital for the designer to have information in achieving the desired operating bands for various applications based on this antenna prototype.

![Fig. 6: Simulated return loss against frequency for the dual-band U-slot PIFA.](a)

![Fig. 6: Simulated return loss against frequency for the dual-band U-slot PIFA.](b)
Fig. 7: Radiation pattern xy-plane (E-plane), yz-plane (H-plane) and xz-plane at frequency (a) 2.45 GHz (b) 5.8 GHz for designed U-PIFA.
5. RADIATION PERFORMANCE

The far-field radiation characteristics at frequencies of 2.44 and 5.80 GHz for the proposed antenna have also been studied and shown in two forms, 2D and 3D representation, Figs. 7 and 8, respectively. The results, in general, show this antenna has a stable monopole-like radiation pattern with conical radiations planes (xz and yz planes) and a nearly omnidirectional pattern in the azimuth plane (xy plane). Finally, the peak gains and efficiencies against frequency for the proposed antenna across the dual bands are illustrated in Figs. 9 and 10, respectively. It should be noted that the gain and efficiency at 2.45 and 5.8 GHz are, 2.2 dB and 97%, and 6.55 dB and 93%, respectively.

![3D simulated radiation pattern at 2.45 GHz](image1)

![3D simulated radiation pattern at 5.80 GHz](image2)

Fig. 8: (a) 3D simulated radiation pattern at 2.45 GHz. (b) 3D simulated radiation pattern at 5.80 GHz.

![Peak antenna gains for the proposed antenna](image3)

Fig. 9: Peak antenna gains for the proposed antenna. (a) Lower band. (b) Upper band.

6. CONCLUSION

A dual band PIFA antenna has been designed and simulated by CST Microwave Studio. The PIFA antenna has been designed to meet the RFID applications. Simulation results show that dual band characteristics of 2.340 to 2.546 GHz and from 5.644 to 6.037 GHz have been achieved. The bandwidth at 2.45 GHz is 206 MHz, and at 5.8 GHz is 393 MHz. The minimum return loss of the antenna for the 2.45 GHz band is -40.17 dB while for the 5.8 GHz band is -46.67 dB. The radiation pattern shows an omnidirectional pattern with broadsight direction for both frequencies at 2.45 GHz and 5.8 GHz. The antenna gain at frequency 2.45 GHz and 5.8 GHz is 2.2 dB and 6.55 dB, respectively.
REFERENCES


AUTHOR PROFILES

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