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Keywords:
Antenna, Gain, Return loss, RFID, Ultra-wideband.

A B S T R A C T

A Miniaturized Compact Wideband Partial Ground Antenna Used in RFID Systems

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typical RFID system consists of an RFID tag and an RFID reader device. The reader’s antenna sends a radio-frequency (RF) signal to the tag and receives an information signal from it [3].

The RFID bands are the high frequency (HF) band at 13.56 MHz, ultra-high frequency (UHF) band from 860 to 960 MHz, and Industrial, Scientific, and Medical (ISM) band at 2.4 GHz. RF applications in the UHF band use different frequency bands in different countries. The frequency bands used are as follows: (902 – 928) MHz in North America, (840.5 – 844.5) MHz and (920.5 – 924.5) MHz in China, (950 – 956) MHz in Japan, (866 – 869) MHz in Europe, (920 – 926) MHz in Australia, (865 – 867) MHz band in India, and (908.5 – 914) MHz in South Korea [6–8]. The (UHF) RFID full coverage band in each country is about (840 – 960) MHz.

In practical usage, the tag antennas usually are linearly polarized (LP), and the RFID tags are mostly oriented arbitrarily. A circularly polarized (CP) antenna is necessary for the RFID reader to ensure reliable communication between tags and reader [9]. Several limitations of using microstrip patch antennas exist such as narrow bandwidth, low gain, and low efficiency led to reduce antenna performance [10, 11].

Generally, the basic configuration of conventional microstrip antenna consists of a thin conducting patch that most made adequately of copper or gold printed on the one side of substrate whose dielectric constant typically in the range of 2.2 ≤ ε_r ≤ 12, which mounted on a ground plane on the other side as shown in Fig. 1 [12, 13].

The microstrip antennas have been widely used in RFID systems because of their good characteristics such as: electrically thin, low profile, low cost, conformable, simple, and inexpensive to manufacture. The main disadvantages of microstrip patch antennas are narrow bandwidth, lesser gain, and poor efficiency, which disturbed the efficiency of this antenna. Many substrate types are available for use in the design of microstrip antenna such as Duroid 5880, RO 3003, RO 3010, and FR4. The FR4 is a very popular substrate for microstrip designs that have a dielectric constant of 4.3 with a tangent loss of 0.025 [14]. Various researchers currently studied different shapes of antenna design for RFID readers by applying a varied approach of patch and ground geometry. Generally, in order to achieve a smaller size, good directivity, and wider bandwidth of RFID antenna systems are an important topic of most researches.

In [15], a new type of compact antenna made with a size of (30 × 30 × 1.6) mm³ and narrow bandwidth with appreciate gain value. N. O. Parchin et al. [16] designed an antenna to cover 2.4/ 5.8 GHz RFID operation bands. An antenna structure is like a modified F-shaped radiator. The overall size of (38 × 45 × 1.6) mm³ and good realized gain is achieved. M. Z. A. Abd Aziz et al. [17] presented the dual-band printed omnidirectional antenna to operate at 2.45 GHz. The substrate that has been used is FR4. Dimensions for the substrate material are (15 × 85.75) mm² and dielectric thickness of 1.6 mm. The return loss of this antenna at 2.45GHz is -10.61dB, and the bandwidth is 122 MHz. The gain that has been achieved for this antenna is 3.798 dB. M. R. Reader [18] presented a compact microstrip stacked patch antenna proposed for a mobile operating at 2.45 GHz passive RFID reader. The antenna has dimensions of (58 × 58) mm² with a large thickness of 11mm and narrow bandwidth with a frequency range from 2.31 to 2.56 GHz, and the peak gain achieves 6.32 dB in the center frequency 2.45 GHz.

In this work, a microstrip antenna operates at resonating frequency of 2.45 GHz for the RFID band is presented. The proposed idea is different from general microstrip antenna designs, where the proposed design combines the partial ground technique with omnidirectional radiation. Its size of 43 × 30 × 1.67 mm³ achieves good impedance matching, suitable gain, wide bandwidth, good efficiency, and radiation patterns over the entire operating band. When comparing the performance of the proposed antenna with the other similar antennas, it is explicitly seen that the proposed antenna has a smaller size, a wide bandwidth with improved radiation pattern, and good efficiency. Detailed geometry Structure, design, and experimental results of this antenna are explained and discussed in the following sections.

Fig.1. Microstrip antenna configuration

2. ANTENNA DESIGN

The basic idea designed in this paper for an omnidirectional pattern is achieved using a partial ground method. In this method, the return loss is as low as possible at a value of -33.2 dB at a resonant frequency of 2.45 GHz. To miniaturize the proposed antenna, the partial ground and slots are used. Before adding partial ground and slots, the resonance frequency occurred at 3.8 GHz when using the same dimensions of antenna that means the miniaturization in the proposed antenna is approximate to 64.5 %. The geometry of the proposed microstrip patch antenna with the partial ground is shown in Fig. 2. The slotted patch is printed on an FR4–epoxy substrate of thickness, h = 1.6 mm with relative permittivity, ε_r = 4.3, and loss tangent, tan δ = 0.025 [19]. The designed antenna operates at a frequency range of (2.1 – 2.98) GHz. With respect to the transmission line model, the dimensions of the general microstrip patch antenna have been obtained as follows [20]. The width of the antenna structure depends on the speed of light in free space (c), relative permittivity (ε_r)
and the resonance frequency \( f_o \) and it is calculated as below.

\[
W = \frac{1}{2} \frac{2}{f_o \sqrt{\varepsilon_{\text{ref}f}}} \left( \frac{2}{f_o \sqrt{\varepsilon_{\text{ref}f}}} \right) = \frac{1}{c} \left( \frac{2}{f_o \sqrt{\varepsilon_{\text{ref}f}}} \right) \quad ... (1)
\]

Where \( c = 3 \times 10^8 \text{ m/s} \), \( \mu_o = 4\pi \times 10^{-7} \text{ H/m} \) and \( \varepsilon_o = 8.85 \times 10^{-12} \text{ F/m} \). The effective permittivity for the patch (\( \varepsilon_{\text{eff}} \)) is calculated as

\[
\varepsilon_{\text{eff}} = \frac{\varepsilon_o + 1}{2} + \frac{\varepsilon_o - 1}{2} \left( 1 + \frac{12h}{W} \right)^{-1/2} \quad ... (2)
\]

The length of the antenna increases due to the fringing effect as

\[
\Delta L = \frac{0.412}{h} \left( \frac{\varepsilon_{\text{eff}} + 0.3}{\varepsilon_{\text{eff}} - 0.258} \right) \left( \frac{W}{T} + 0.264 \right) \quad ... (3)
\]

\( \Delta L \) is the patch length due to fringing

The effective length is calculated by

\[
L_{\text{eff}} = \frac{1}{2} \frac{2f_o \sqrt{\varepsilon_{\text{eff}}/\mu_o \varepsilon_o}}{c} = \frac{1}{2} \frac{2f_o \sqrt{\varepsilon_{\text{eff}}}}{c} \quad ... (4)
\]

The actual length \( L_{\text{act}} \) of the patch is calculated by

\[
L_{\text{act}} = L_{\text{eff}} - 2\Delta L \quad ... (5)
\]

The ground plane dimensions, Width \( W_g \) and Length \( L_g \) is given by

\[
W_{\text{substrate}} = W + 6h \quad ... (6)
\]

\[
L_{\text{substrate}} = L + 6h \quad ... (7)
\]

By using the above equations, the dimensions of the antenna are achieved, as shown in Fig. 2. The technical slots with different dimensions loaded into the patch with dimensions of the antenna are listed in Table 1.

**Table 1**

<table>
<thead>
<tr>
<th>Elements</th>
<th>Material type</th>
<th>Dimensions in mm²</th>
<th>Thickness (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Substrate</td>
<td>FR-4</td>
<td>43 × 30</td>
<td>1.6</td>
</tr>
<tr>
<td></td>
<td>14 × 30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ground plane</td>
<td>Copper</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slots</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Side slots</td>
<td>0.5 × 13.95</td>
<td>0.035</td>
<td></td>
</tr>
<tr>
<td>Circle slot</td>
<td>Radius = 3 mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Two upper slots</td>
<td>0.15 × 25, 0.31 × 25</td>
<td>0.035</td>
<td></td>
</tr>
<tr>
<td>Patch</td>
<td>Copper</td>
<td>26.3 × 27</td>
<td>0.035</td>
</tr>
<tr>
<td>Microstrip feed line</td>
<td>Copper</td>
<td>15 × 3</td>
<td>0.035</td>
</tr>
</tbody>
</table>

3. SIMULATION RESULTS

Initially, Return loss or reflection coefficient \([S_{11}]\) calculation with respect to frequency is presented in Fig. 3. The simulated bandwidth evaluated at −10 dB is 878.6 MHz that is measured in the frequency range \((2.104 – 2.9826) \text{ GHz}\).

Another critical parameter besides the return loss, which is related to the bandwidth and effects on the performance of the antenna, is Voltage Standing Wave Ratio (VSWR). Typically, \( VSWR \leq 2 \). Therefore, the antenna can be able to operate at frequencies where the value of VSWR is below 2 [21]. The VSWR curve of the proposed antenna is shown in Fig. 4. As can be observed from Fig. 4, the minimum VSWR of the proposed antenna is 1.07 at 2.45 GHz that means the maximum power will be transferred at the operating frequency (2.45 GHz).

By adding slots in the patch and the ground plane, the input impedance is closely 50 Ω with a resonant
frequency of 2.45 GHz. The exact value of the real value of impedance is 49.8 Ω, and the imaginary value of impedance approach to zero and equals 0.25 Ω. So, these slots give good antenna performance as well as suitable input impedance in the required band of frequencies. The simulated real and imaginary input impedance of the antenna is shown in Fig. 5 (a) and (b), respectively. In the resonant frequency (2.45 GHz), the input impedance of the proposed antenna is (49.5 + j0.25) Ω, which provides a good impedance matching between the transmission line and antenna.

As depicted from the realized gain curve of the designed antenna in Fig. 6, a good amount of gain 2.47 dB is obtained. Another major design parameter related to gain which is involved in the performance of the antenna is the directivity. Fig. 7 presents the radiation pattern of the designed antenna. Theoretically, the relation between the gain (G) and directivity (D) is related to antenna efficiency factor (η) as in Equation (8).

\[ G = \eta D \]  

The antenna efficiency factor value is enclosed by \((0 \leq \eta \leq 1)\). If \(\eta=1\), i.e., for a lossless antenna. In practice, the gain is always less than the directivity \(D\). As observed from Fig. 7, most incident power is radiated with less back lobe. Thus the maximum directivity obtained is 2.84 dB. The summary of the simulation results for the proposed antenna is presented in Table 2.
4. CONCLUSIONS

In this study, a wideband microstrip slot loaded patch antenna with a microstrip feed line has been presented. The proposed microstrip patch antenna operates in a wide range of frequencies (2.104 – 2.9826) GHz, which covers the RFID applications at 2.45 GHz. By using a partial ground method and adding slots in patch and ground plane that present good antenna performance as well as suitable input impedance in the required band of frequencies. The antenna performance has been improved where the critical parameters of the designed antenna offer wide bandwidth, less return loss, minimum VSWR, and high directivity with a suitable amount of gain. To miniaturize the proposed antenna, the partial ground and slots are used, and the miniaturization in the proposed antenna is arrived to 64.5 %. The gain value of 2.47dB and directivity equals 2.84 dB lead to get good efficiency of 86.9 %. Therefore, it's capable to operate in most countries according to their standards, where the RFID system requires a compact size, good agreement performance with wide bands and low cost.
### Table 2
Summary results of simulated parameters

<table>
<thead>
<tr>
<th>Antenna’s parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency range</td>
<td>2.104 – 2.9826 GHz</td>
</tr>
<tr>
<td>Resonance frequency ( f_0 )</td>
<td>2.45 GHz</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>878.6 MHz</td>
</tr>
<tr>
<td>Return loss at ( f_0 )</td>
<td>-33.2 dB</td>
</tr>
<tr>
<td>VSWR at ( f_0 )</td>
<td>1.07</td>
</tr>
<tr>
<td>Real impedance</td>
<td>49.8 Ω</td>
</tr>
<tr>
<td>Imaginary impedance</td>
<td>0.25 Ω</td>
</tr>
<tr>
<td>Directivity</td>
<td>2.84 dB</td>
</tr>
<tr>
<td>Gain</td>
<td>2.47 dB</td>
</tr>
</tbody>
</table>

### REFERENCES


